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Characterization of color vision by spectroscopy and nanotechnology: application to media photonics

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ÉCOLE DOCTORALE msii

Characterization of color vision by spectroscopy and nanotechnology: application to media photonics

Résumé

Les dispositifs d'affichage et de visualisation sont les interfaces les plus importantes entre l'information numérique et la perception humaine. Cette recherche examine et établit une corrélation entre, d'une part, la perception des couleurs par les observateurs humains et, d'autre part, les écrans LCD renforcés par des boîtes quantiques. L'accent est mis sur la perception visuelle du spectre produit par des nanoparticules en interaction avec le rétroéclairage de l'écran. Un plan de recherche comprenant des expériences colorimétriques a été élaboré pour traiter spécifiquement cette question, et un environnement de recherche approprié a été créé à cet effet. Les expériences colorimétriques comprennent, tout d'abord, des comparaisons de performance de différents dispositifs de calibrage d'écran. Une évaluation comparative des performances de quatre écrans sera effectuée, avant que ces derniers ne soient utilisés pour des expériences de comparaison des couleurs avec des observateurs individuels.

Résumé en anglais

Display and visualization devices are the most important interfaces between digital information and human perception. This research discusses and correlates the color perception of human observers and QD-enhanced LCDs. The focus is on the visual perception of the spectrum produced by these nanoparticles in interaction with the display backlight. A research design with colorimetric experiments was developed to specifically address this issue, and a suitable research environment was created for this purpose. The colorimetric experiments include firstly, performance comparisons of different display calibration devices. A performance benchmarking of four selected QD-enhanced LCDs is performed before they are used for color matching experiments with individual observers.

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Bref résumé en francais

Introduction

Dans la production moderne de médias numérisés, les écrans sont les interfaces les plus importantes entre l'information numérique et la perception humaine. Pour cette raison, la qualité et la précision de la représentation des couleurs sont d'une grande importance, et c'est là que cette thèse entre en jeu. La représentation des couleurs est fortement influencée par les spécifications techniques et les performances des différentes technologies d'affichage. En utilisant la gestion des couleurs, ces différences peuvent être prises en compte dans la production des médias. Cela permet d'assurer un haut degré de cohérence dans la représentation des couleurs d'un contenu numérique identique sur différents écrans.

Comme le montrent également les résultats de cette thèse, les gammes de couleurs natives affichables de la multitude d'écrans disponibles peuvent différer considérablement. Afin d'atteindre l'objectif d'une grande cohérence des couleurs, quel que soit le périphérique de sortie, des gammes de couleurs dites standards ont été définies. Celles-ci sont généralement basées sur les possibilités techniques des écrans actuellement disponibles. Toutefois, les besoins des utilisateurs et des applications qu'ils utilisent ont également été pris en compte dans le processus de normalisation. À l'aide d'un système de gestion des couleurs, la gamme de couleurs natives de l'écran utilisé est adaptée aux spécifications de ces espaces colorimétriques standards. Les technologies de capture d'images, les technologies d'affichage, les normes et le contenu numérique ont tous évolué au fil du temps. Les exigences et les attentes des différents domaines de la production médiatique se reflètent dans les gammes de couleurs standards définies. Par conséquent, d'une part, ces dernières sont le reflet des performances technologiques actuelles, mais, d'autre part, elles montrent une attente et deviennent ainsi les moteurs d'un développement constant, en particulier dans le domaine des technologies d'affichage.

L'espace couleur sRGB reste la gamme de couleurs la plus courante, notamment en raison de sa mise en œuvre dans le système d'exploitation Windows. Aujourd'hui, elle est couverte par une multitude d'écrans différents et, donc, principalement utilisée dans la production de contenus en ligne. L'espace couleur AdobeRGB a été développé en tant que norme pour la production de médias imprimés, et est utilisé en particulier dans les programmes d'édition d'images professionnels. La représentation complète de cet espace de couleurs reste un défi, mais de plus en plus d'écrans atteignent une couverture presque complète. Les exigences sont de plus en plus élevées, notamment dans le domaine de la production vidéo et cinématographique. Dans ce secteur, l'évolution des technologies d'affichage vers des écrans à larges espaces de couleurs et la télévision 4K UHD est particulièrement remarquable. Cependant, la norme actuelle d'espace couleur DCI-P3 n'est considérée que comme une étape intermédiaire. Avec la norme Rec.2020, la prochaine génération d'espaces de couleurs standards a déjà été définie. Cela montre clairement à quel point les attentes sont grandes pour les futurs écrans, ce qui traduit un acte de foi important vis-à-vis du développement technique. Cette évolution constante s'accompagne également de défis. En raison de l'augmentation permanente de la quantité de couleurs représentables et de l'amélioration incessante de la qualité de représentation, la perception individuelle de l'utilisateur joue un rôle de plus en plus important et doit être prise en compte. Celle-ci dépend de divers facteurs physiologiques et psychologiques, et peut varier fortement d'un utilisateur à l'autre.

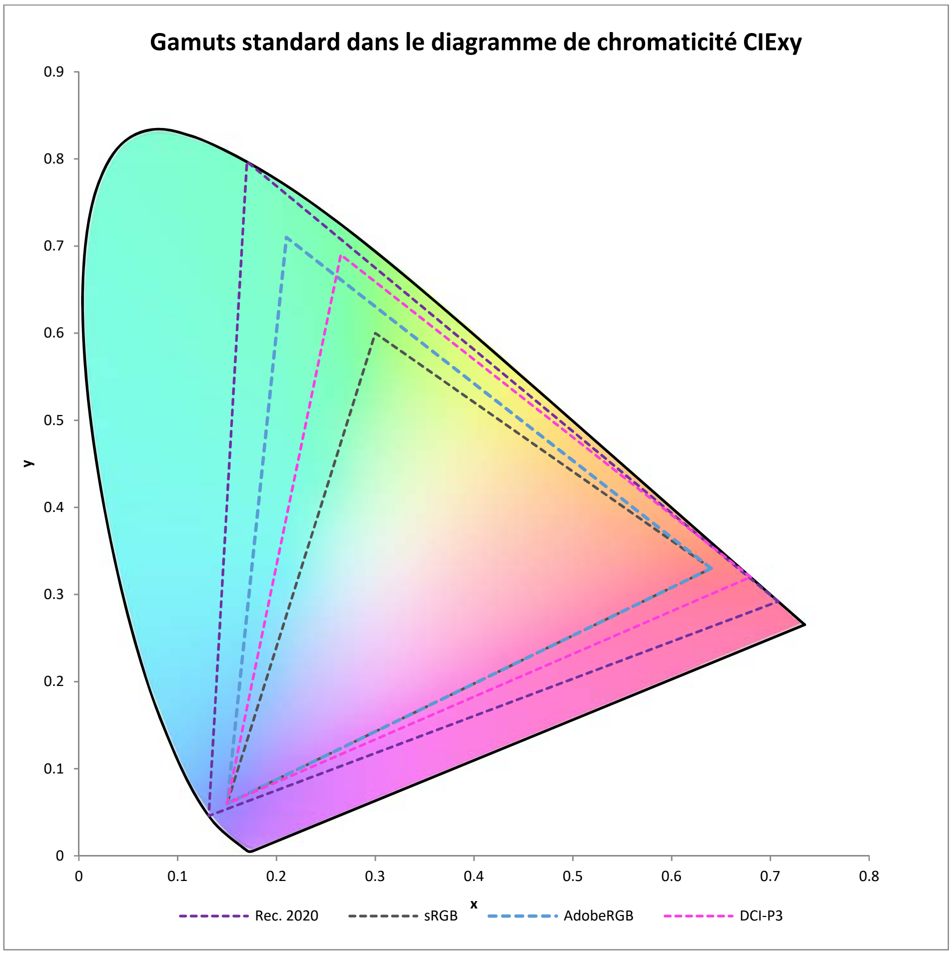


Figure I : Cartographie des espaces couleurs standards sRGB, AdobeRGB, DCI-P3 et Rec.2020 dans le diagramme de chromaticité CIExy.

Approche

Cette recherche examine et met en corrélation, d'une part, la perception des couleurs par les observateurs humains avec, d'autre part, les écrans LCD renforcés par des points quantiques (QD). Les TFT-LCD restent aujourd'hui la technologie d'affichage à écran plat dominante, révolutionnée et revigorée par l'intégration de points quantiques dans le rétroéclairage. L'accent est mis sur la perception visuelle du spectre produit par ces nanoparticules, interagissant avec le rétroéclairage de l'écran. Les points quantiques permettent un réglage et un contrôle précis de l'émission de lumière, qui se traduit par des blancs purs et nets, ainsi que par des couleurs plus précises et réalistes. Des couleurs primaires hautement saturées sont produites. En même temps, les écrans LCD renforcés par des QD offrent un pic de luminosité élevé, qui se traduit par un plus grand contraste entre les parties les plus claires et les plus sombres de l'image, permettant ainsi la prise en charge des écrans à grande gamme dynamique (HDR). En somme, cette application unique de la physique quantique permet d'améliorer les performances en matière de gamme de couleurs représentables et de saturation des couleurs, tout en améliorant la luminance et l'efficacité énergétique des écrans.

Sur la base des sujets sélectionnés, les tâches et objectifs suivants ont été formulés pour cette recherche :

1. l'analyse de la technologie d'affichage QD et de ses perspectives dans le domaine de la photonique des médias ;
2. une étude comparative des dispositifs actuels de calibrage des écrans ;
3. une étude comparative de l'impact des écrans à base de QD sur la perception visuelle ;
4. l'évaluation des améliorations attendues pour les applications liées aux médias, en termes de normalisation souhaitée des processus de production.

Expériences colorimétriques

La qualité de la représentation des couleurs d'un écran a une influence significative sur leur perception individuelle par un observateur. Sur la base de diverses études, la relation entre cette perception individuelle et les valeurs colorimétriques représentées réelles des écrans utilisés sera analysée. Pour cette question, un plan de recherche, avec des expériences colorimétriques, a été spécialement développé et un environnement de recherche approprié a été créé. L'installation technique consiste en quatre écrans disponibles dans le commerce et provenant de différents fabricants, quatre dispositifs de calibrage d'écrans, un spectromètre pour la mesure de la couleur et de la luminance, et des ordinateurs avec des applications logicielles définies pour le contrôle numérique des différents appareils. Lors de la sélection des écrans, l'accent a délibérément été mis sur les écrans LCD renforcés par des QD. Les quatre dispositifs de calibration d'affichage utilisés sont particulièrement courants dans l'industrie des médias, et seront très fréquemment utilisés ici.

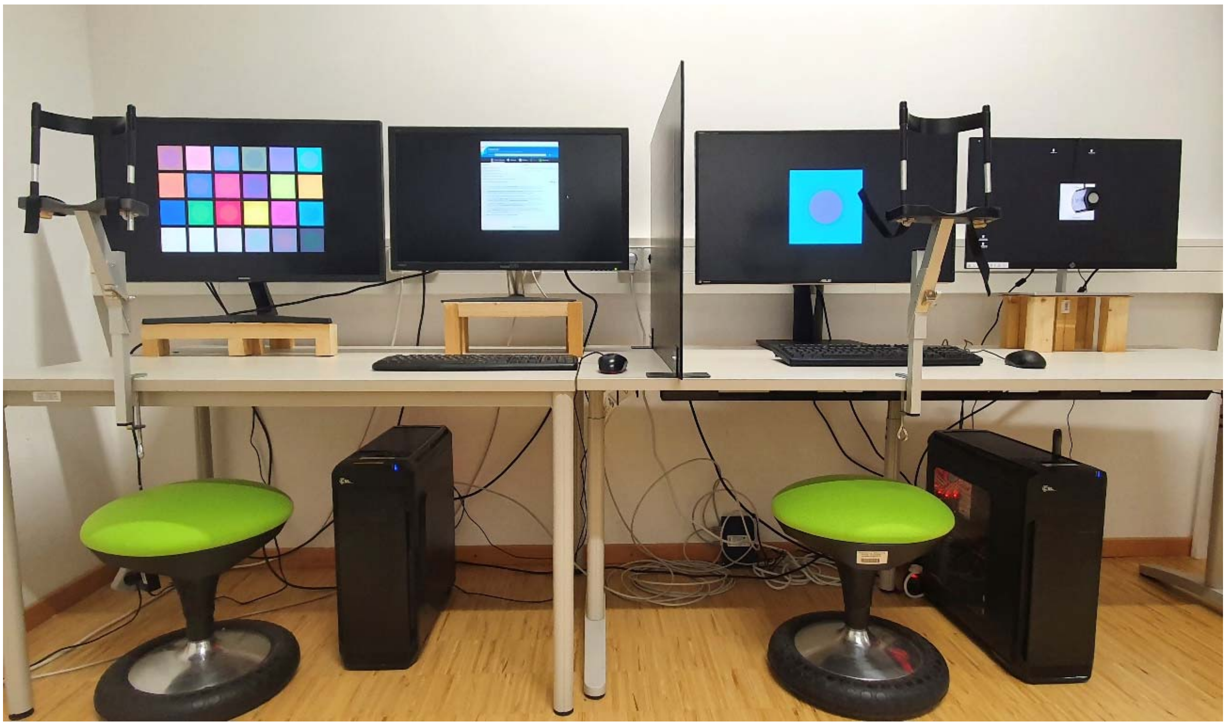


Figure II : Les expériences sont réalisées sur deux postes de travail séparés par une cloison de séparation.

Les expériences colorimétriques ont été réalisées en plusieurs étapes. La condition de base est de mettre les écrans utilisés dans un état reproductible, afin d'obtenir une représentation stable et répétable des couleurs. C'est pourquoi nous avons d'abord procédé à l'étalonnage et au profilage colorimétrique des écrans, ce qui constitue une partie essentielle des méthodes expérimentales de traitement de l'image et revêt, donc, une importance capitale. Il faut tenir compte des caractéristiques typiques des appareils, comme le temps de préchauffage nécessaire, qui influencent considérablement les caractéristiques et la stabilité de la représentation des couleurs. L'objectif de cette définition est de garantir une représentation des couleurs qui soit reproductible pour toute utilisation ultérieure de l'écran. La qualité de l'étalonnage et des profils ICC générés par la suite étant déterminante pour celle de la représentation des couleurs, une comparaison des performances des quatre appareils de mesure courants disponibles, largement utilisés notamment dans l'industrie des médias, a d'abord été effectuée. Une analyse détaillée des résultats obtenus a ensuite été réalisée. Les instruments de mesure sélectionnés sont des appareils tout-en-un, conçus pour une fonctionnalité et une utilisation simples. Le processus de mesure proprement dit est automatisé. Afin de permettre une comparaison des appareils et de la qualité des mesures effectuées, le logiciel d'application DisplayCal version 3.8.9.3, indépendant du fabricant, a été utilisé dans le cadre de cette thèse, car les programmes d'application des fabricants ne permettent pas une comparaison qualitative des résultats de mesure. Les géométries de mesure utilisées sont très différentes, ce qui devrait également s'appliquer aux transformations utilisées pour le profilage. DisplayCal, en revanche, offre de nombreuses possibilités pour adapter spécifiquement le processus de calibrage et de profilage aux besoins individuels. L'utilisation de tous les appareils de mesure avec le même logiciel utilisateur, en tenant compte des informations du fabricant relatives aux appareils importables, a permis la meilleure comparaison possible des résultats obtenus.

Afin d'acquérir les données nécessaires à la comparaison prévue des dispositifs d'étalonnage des écrans utilisés, les mesures nécessaires ont été effectuées en deux sous-étapes. L'objectif de l'étape 1 était de définir un écran de référence, à l'aide duquel nous pourrions ensuite effectuer la comparaison réelle des performances des dispositifs de mesure de l'étape 2. Une évaluation de la cohérence, entre appareils, des résultats colorimétriques obtenus sur cette référence a alors été effectuée. Sur la base de cet examen de la qualité du processus, le dispositif qui serait utilisé pour l'étalonnage de base des écrans employés dans les expériences a été sélectionné.

		Measurement device 1		Measurement device 2		Measurement device 3		Measurement device 4	
		Gamut		Gamut		Gamut		Gamut	
		Coverage	Volume	Coverage	Volume	Coverage	Volume	Coverage	Volume
Display 1	sRGB	99,5%	164,2%	99,5%	163,8%	99,2%	179,5%	99,3%	160,9%
	AdobeRGB	99,2%	113,1%	99,2%	112,9%	99,2%	123,7%	99,0%	110,9%
	DCI-P3	93,3%	116,3%	93,2%	116,3%	96,8%	127,1%	91,8%	114,0%
Display 2	sRGB	99,4 %	168,5 %	99,2 %	166,3 %	99,0 %	181,5 %	99,3 %	164,9 %
	AdobeRGB	92,2 %	116,1 %	90,7 %	114,6 %	92,3 %	125,1 %	93,2 %	113,6 %
	DCI-P3	96,5 %	119,4 %	96,3 %	117,8 %	98,2 %	128,6 %	95,2 %	116,8 %
Display 3	sRGB	99,9%	143,9%	99,9%	144,5%	99,9%	154,4%	99,8%	144,3%
	AdobeRGB	87,8%	99,2%	88,1%	99,6%	91,6%	106,4%	87,7%	99,4%
	DCI-P3	92,4%	102,0%	92,5%	102,0%	95,7%	109,4%	92,3%	102,2%
Display 4	sRGB	95,1%	95,2 %	95,0 %	95,3 %	97,0 %	100,4 %	93,3 %	93,4 %
	AdobeRGB	65,5 %	65,6%	65,5 %	65,6 %	69,1 %	69,1 %	64,3%	64,3 %
	DCI-P3	67,5 %	67,5 %	67,5 %	67,5 %	71,0 %	71,1 %	66,1 %	66,1 %

Tableau I : Résultats du profilage des écrans de test par rapport à la couverture et au volume des espaces de couleur standards sRGB, AdobeRGB et DCI-P3.

Au début de la comparaison des appareils de mesure, il a donc fallu sélectionner un écran de référence pour les mesures à effectuer. L'idée de base était de choisir l'écran offrant la meilleure couverture de l'espace de couleurs standards AdobeRGB (1998). Pour vérifier les spécifications du fabricant, les quatre écrans disponibles ont d'abord été étalonnés avec chacun des quatre appareils de mesure, et des profils d'appareils ont été créés. Ces profils étaient basés sur les paramètres par défaut de l'espace de couleurs AdobeRGB, c'est-à-dire une luminance de 160 cd/m², une température de couleur de 6 500 K et un gamma de 2,2. Toutes les données nécessaires ont été déterminées sur la base de ces profils d'affichage. L'analyse des mesures effectuées a conduit à la décision de choisir l'écran 1 comme écran de référence pour les mesures à venir, car il a obtenu le meilleur résultat avec une couverture de l'espace de couleurs standards Adobe RGB de 99,2 %.

Afin de pouvoir analyser les performances des quatre dispositifs de calibrage d'affichage sélectionnés, l'affichage de référence a été recalibré, et quatre profils d'affichage attribués aux dispositifs de mesure ont été créés. Pour les mesures à réaliser, l'écran utilisé a été placé dans un état reproductible, défini au moyen de ces profils. Une fiche de test comportant 30 mires a été utilisée pour obtenir les données nécessaires à l'analyse. En dix séries de mesures successives, les valeurs spectrales des couleurs incluses dans la forme-test ont été acquises, puis la différence de couleur ΔE^*_{00}, par rapport aux valeurs nominales définies, a été calculée.

	ΔE_{00} MR1 – MR10				ΔE_{00} Accuracy single colors				ΔE_{00} Repeatability single colors			
	Mean	Min	Max	SD	Mean	Min	Max	SD	Mean	Min	Max	SD
MD 1	0,17	0,02	0,56	0,1747	0,17	0,13	0,21	0,0272	0,04	0,02	0,08	0,0181
MD 2	0,20	0,02	0,59	0,1583	0,20	0,16	0,25	0,0275	0,04	0,02	0,08	0,0207
MD 3	0,25	0,02	1,56	0,3268	0,25	0,17	0,31	0,0444	0,05	0,01	0,12	0,0357
MD 4	0,37	0,09	0,73	0,1835	0,37	0,23	0,57	0,1043	0,15	0,05	0,32	0,0912

Tableau II : Résumé des valeurs de base obtenues pour l'évaluation des performances des dispositifs d'étalonnage d'écran disponibles.

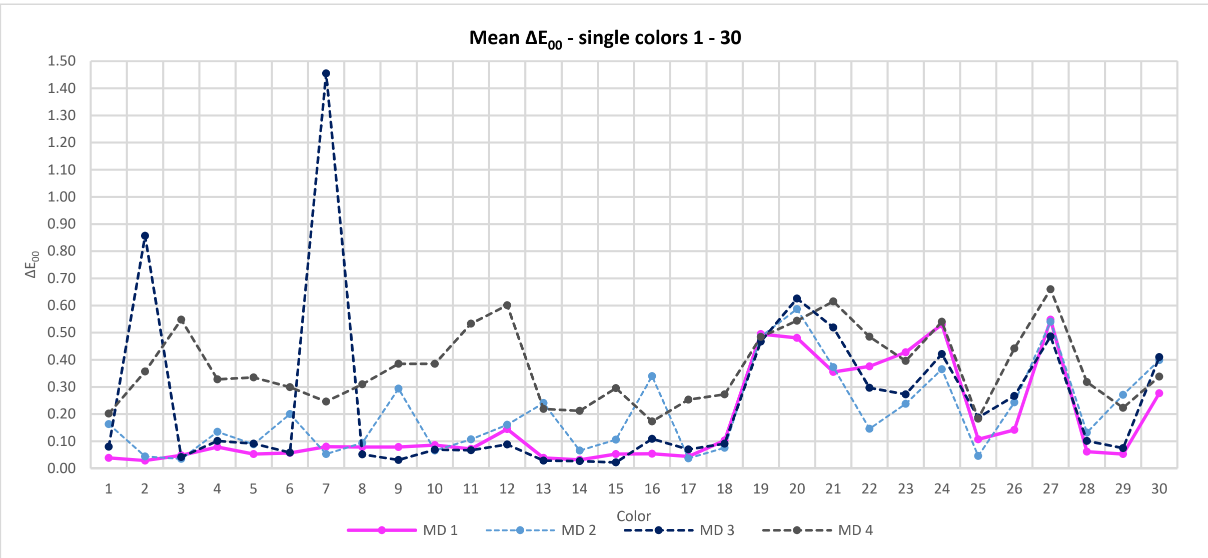


Figure III : Visualisation de la différence de couleur moyenne ΔE_{00} à partir de 30 couleurs uniques par cycle de mesure, sur la base des valeurs mesurées acquises avec les dispositifs de calibration d'affichage disponibles.

Les résultats obtenus ont été évalués en termes d'intravariabilité et d'intervariabilité. Cela nous a permis de nous prononcer sur la reproductibilité et la répétabilité, ainsi que sur la stabilité des mesures effectuées. Enfin, des mesures comparatives de diverses couleurs tests définies ont été faites avec le spectromètre Konica Minolta CS-200, afin de pouvoir juger de la précision des résultats de mesure du dispositif de calibrage d'écran utilisé, par rapport à un spectromètre de haute qualité. Sur la base de ces données, il a ensuite été décidé quel appareil de mesure serait employé pour le calibrage et le profilage des écrans sélectionnés dans le cadre des expériences prévues, afin d'obtenir la meilleure qualité possible de représentation des couleurs pour les mesures et les expériences de correspondance des couleurs qui seraient ensuite réalisées.

L'analyse effectuée a conduit à la décision d'utiliser le dispositif de calibrage d'écran 1 comme dispositif de mesure de choix pour la suite des examens. Les mesures effectuées présentaient les meilleurs résultats pour les critères définis de précision et de répétabilité. L'analyse a d'abord été effectuée sur la base des couleurs individuelles, puis sur celle d'une évaluation globale. Il est également ressorti des résultats que la précision de la mesure était fortement liée à la composition spectrale de la couleur mesurée. Pour cette raison, l'analyse a été spécifiquement divisée en différents groupes de couleurs : les couleurs primaires et secondaires, ainsi que les couleurs tertiaires. Dans la gamme de couleurs tertiaires, une augmentation notable des différences de couleurs déterminées a pu être observée. Des tendances presque identiques étaient visibles sur tous les appareils de mesure. Il convient de noter que le dispositif de mesure 1 a obtenu les meilleurs résultats globaux, avec une très bonne répétabilité. Les résultats du dispositif de mesure 2 étaient également bons. Le dispositif de mesure 3 a présenté des résultats inacceptables pour deux couleurs, qui ont eu un impact sur l'évaluation globale. Le dispositif de mesure 4 a obtenu les plus mauvais résultats dans l'ensemble, ce qui s'est également reflété dans la répétabilité nettement moins bonne des résultats.

L'étape suivante a consisté à effectuer une évaluation comparative des performances de tous les écrans utilisés. Diverses mesures ont été effectuées dans le but de tester les performances et la stabilité de la représentation des couleurs des écrans disponibles et d'établir la comparabilité. Pour cela, nous avons mesuré, entre autres, la luminance maximale, la gamme de couleurs représentables et l'uniformité des écrans. Afin d'effectuer une analyse qualifiée, les mesures à effectuer ont été relevées sur une période définie et répétées plusieurs fois. Étant donné que non seulement les performances, mais aussi la stabilité de la représentation des couleurs devaient être évaluées sur une période d'utilisation longue, les mesures ont été effectuées dans des créneaux horaires définis. L'analyse des résultats a été effectuée après la fin de la phase de test définie, et a permis d'évaluer les propriétés de représentation des couleurs et la stabilité des écrans utilisés. Les résultats obtenus de cette manière ont ensuite été employés dans les expériences de correspondance des couleurs à réaliser. Toutes les mesures ont été effectuées à l'aide du dispositif de calibrage d'écran 1 et du logiciel DisplayCal, qui offre toutes les options nécessaires.

En préparation des mesures à effectuer, une modification des réglages de base en réglages maximums a d'abord été effectuée sur tous les écrans via leur OSD. Cela concernait principalement la luminance, le contraste et le gain des canaux de couleurs R, G, B. Dans un premier temps, la luminance maximale et les besoins en énergie correspondants ont été déterminés. Avec ces valeurs, un calcul de l'efficacité de la luminance était possible. Le niveau de noir, ou luminance du noir, a également été mesuré. En outre, le point blanc natif associé a été déterminé, puis l'espace colorimétrique maximum représentable des écrans, ainsi que la couverture des espaces de couleurs standards sRGB, AdobeRGB et DCI-P3.

	White Lum. (cd/m²)	Power (W)	Lum. Eff. (cd/W)	Black Lum. (cd/m²)	Whitepoint (CIE_xy)		Display Gamut					
							sRGB		AdobeRGB		DCI-P3	
					x	y	Cov. (%)	Vol. (%)	Cov. (%)	Vol. (%)	Cov. (%)	Vol. (%)
Display 1	413	69,2	5,97	0,3535	0,3048	0,3366	99,5	164,1	99,2	113,0	93,2	116,2
Display 2	329	33,6	9,80	0,2341	0,2869	0,3287	99,3	167,6	91,6	115,5	96,4	118,8
Display 3	295	44,9	6,57	0,1056	0,3015	0,3185	99,9	144,2	88,0	99,4	92,5	102,2
Display 4	468	37,0	12,67	0,4737	0,3148	0,3311	94,9	95,2	65,4	65,6	67,4	67,4

Tableau III : Résumé des paramètres de performance définis, moyenne de trois mesures pour les quatre écrans utilisés.

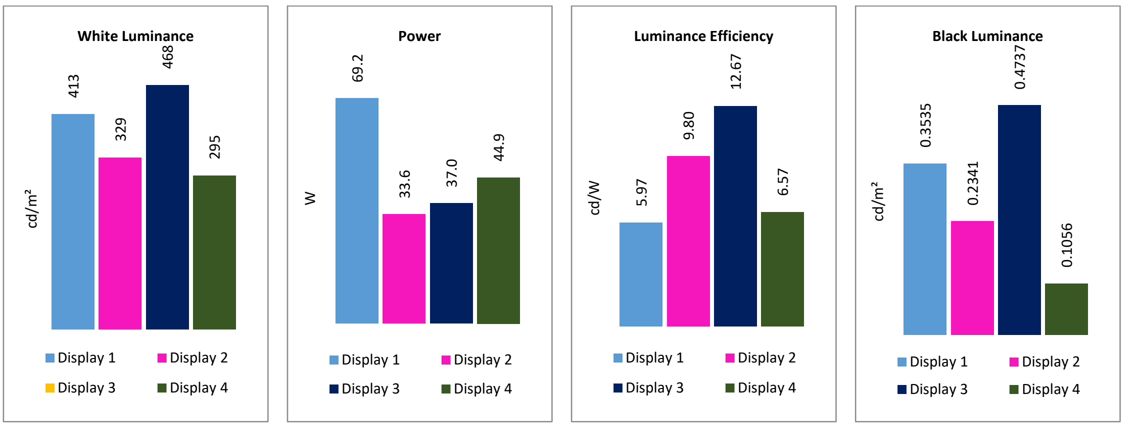


Figure IV : Visualisation des données relatives à la luminance du blanc, à la consommation d'énergie, au rendement de la luminance et à la luminance du noir des écrans d'essai sélectionnés.

Pour effectuer les mesures, le dispositif de calibrage de l'écran 1 a été placé au centre des surfaces d'affichage, à la position spécifiée par l'application DisplayCal. Ensuite, pour mesurer la luminance maximale, une tache de test blanche a été affichée sur toute la surface, puis mesurée. Un voltmètre a été interposé entre l'écran et la source d'alimentation, afin d'afficher la consommation électrique actuelle de l'écran. L'efficacité de la luminance a ainsi pu être calculée à partir des valeurs obtenues. Une mesure de la luminance du noir a suivi, avant que les données des primaires de l'écran ne soient enregistrées avec un patch de test rouge, vert et bleu.

Ensuite, l'uniformité de l'affichage et l'homogénéité de l'image ont été examinées. Un rapport de mesure proposé par DisplayCal a été utilisé à cet effet. Une matrice 5 x 5, c'est-à-dire 25 champs de mesure, a été sélectionnée comme réglage de base et modèle de mesure. Lorsque le processus de mesure a été lancé, l'écran a affiché les 25 champs de mesure sélectionnés, qui ont été activés et mesurés individuellement. Pour ce faire, le dispositif de mesure a toujours été positionné au centre des différents champs de mesure, puis le processus de mesure a été lancé. Quatre mesures pour quatre niveaux de luminance différents (100 %, 75 %, 50 % et 25 %) ont été effectuées automatiquement pour chaque champ. Les résultats obtenus ont été documentés dans un rapport de mesure.

Certaines mesures montraient des différences significatives lorsque nous considérions les paramètres de performance définis. Nous avons rapidement compris à quel point les propriétés de représentation des écrans peuvent être différentes, et à quel point la représentation des couleurs est spécifique à chaque appareil. Une observation de la luminance maximale du blanc montrait déjà de grandes différences. L'écran 4 a atteint la luminance la plus élevée, c'est-à-dire 469 cd/m², avec une luminance noire maximale mesurée de 0,4750 cd/m². Il est évident que les deux paramètres sont directement liés. L'écran 3 a présenté la valeur la plus basse pour la luminance maximale représentable, avec 239 cd/m². La luminance noire mesurée de 0,1052 cd/m² était également la valeur la plus faible. Comme prévu, la consommation d'énergie des deux écrans avec une diagonale de 32 pouces était plus élevée que celle des écrans avec une diagonale de 27 pouces. Les écrans 2 et 4 ont donné les meilleurs résultats. Cela a également un eu effet direct sur l'efficacité de la luminance déterminée. L'écran 4 a affiché la meilleure valeur avec 12,69 cd/W, tandis que les écrans 1 et 3, avec une diagonale d'écran plus grande, ont enregistré une baisse significative.

L'écran 2 a présenté la plus grande gamme de couleurs natives, qui s'est exprimée par une couverture de 91,6 % (vol. 115,5 %) de l'espace couleur AdobeRGB. L'écran 1 a présenté une couverture plus élevée de 99,2 % (vol. 113 %) de l'espace couleur AdobeRGB, mais le volume global est resté légèrement inférieur. Ces différences sont dues aux valeurs spectrales des couleurs primaires R, G, B des deux écrans. Sur la base de ces valeurs, il a été décidé de calibrer et de profiler les deux écrans pour les expériences de correspondance des couleurs suivantes, basées sur l'espace couleur AdobeRGB. La gamme de couleurs de l'écran 3 était déjà considérablement réduite, tandis que l'écran 4 offrait de loin la plus petite gamme de couleurs natives. Il a donc été décidé de calibrer et de profiler ces deux écrans sur la base de l'espace colorimétrique standard sRGB, pour les expériences de correspondance des couleurs prévues.

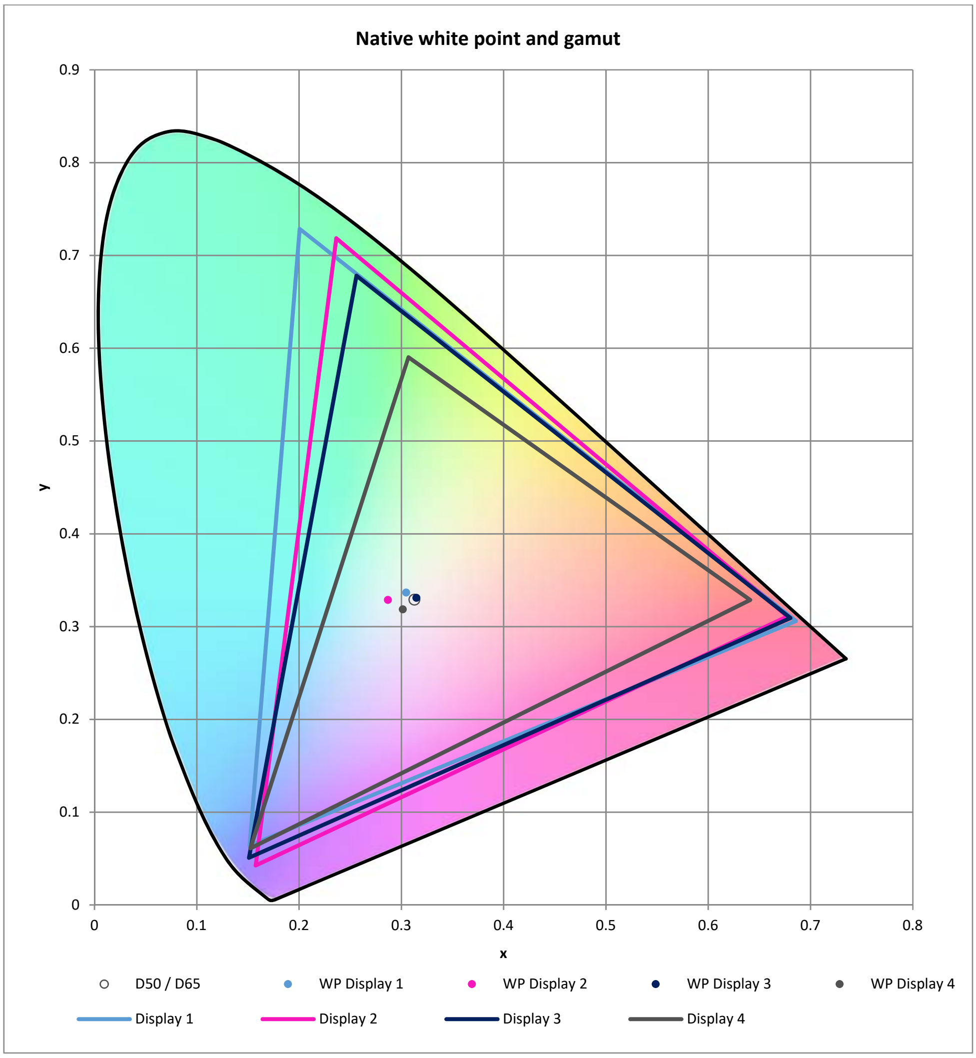


Figure V : Visualisation du point blanc natif et des espaces couleurs natifs des écrans utilisés.

L'uniformité et l'homogénéité des écrans sont très différentes, ainsi que le montrent les mesures. L'écran 4 a présenté les meilleures valeurs, avec un écart moyen de la distribution de la luminosité de 8,20 %. Cela s'est également appliqué à la différence de chromaticité moyenne de $\Delta C^*_{00} = 1{,}40$. Les résultats des autres affichages ont dépassé le seuil de perception supposé pour les variations de luminance de 10 %, ce qui signifiait que les résultats devaient être considérés comme insatisfaisants. L'écart moyen le plus élevé pour la distribution de la luminosité, soit 12,11 %, était visible sur l'affichage 3. La différence moyenne de chromaticité la plus élevée était $\Delta C^*_{00} = 3{,}79$, et a également été mesurée pour l'affichage 3. La luminosité de tous les affichages diminuait vers les bords et, surtout, vers les coins. Cependant, les différences et les tendances variaient d'un écran à l'autre. Il convient de noter ici que les performances des expériences de correspondance des couleurs n'ont pas été affectées. La structure de la tâche 1 garantissait que les taches de test soient représentées au centre de l'écran, donc dans la zone de luminance la plus élevée. La tâche 2, avec sa structure de base plus grande en termes de surface, n'a pas non plus été influencée de manière perceptible.

Figure VI : Visualisation des différences de luminance mesurées à 100 % pour l'écran 1.

Pour vérifier la stabilité de la représentation des couleurs, des mesures de contrôle ont été effectuées à l'aide d'une forme-test définie, dans trois créneaux horaires et sur une période de cinq jours. Pour chaque mesure effectuée, les valeurs du point blanc, de la température de couleur, de la luminance blanche et de la luminance noire ont été acquises, ainsi que les valeurs spectrales de 30 couleurs de test définies. Tous les écrans montrent une bonne stabilité des valeurs de performance, avec des variations attendues. Pour l'analyse, une vue globale des résultats a d'abord été effectuée, avant qu'ils ne soient évalués au niveau des jours de test et, finalement, à celui des tranches horaires.

Les écrans 1 et 2 ont été calibrés et profilés sur la base de l'espace couleur AdobeRGB pour les mesures. Les deux affichaient des valeurs très stables. La luminance mesurée était de 159,8 cd/m², et de 159,9 cd/m² en moyenne. La luminance cible des profils d'affichage était de

160 cd/m². Les valeurs de température de couleur servant de référence pour mesurer le point blanc étaient en moyenne de 6 430 K pour l'écran 1 et de 6 513 K pour l'écran 2. En principe, il est possible de dire que pour l'écran 1, les valeurs ont augmenté avec la durée de fonctionnement. Les valeurs moyennes les plus élevées ont été enregistrées dans l'intervalle de temps 3. L'écran 2 a donné les valeurs les plus élevées dans le créneau 1, qui ont diminué quelque peu dans le créneau 2, et augmenté de nouveau dans le créneau 3. Il convient de noter que les fluctuations sont très faibles. Par exemple, la différence de température de couleur entre les créneaux 1 et 2 n'est que de 5 K pour l'écran 2.

	Device Values			Display 1 ΔE_{00}				Display 2 ΔE_{00}				Display 3 ΔE_{00}				Display 4 ΔE_{00}			
Color	R	G	B	Mean	Min	Max	SD	Mean	Min	Max	SD	Mean	Min	Max	SD	Mean	Min	Max	SD
1	128	0	0	0,07	0,01	0,16	0,0591	0,07	0,03	0,10	0,0201	0,07	0,04	0,09	0,0147	0,03	0,02	0,05	0,0089
2	255	0	0	0,03	0,00	0,08	0,0253	0,06	0,01	0,14	0,0422	0,03	0,01	0,04	0,0102	0,06	0,04	0,09	0,0155
3	255	128	128	0,09	0,04	0,15	0,0347	0,09	0,03	0,16	0,0514	0,08	0,05	0,14	0,0262	0,17	0,04	0,27	0,0710
4	0	128	0	0,09	0,03	0,25	0,0648	0,18	0,03	0,36	0,1244	0,12	0,06	0,16	0,0294	0,13	0,06	0,19	0,0376
5	0	255	0	0,05	0,02	0,11	0,0280	0,08	0,04	0,13	0,0320	0,09	0,00	0,14	0,0441	0,08	0,03	0,15	0,0317
6	128	0	95	0,08	0,02	0,13	0,0402	0,07	0,02	0,17	0,0464	0,11	0,06	0,18	0,0373	0,10	0,03	0,14	0,0323
7	0	0	128	0,06	0,01	0,11	0,0331	0,08	0,02	0,12	0,0294	0,06	0,04	0,08	0,0128	0,06	0,02	0,12	0,0268
8	0	0	255	0,06	0,02	0,14	0,0314	0,06	0,03	0,12	0,0253	0,06	0,04	0,14	0,0291	0,05	0,02	0,14	0,0307
9	128	128	255	0,14	0,06	0,26	0,0753	0,17	0,02	0,34	0,1312	0,08	0,04	0,19	0,0410	0,12	0,05	0,18	0,0500
10	0	128	128	0,10	0,05	0,18	0,0412	0,17	0,02	0,36	0,1414	0,18	0,03	0,23	0,0539	0,27	0,06	0,41	0,1222
11	0	255	255	0,08	0,05	0,13	0,0260	0,08	0,03	0,15	0,0431	0,11	0,06	0,16	0,0270	0,14	0,07	0,26	0,0582
12	170	255	255	0,14	0,04	0,23	0,0518	0,09	0,02	0,18	0,0458	0,12	0,07	0,22	0,0389	0,10	0,06	0,20	0,0419
13	128	0	128	0,09	0,02	0,21	0,0718	0,06	0,01	0,12	0,0396	0,08	0,06	0,11	0,0137	0,07	0,03	0,12	0,0277
14	255	0	255	0,05	0,01	0,10	0,0233	0,06	0,03	0,09	0,0170	0,06	0,01	0,09	0,0221	0,06	0,03	0,10	0,0214
15	255	170	255	0,05	0,02	0,09	0,0210	0,14	0,12	0,18	0,0187	0,21	0,17	0,25	0,0233	0,14	0,08	0,20	0,0418
16	128	128	0	0,09	0,03	0,16	0,0400	0,17	0,03	0,29	0,0971	0,14	0,09	0,20	0,0298	0,14	0,06	0,20	0,0460
17	255	255	0	0,04	0,02	0,08	0,0194	0,02	0,01	0,05	0,0127	0,15	0,09	0,20	0,0323	0,14	0,05	0,25	0,0534
18	255	255	170	0,10	0,05	0,18	0,0349	0,09	0,03	0,14	0,0303	0,19	0,14	0,26	0,0352	0,15	0,04	0,26	0,0669
19	170	85	85	0,54	0,46	0,61	0,0533	0,33	0,26	0,43	0,0666	0,26	0,18	0,32	0,0532	0,12	0,07	0,14	0,0219
20	85	170	85	0,48	0,44	0,56	0,0361	0,19	0,11	0,28	0,0513	0,36	0,25	0,41	0,0540	0,15	0,10	0,20	0,0359
21	85	85	170	0,42	0,34	0,51	0,0734	0,39	0,21	0,48	0,0738	0,28	0,26	0,29	0,0111	0,14	0,06	0,19	0,0472
22	85	170	170	0,38	0,34	0,44	0,0299	0,16	0,11	0,19	0,0241	0,47	0,36	0,53	0,0452	0,15	0,06	0,28	0,0689
23	170	85	170	0,44	0,39	0,52	0,0395	0,25	0,19	0,28	0,0258	0,33	0,28	0,38	0,0272	0,18	0,13	0,21	0,0214
24	170	170	85	0,52	0,49	0,56	0,0173	0,18	0,14	0,23	0,0272	0,35	0,29	0,40	0,0328	0,14	0,04	0,20	0,0524
25	255	0	170	0,11	0,08	0,15	0,0237	0,10	0,04	0,17	0,0434	0,20	0,12	0,23	0,0327	0,11	0,07	0,13	0,0215
26	170	255	0	0,13	0,08	0,18	0,0352	0,07	0,02	0,16	0,0463	0,16	0,13	0,20	0,0224	0,11	0,07	0,15	0,0241
27	0	170	255	0,59	0,48	0,64	0,0440	0,25	0,16	0,33	0,0520	0,33	0,24	0,41	0,0626	0,11	0,05	0,22	0,0507
28	0	255	170	0,10	0,02	0,20	0,0590	0,08	0,02	0,12	0,0353	0,21	0,10	0,24	0,0386	0,08	0,03	0,15	0,0335
29	170	0	255	0,10	0,04	0,16	0,0402	0,10	0,05	0,13	0,0290	0,22	0,19	0,24	0,0166	0,08	0,03	0,12	0,0297
30	255	170	0	0,25	0,17	0,36	0,0590	0,19	0,12	0,27	0,0552	0,33	0,21	0,41	0,0564	0,11	0,05	0,18	0,0404
			Mean	0,18	0,13	0,25	0,0411	0,13	0,07	0,21	0,0493	0,18	0,12	0,23	0,0325	0,12	0,05	0,18	0,0411

Tableau IV : Résumé des différences de couleur ΔE_{00} déterminées pour l'ensemble des 30 couleurs de test pour les quatre écrans utilisés.

Pour les mesures, les écrans 3 et 4 ont été calibrés et profilés sur la base de l'espace couleur sRGB. La luminance cible était ici de 80 cd/m². Les valeurs obtenues ont montré, ici aussi, une bonne stabilité. Les 30 mesures effectuées ont montré une luminance blanche moyenne de 79,8 cd/m² et une température de couleur moyenne de 6 481 K pour l'écran 3. Pour l'écran 4, la luminance moyenne du blanc était de 81,2 cd/m², et la température moyenne de la couleur de 6 401 K. Un examen plus approfondi des résultats de l'écran 3 a montré que la performance diminuait avec l'augmentation du temps d'exécution, c'est-à-dire que les valeurs moyennes de la luminance et de la température de la couleur diminuaient presque. L'écran 4, quant à lui, a montré une augmentation de la luminance moyenne de la tranche de temps 1 à la tranche de temps 3, tandis que la température de couleur moyenne diminuait par contraste.

Afin de disposer d'une base de données plus importante pour évaluer la stabilité de la représentation des couleurs, les valeurs des 30 couleurs de test ont été analysées à partir de deux mesures choisies au hasard par jour du cycle de mesure. La différence de couleur déterminée entre les valeurs nominales et les valeurs réelles mesurées a été utilisée à cette fin. L'évaluation a été réalisée ici à deux niveaux. Tout d'abord, les résultats des 30 couleurs de test provenant des mesures individuelles ont été combinés pour une évaluation globale, avant que les résultats de toutes les mesures ne soient employés pour évaluer les couleurs individuelles.

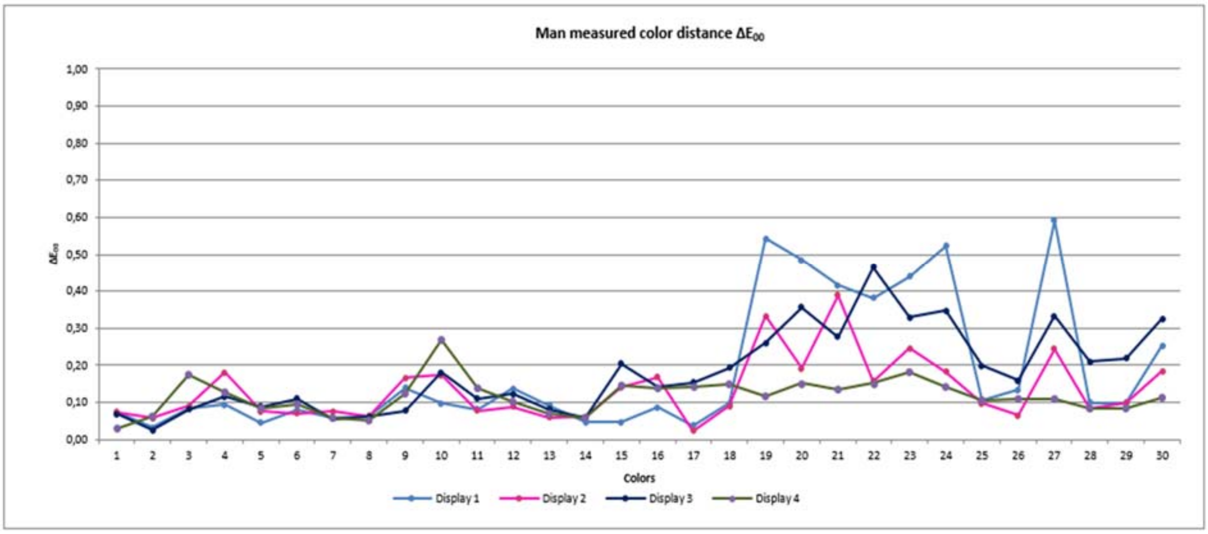


Figure VII : Visualisation résumée des différences de couleur moyennes ΔE_{00} mesurées pour les 30 couleurs de test pour les écrans 1 à 4.

Dans l'analyse globale des essais, l'écran 1 a montré une différence de couleur globale ΔE_{00} = 0,18 en moyenne. Cette valeur a été confirmée par l'écart de couleur moyen ΔE_{00} = 0,18 de l'analyse des couleurs individuelles. Au total, la représentation des couleurs des valeurs spectrales nominales était très bonne. Cependant, il faut noter que plusieurs couleurs tertiaires présentaient des différences nettement plus élevées. Pour trois couleurs, cela s'est traduit par une différence qui pouvait être perçue par des observateurs expérimentés. L'écran 2 a présenté une différence de couleur moyenne ΔE_{00} = 0,13, soit un très bon résultat. Pour l'écran 3, la différence de couleur moyenne était ΔE_{00} = 0,18. Ici aussi, comme dans l'affichage 1, on a observé des différences légèrement plus élevées dans la gamme de couleurs tertiaires, lors de la mise en œuvre des valeurs nominales. Cependant, cela n'était visible que pour une seule couleur, et avec des observateurs expérimentés. L'écran 4 a systématiquement montré d'excellents résultats dans la conversion spectrale des valeurs cibles. L'écart de couleur moyen était de ΔE_{00} = 0,12.

Globalement, nous pouvons affirmer que tous les écrans utilisés ont fait preuve d'une grande stabilité dans la représentation des couleurs. La conversion des valeurs spectrales nominales a également été très bonne dans la répétition. Cette conclusion a aussi été confirmée par les mesures effectuées dans la suite du processus, pour déterminer les valeurs spectrales des 24 couleurs cibles pour l'évaluation des tests de correspondance des couleurs à effectuer. Ceci dit, les résultats obtenus ici montrent aussi qu'il faut faire une distinction entre les couleurs chromatiques et achromatiques, ces dernières étant généralement plus difficiles à convertir pour les écrans.

L'écran 1 a montré une différence moyenne de couleur ΔE_{00} = 0,56 par rapport aux valeurs nominales sur toutes les couleurs. Si seules les couleurs achromatiques étaient prises en compte, la différence de couleur moyenne était réduite à ΔE_{00} = 0,43. En comparaison, la différence de couleur moyenne des couleurs achromatiques était de ΔE_{00} = 0,95. L'écran 2 a donné de meilleurs résultats. Les différences de couleur déterminées ΔE_{00} des valeurs mesurées par rapport à la valeur nominale par défaut ont en moyenne été de ΔE_{00} = 0,34. Il convient de noter que les différences de couleur mesurées étaient un peu plus élevées pour les couleurs achromatiques. L'écran 3 a montré une différence de couleur moyenne de ΔE_{00} = 0,30. Ici aussi, il y avait une tendance, bien que moins prononcée, des couleurs achromatiques à montrer des différences légèrement plus élevées par rapport à la cible nominale. L'écran 4 a présenté les meilleurs résultats. En comparant les valeurs nominales avec les valeurs spectrales moyennes mesurées, la différence de couleur moyenne était de ΔE_{00} = 0,24. La différence entre les couleurs achromatiques et les couleurs achromatiques n'était pas aussi prononcée ici. Il convient de noter qu'en termes de stabilité de la représentation des couleurs, la répétabilité était excellente.

Expériences de comparaison des couleurs

La qualité de la représentation des couleurs d'un écran a une influence significative sur leur perception individuelle par un observateur. À l'aide des expériences de correspondance des couleurs à réaliser, la corrélation entre la perception visuelle individuelle et les valeurs colorimétriques réellement reproduites des écrans a été étudiée. L'objectif était d'obtenir le plus grand nombre possible d'ensembles de données, sur la base desquels une analyse de la perception individuelle des couleurs par les participants était possible, mais aussi l'influence de l'écran utilisé.

En raison de la situation pandémique provoquée par le Covid-19, la réalisation des expériences prévues n'a été possible que de manière limitée, et ce après approbation de l'administration de l'Université d'Offenburg, qui était notre lieu d'étude. Sur la base d'un respect strict des règles d'hygiène, l'autorisation a été accordée début septembre 2020. Malheureusement, les créneaux horaires étaient très limités en raison d'une détérioration de la situation et d'un confinement en Allemagne, de sorte que le nombre souhaité de participants n'a pu être atteint, et de loin. En raison de perspectives incertaines, il a finalement été décidé de terminer cette élaboration avec les résultats existants. Les expériences seront de toute façon poursuivies dès que la situation sanitaire le permettra à nouveau. Le laboratoire nouvellement conçu pour la recherche prévue sera intégré dans l'environnement d'enseignement de la technologie des médias de l'université d'Offenburg, dans le cadre du concept d'éducation orientée vers la recherche.

Tous les écrans d'essai ont été réglés dans un état reproductible pour les expériences à réaliser. À cette fin, les profils créés lors des examens déjà effectués ont été utilisés. Au cours de la série d'expériences de correspondance des couleurs, l'étalonnage et le profilage des écrans ont été vérifiés quotidiennement, après une période de « réchauffement » de 60 minutes, avant qu'une autorisation ne soit donnée pour les expériences. Celles-ci se sont déroulées dans des conditions de mesures définies et dans une pièce sombre. Les participants disposaient d'un temps suffisant pour s'habituer aux conditions de lumière ambiante (adaptation chromatique). Ce temps était mis à profit pour mener une conversation d'introduction avec les participants. La procédure et les détails des examens leur étaient présentés, les risques éventuels étaient discutés, et le traitement et l'utilisation des données obtenues expliqués. Le formulaire d'information et de consentement de l'université de Strasbourg servait de fil conducteur. Il devait être signé par les participants et les personnes chargées de la collecte des données avant que celle-ci ne commence. En outre, les participants recevaient un questionnaire, dans lequel diverses informations personnelles leur étaient demandées. Celles-ci étaient utilisées pour créer un profil sociologique du participant, qui pouvait être directement lié aux résultats individuels obtenus et inclus dans l'analyse détaillée des données. Toutes les données étaient collectées de manière anonyme, et ne pouvaient être reliées les unes aux autres que par un identifiant attribué.

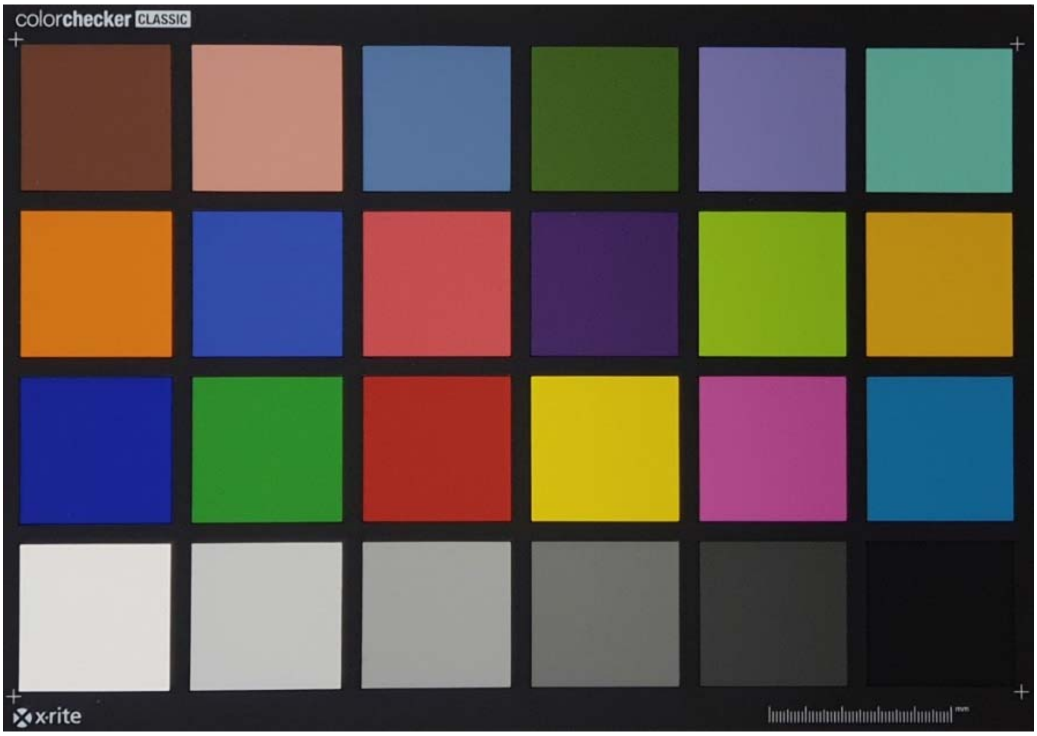


Figure VIII : La charte ColorChecker classique avec 24 couleurs.

Pour les expériences à réaliser, une application a été programmée dans l'environnement de développement logiciel Unity, qui guidait les participants à travers deux sous-expériences définies. Les participants avaient pour tâche centrale de faire correspondre une couleur cible représentée sur un écran de taille définie dans un masque inséré à l'aide des trois couleurs primaires rouge, vert et bleu (R, G, B) jusqu'à une correspondance visuelle aussi exacte que possible. Idéalement, aucune différence de couleur ne devrait être visible ni mesurable après la correspondance des couleurs. Les couleurs cibles des patchs de test étaient basées sur les patchs colorimétriques de la charte X-Rite ColorChecker Classic. Les tests ont été réalisés avec deux géométries d'essai différentes. Dans la tâche 1, les modèles et les définitions de Hunt et Fairchild ont été considérés pour la structure et la représentation des couleurs uniques. Un seul champ de couleur (stimulus) à éditer était affiché. Les spécifications pour le champ proximal, l'arrière-plan, l'entourage et le champ d'adaptation étaient mises en œuvre. La structure de la tâche 2 s'en écartait considérablement. La taille des champs de couleur était considérablement réduite et les 24 champs de couleur affichés simultanément.

Dans la tâche 1, le participant ne recevait initialement que des couleurs uniques à traiter. Nous considérions ici que l'apparence de la couleur visuellement perçue d'un champ de couleur (stimulus) dépendait de différentes influences externes. Le champ de couleur affiché avait une taille de 10 x 10 cm. Au centre se trouvait un masque rond d'un diamètre de 5 cm. Il fallait alors l'ajuster visuellement à la couleur cible en modifiant les valeurs des couleurs primaires R, G, B. Un fond noir sur toute la surface assurait une adaptation stable de l'observateur. Une fois l'adaptation terminée, le participant pouvait passer au champ de couleurs suivant. L'ordre dans lequel les couleurs étaient affichées était prédéterminé, suivant l'ordre des numéros de couleurs de la charte ColorChecker. Dans la tâche 2, la charte complète était affichée à l'écran, sous forme de champs de couleurs. Sa taille totale était de 29 x 19 cm, et il y avait 24 échantillons de couleurs d'une taille de 4 x 4 cm. Chacune de ces pastilles de couleur était munie d'un masque rond d'un diamètre de 2,2 cm. La tâche consistait, de nouveau, à réaliser une correspondance visuelle avec la couleur cible. Cependant, la séquence de traitement n'était pas spécifiée ici, mais librement sélectionnable, et le participant pouvait procéder selon ses préférences. Le masque à éditer était activé en cliquant sur le bouton gauche de la souris. La sélection d'un nouveau champ de couleur enregistrait les valeurs numériques actuelles pour les trois valeurs de couleur. Des modifications ultérieures étaient également possibles.

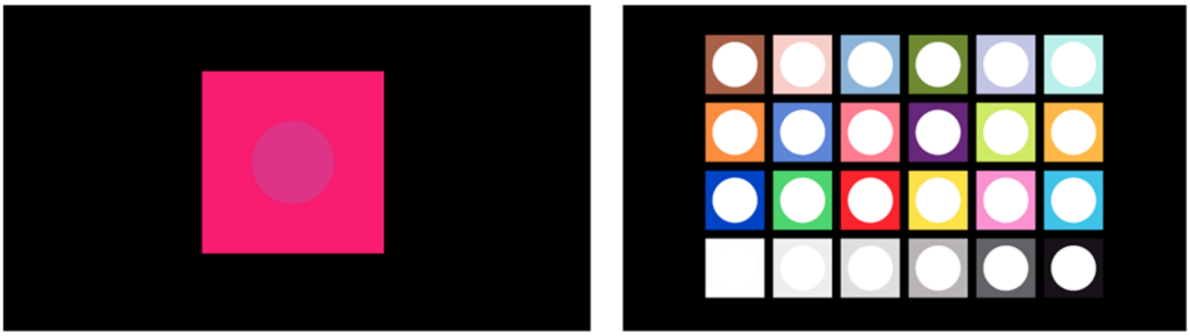


Figure IX : Vue d'écran des expériences 1 et 2 en deux parties (tâche 1 et tâche 2). À gauche, les couleurs simples avec le masque intégré. À droite, la target complète avec 24 couleurs.

Comme base pour des évaluations ultérieures, les valeurs numériques R, G, B de la correspondance visuelle ont été enregistrées pour chaque couleur dans les deux expériences. De même, le temps requis pour chaque couleur a été enregistré, et le temps total pour chacune des répétitions a été calculé. Dans la sous-expérience 2, la séquence de traitement des couleurs individuelles dans laquelle les expériences de correspondance des couleurs étaient effectuées a également été documentée. Enfin, tous les champs de couleurs ont été mesurés avec un colorimètre, et les valeurs spectrales ont été saisies. L'évaluation des résultats obtenus était anonyme. L’analyse et l’évaluation ont été effectuées de manière standard, dans un système de référence et avec un observateur fixe (CIE 1931, CIE 1964, CIE L*a*b* 1976). Les données obtenues nous ont permis de comprendre la relation entre la perception visuelle individuelle des couleurs et les valeurs colorimétriques représentées réelles. En attribuant les résultats obtenus aux écrans utilisés, il était possible d’obtenir une déclaration qualitative relative à l’influence de la technologie d’affichage utilisée sur la perception des couleurs par l’observateur. L’objectif de l’évaluation était de déterminer la précision ou l’écart de la correspondance visuelle avec les valeurs cibles spécifiées. L’intravariabilité, c’est-à-dire la capacité d’un observateur à effectuer de manière répétée une tâche identique, a été examinée. Dans l’étape suivante, l’intervariabilité des résultats de tous les participants a été considérée. L’analyse s’est basée sur les valeurs nominales des couleurs déterminées et les valeurs spectrales mesurées. Les couleurs cibles données ont été mesurées plusieurs fois, et les valeurs moyennes calculées pour chaque couleur. Cela nous a permis de compenser d’éventuelles fluctuations mineures dans la représentation des couleurs de l’écran. Le niveau de couleur ΔE00 a été déterminé et utilisé pour évaluer les résultats. La base de l’interprétation et de l’évaluation des résultats est une échelle d’évaluation, révisée pour cette analyse, en principe basée sur l’interprétation proposée par la CIE, mais qui tient également compte des interprétations actuellement utilisées dans l’industrie médiatique.

ΔE_{00}	Interpretation	Rating
0 – 0,2	Visuell not perceptible	0
0,2 – 0,5	Almost unnoticeable	1
0,5 – 1	Noticeable to the trained eye	2
1 – 2	Small color difference	3
2 – 4	Perceived color difference	4
4 - 5	Significant color difference	5
5 - ….	Rating as another color	6

Tableau V : L’échelle de notation de base pour l’interprétation et l’évaluation des différences de couleur déterminées.

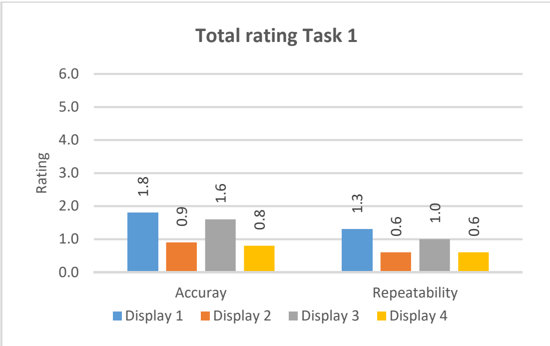
L'objectif d'obtenir le plus grand nombre possible d'ensembles de données, sur la base desquels il est possible d'analyser la perception individuelle des couleurs par les participants, mais aussi d'évaluer l'influence de l'écran utilisé, n'a pu être atteint de cette manière. Malheureusement, seuls les résultats de 17 participants ont été inclus dans l'évaluation. Soixante-quatorze ensembles de données ont été obtenus pour la tâche 1 et la tâche 2. Quatre participants seulement ont pu réaliser la totalité, c'est-à-dire une double exécution des expériences présentées sur chacun des écrans utilisés. Par conséquent, dans le cadre de cette thèse, nous nous abstiendrons dans un premier temps de tenter de classer les participants dans d'éventuels

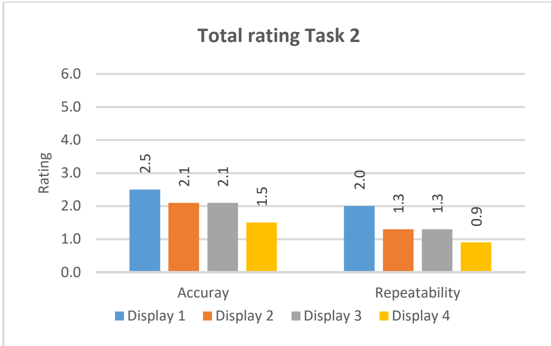
groupes d'observateurs. La base de données n'est pas assez importante pour une telle mise en œuvre. Néanmoins, on peut déjà affirmer que les participants représentent un large échantillon de la société. Toutes les tranches d'âge de 20 à 69 ans sont couvertes. Malheureusement, les femmes sont encore un peu sous-représentées avec cinq participants. Les professionnels des médias sont tout aussi bien représentés que les utilisateurs totalement inexpérimentés.
Comme nous l'avons déjà mentionné, l'environnement de recherche pour la réalisation des expériences a été nouvellement créé. Un élément important pour le choix de l'emplacement était, entre autres, la possibilité de climatisation, mais surtout la possibilité d'obscurcir la pièce. Cela a permis de maintenir l'uniformité des conditions de mesure présentées pendant toute la durée de la recherche. La technologie utilisée a été choisie très consciemment, en tenant compte des processus courants dans l'industrie des médias. Le concept de sécurité et d'hygiène a été approuvé par l'administration de l'université et mis en œuvre en conséquence. Tous les participants ont été positifs à ce sujet, et aucune inquiétude n'a été exprimée. D'un point de vue organisationnel, le temps nécessaire a été le grand défi. Compte tenu de divers aspects tels que les mesures d'hygiène à effectuer jusqu'à la réalisation des mesures de contrôle prévues, des plages horaires de 90 minutes ont été prévues par participant pour la réalisation unique des tests. Ce laps de temps a été bien choisi et n'a été dépassé par aucun participant. Mais bien sûr, cela signifiait que l'engagement en temps que les participants devaient prendre était immense. Néanmoins, 50 participants ont été recrutés au cours de la période précédant les études. Cependant, comme nous l'avons déjà mentionné, l'évolution de la situation pandémique a fait que la planification effective n'a malheureusement pu être mise en œuvre que dans un cadre limité.
La mise en œuvre technique des tâches a reçu un très bon accueil de la part de tous les participants. Bien sûr, l'évaluation a été très utile, mais aussi nécessaire. L'organisation, la procédure et la convivialité de l'application ont été mises à l'épreuve afin de garantir la meilleure performance possible des expériences. Les entretiens finaux ont montré que les participants considéraient que la tâche réelle à accomplir était définie de manière claire et compréhensible. La conception de l'application programmée et sa facilité d'utilisation ont également été jugées très positivement tout au long du projet. La tâche fixée est assez exigeante et épuisante, ce qui a été confirmé par tous les participants. Mais la charge de travail était acceptable. Ce n'est que dans certains cas que l'on a noté que la capacité de concentration diminuait quelque peu vers la fin des tâches. Aucun signe de fatigue n'a été observé, ce qui a également été attribué à la pause de 15 minutes entre la tâche 1 et la tâche 2. Aucune routine, au sens d'une approche déjà consciente, n'a été observée pour le réglage des différents canaux de couleur. Les éventuelles

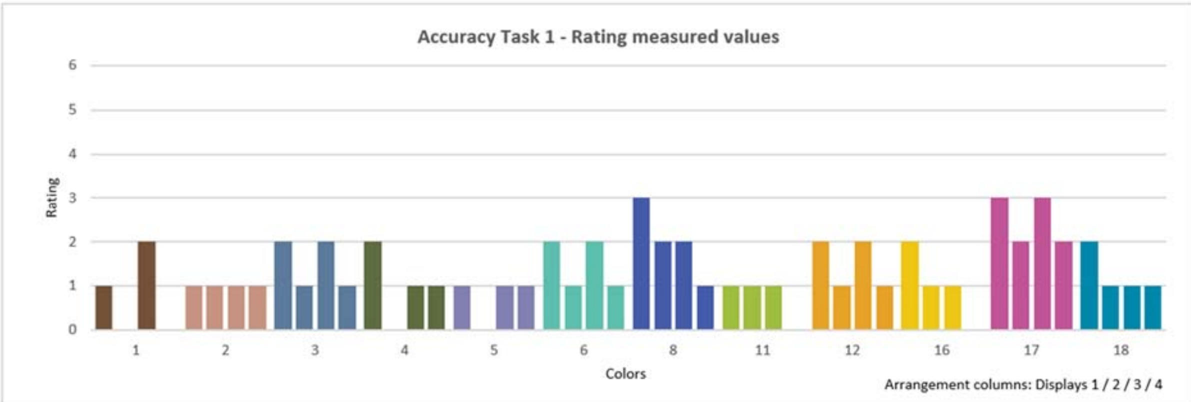
erreurs systématiques n'ont pas pu être détectées. On peut affirmer que la première participation est surtout à considérer comme une sorte d'approche de la tâche fixée. Cela se traduit par une dépense de temps généralement plus élevée et, dans l'évaluation globale, par des résultats un peu moins bons. Cette conclusion ne s'applique toutefois pas au niveau des couleurs individuelles, où l'on obtient une image très contrastée.

Task 1	Accuray		MR1 → MR 2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	0,67	1,8	0,92	2,3	0,46	1,3
Display 2	0,32	0,9	0,48	1,3	0,24	0,6
Display 3	0,49	1,6	0,71	1,8	0,36	1,0
Display 4	0,29	0,8	0,40	1,3	0,20	0,6

Task 2	Accuray		MR1 → MR 2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	1,23	2,5	1,71	2,8	0,85	2,0
Display 2	0,81	2,1	0,92	2,0	0,46	1,3
Display 3	0,83	2,1	1,03	2,2	0,51	1,3
Display 4	0,52	1,5	0,68	1,8	0,34	0,9







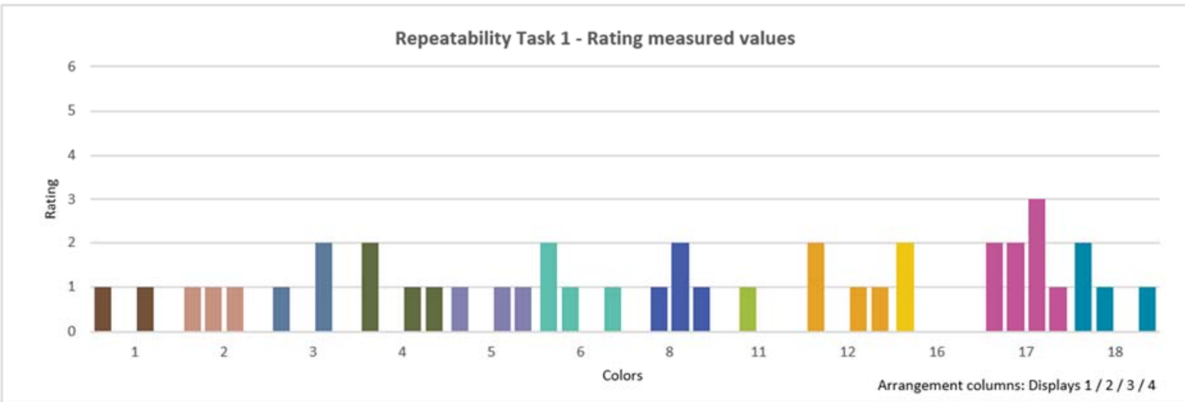


Figure X : Résumé et visualisation des résultats obtenus par le participant ID 01 dans la tâche 1 pour tous les écrans.

Les données collectées lors des expériences et les notations se trouvent sous forme comprimée à l'annexe 4.4. Elles ont été résumées et visualisées en détail en fonction de l'utilisateur pour chaque affichage utilisé. Une analyse séparée des mesures individuelles de la tâche 1 et de la tâche 2 est fournie, qui est convertie en une déclaration globale sur la précision et la répétabilité des résultats. Le temps nécessaire est également indiqué. Les résultats des deux tâches sont ensuite utilisés pour une comparaison directe sur la base des 12 champs de couleur contenus dans les deux sous-expériences. L'évaluation est basée sur l'échelle de notation présentée. Le résultat final est une comparaison globale des résultats obtenus sur tous les écrans. Afin d'analyser et d'évaluer la perception individuelle des couleurs des participants, seuls les résultats de la tâche 1 obtenus sur tous les écrans ont été initialement utilisés. Le dispositif expérimental correspond à la procédure scientifiquement définie et habituelle pour l'extraction des valeurs spectrales individuelles perçues. Les données montrent très clairement à quel point la perception des couleurs est individuelle. Les évaluations diffèrent non seulement d'un participant à l'autre, mais aussi à l'intérieur d'une même personne, notamment lorsque l'on compare les résultats obtenus par les participants pour différents écrans, des différences parfois plus importantes pouvant être observées. Il est à noter que la représentation des couleurs sur les écrans dépend fortement de l'appareil et est déterminée de manière significative par la gamme de couleurs natives et les profils d'affichage spécialement créés et utilisés.

Lorsque les résultats de tous les participants sont combinés, l'évaluation globale de la précision des résultats donne une note de 1,7. Cela signifie que dans la majorité des résultats, il existe des différences entre les correspondances de couleurs obtenues et les couleurs cibles définies perceptibles par des observateurs expérimentés. Il s'agit d'un bon résultat, car seules les couleurs 17 et 18 dépassent minimalement la valeur limite ΔE_{00} = 1,00 sur la moyenne. Les couleurs 1, 4 et 14 reçoivent une note de 1, pour des différences de couleur à peine perceptibles. Il est également clair que les couleurs les moins saturées (1-6) donnent de meilleurs résultats que les couleurs les plus saturées (8-18). L'exception est la couleur 11, près du vert primaire de l'écran. Les couleurs les moins saturées et les plus saturées, dans la gamme spectrale du vert au vert jaunâtre, présentent ici certains des meilleurs résultats. En comparaison, les couleurs moins et davantage saturées de la gamme spectrale qui va de bleu-vert à violet-rose donnent de moins bons résultats.

Ces résultats sont également confirmés par l'évaluation de la répétabilité des résultats, qui donne une note de 1,2. Ce bon score signifie que la majorité des résultats montre des différences de couleur à peine perceptibles des correspondances de couleurs réalisées par rapport aux couleurs cibles définies. La valeur limite ΔE_{00} = 1,00 n'est jamais dépassée en moyenne. La tendance à obtenir de meilleurs résultats avec les couleurs les moins saturées se confirme, tout comme l'évaluation des différentes plages spectrales. En examinant les couleurs saturées, on constate que les couleurs 12 et 16 ont une bonne répétabilité dans la gamme spectrale jaune à jaune orangé, tandis que les couleurs saturées 8, 17 et 18 reçoivent une note de 2.

	Rating chromatic colors											
Task 1	4	1	11	6	2	3	5	16	12	8	17	18
Accuray	1	1	1	2	2	2	2	2	2	2	2	2
Repeatability	1	1	1	1	1	1	1	1	1	2	2	2

	Rating chromatic colors											
Task 1	1	4	6	11	2	3	16	5	12	18	8	17
Repeatability	1	1	1	1	1	1	1	1	1	2	2	2
Accuray	1	1	2	1	2	2	2	2	2	2	2	2

Tableau VI : Classement pour les couleurs uniques de la tâche 1 à partir du résumé des résultats de tous les participants. L'ordre est ascendant à partir de la plus faible différence de couleur mesurée ΔE_{00}.

Les correspondances de couleurs de la tâche 2 donnent des résultats nettement moins bons. Toutefois, cela était prévisible. La structure de la tâche 2 a indéniablement influencé ce résultat. La taille des champs de couleur est considérablement réduite, et 24 champs de couleur différents étaient affichés simultanément. Cette multitude de stimuli différents a influencé la perception des participants, et compliqué la tâche à accomplir. Les couleurs achromatiques contenues dans la tâche étaient particulièrement problématiques. Les mesures effectuées pour déterminer les valeurs cibles montraient déjà que les écrans utilisés pour les couleurs achromatiques 19-24 présentaient généralement des différences un peu plus élevées que les couleurs chromatiques, et que la représentation des couleurs variait fortement dans certains cas. Pour les couleurs chromatiques (1-18), on peut affirmer que tous les écrans convertissent les valeurs nominales des couleurs de manière excellente et stable. La précision globale des résultats, pour les 24 couleurs, montre une note moyenne de 2,8. La répétabilité montre une note moyenne de 2,1.

La séparation des couleurs achromatiques et chromatiques présente les problèmes mentionnés. L'évaluation moyenne des couleurs chromatiques est de 2,6 pour la précision et de 1,9 pour la répétabilité. En revanche, les couleurs achromatiques ont une note moyenne de 3,3 pour la précision. La note de 2,6 pour la répétabilité est également nettement moins bonne. Cela montre que, dans le cas des couleurs achromatiques en particulier, l'influence des stimuli colorés environnants est plus perceptible. L'examen des résultats confirme les tendances de base de leur qualité dans les différentes gammes spectrales et les couleurs moins et plus saturées trouvées dans la tâche 1, et ce malgré les différences de couleurs plus élevées observées. Une étude plus approfondie de la façon dont la disposition des différents champs de couleur affecte les résultats individuels est prévue, qui n'a pas encore pu être mise en œuvre en raison des motifs évoqués plus haut.

	Rating chromatic colors																		Rating achromatic colors					
Task 2	4	9	2	11	1	14	12	15	16	7	10	6	3	5	8	17	13	18	23	24	21	20	22	19
Accuray	2	2	2	2	2	2	3	2	2	3	2	3	3	2	3	3	4	3	3	3	3	3	3	4
Repeatability	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	2	3

	Rating chromatic colors																		Rating achromatic colors					
Task 2	4	9	11	2	1	14	12	16	15	7	6	3	10	17	8	5	13	18	23	22	21	24	20	19
Repeatability	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	2	3	3
Accuray	2	2	2	2	2	2	3	2	2	3	3	3	2	3	3	2	4	3	3	3	3	3	3	4

Tableau VII : Classement pour les couleurs uniques de la tâche 2 à partir du résumé des résultats de tous les participants. L'ordre est ascendant à partir de la plus faible différence de couleur mesurée ΔE_{00}.

Si l'on considère les résultats obtenus dans la tâche 1 au niveau des écrans individuels, on a une impression de la dépendance de ces résultats par rapport au appareil utilisé. La vue globale des résultats obtenus par les participants et par écran montre des différences perceptibles dans la qualité des résultats. L'écran 1 a reçu une note moyenne de 1,9 dans l'évaluation globale de tous les participants pour la précision, ce qui est la note la plus élevée. L'écran 3 affiche une note moyenne de 1,8, suivi de l'écran 4 avec 1,4. La meilleure note moyenne, 1,3, est obtenue par l'écran 2. Ainsi, les écrans 1 et 3 montrent en majorité des différences de couleurs perceptibles par des observateurs expérimentés, tandis que les correspondances de couleurs obtenues pour les écrans 2 et 4 montrent des différences de couleurs à peine perceptibles par rapport à la couleur cible. L'évaluation de la répétabilité des résultats présente une image similaire. L'évaluation moyenne de 1,6, pour l'écran 1, est de nouveau la valeur la plus élevée. L'écran 3 suit avec une note moyenne de 1,1, puis l'écran 2 avec 0,9. La meilleure note de répétabilité est attribuée à l'écran 4 avec une note moyenne de 0,8. Une fois de plus, les écrans 2 et 4 affichent les meilleures et, dans ce cas, de très bonnes valeurs. En principe, il faut également tenir compte du fait que, malheureusement, tous les participants n'ont pas été en mesure de résoudre la tâche définie pour chaque écran, ce qui explique pourquoi un nombre différent de résultats est inclus dans cette évaluation globale présentée en fonction de l'écran.

Par conséquent, les résultats des participants avec les ID 01, 03, 04 et 05, pour lesquels les résultats des quatre écrans utilisés sont disponibles, ont été spécifiquement combinés. Il faut tenir compte du fait que les espaces colorimétriques natifs des quatre écrans sont parfois très différents, ce qui se reflète dans la représentation des couleurs cibles définies. L'écran 1 représente les couleurs chromatiques avec la saturation la plus élevée de tous les écrans, à quelques exceptions près, et utilise donc également la plus grande quantité de couleurs représentables. En comparaison, l'espace colorimétrique natif de l'écran 2 présente un bleu de couleur primaire nettement plus saturé et, ici, une gamme de couleurs représentables un peu plus étendue. Des différences plus importantes dans l'espace de couleurs représentables peuvent également être observées dans la comparaison avec l'écran 3, qui s'avère plus petit en raison des couleurs primaires vertes et bleues de l'écran. L'écran 4 présente le plus petit espace colorimétrique représentable et, à l'exception de la couleur 1, les valeurs nominales et spectrales mesurées des couleurs chromatiques sont les moins saturées. Les couleurs neutres (19-24) sont représentées de manière légèrement différente d'un écran à l'autre, en fonction du point blanc du profil.

L'examen de la moyenne des résultats des quatre participants permet d'obtenir un aperçu détaillé des couleurs individuelles. Les résultats de l'écran 1 montrent que quatre couleurs correspondent à une note de 3, pour de petites différences de couleur perceptibles. Seules deux couleurs reçoivent une note de 1, ce qui se traduit naturellement par une note moyenne globale plus élevée. L'écran 2 présente le meilleur résultat, qui s'exprime par une note de 1 pour sept couleurs. Une note de 3 ne donne que la couleur 17. Les deux écrans sont profilés sur la base de la gamme de couleurs AdobeRGB, et couvrent une gamme de couleurs plus étendue que les écrans 3 et 4. Les résultats de l'écran 3 montrent une note de 1 à trois reprises, et une note de 2 à neuf reprises. L'évaluation de l'écran 4 est légèrement meilleure. Dans la vue d'ensemble des couleurs individuelles déjà présentée, on observe que dans les couleurs moins saturées, les correspondances de couleurs donnent un résultat plus précis que dans les couleurs plus saturées. Cette conclusion peut être appliquée à tous les écrans. Cependant, l'exemple de l'écran 4 montre que plus la gamme de couleurs représentables est petite, donc plus la saturation des couleurs les plus saturées est faible, plus la transition est douce. La vue d'ensemble des couleurs individuelles montre également que les couleurs les moins et les plus saturées, dans la gamme spectrale du vert au vert jaunâtre, présentent certains des meilleurs résultats. Cette impression est déterminée par le fait que la majorité des résultats inclus dans l'analyse globale ont été obtenus pour l'écran 1, où ce point est très clairement visible. Cette conclusion peut également être pleinement adoptée pour l'écran 3. Les résultats des écrans 2 et 4 confirment cette conclusion pour la gamme spectrale la moins saturée, tandis que dans la gamme la plus saturée, la correspondance des couleurs a détecté des différences de couleurs perceptibles par des observateurs expérimentés.

Finalement, l'observation globale permet de conclure que les couleurs les moins et les plus saturées, dans la gamme spectrale du bleu vert au rose violacé, représentent une zone à problème et présentent, la plupart du temps, de moins bons résultats en comparaison. Cette conclusion est confirmée par les résultats des quatre écrans. Elle est particulièrement claire pour l'écran 1. L'écran 4, avec la plus petite gamme de couleurs représentables, présente les meilleurs résultats en termes de répétabilité. Plus cette dernière est grande, plus les différences entre les correspondances de couleurs obtenues sont élevées, avec une saturation plus élevée de la couleur cible.

Task1	Accuray		MR1 → MR 2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	0,80	1,98	0,95	2,08	0,47	1,27
Display 2	0,50	1,27	0,73	1,56	0,37	0,87
Display 3	0,62	1,63	0,73	1,71	0,37	0,96
Display 4	0,56	1,54	0,58	1,52	0,29	0,79

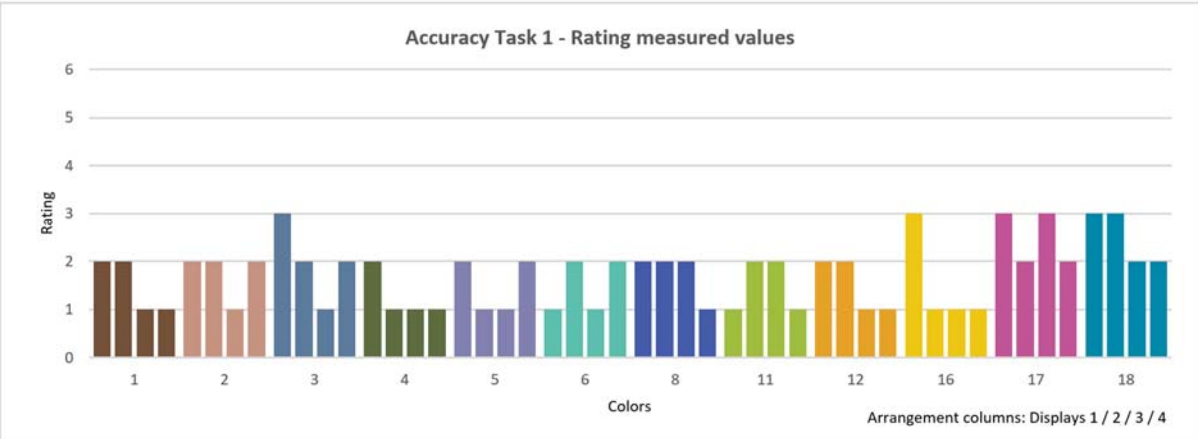
Task 2	Accuray		MR1 → MR 2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	1,50	2,86	1,83	3,01	0,92	2,05
Display 2	1,11	2,47	1,32	2,56	0,66	1,69
Display 3	1,35	2,59	1,95	2,27	0,96	1,50
Display 4	1,19	2,53	1,51	2,78	0,75	1,82

Display 1	Rating chromatic colors											
Task 1	6	11	2	5	4	12	1	8	16	3	18	17
Accuray	1	1	2	2	2	2	2	2	3	3	3	3
Repeatability	1	1	1	1	2	2	1	1	1	1	2	2

Display 2	Rating chromatic colors											
Task 1	4	12	5	6	1	16	2	3	11	8	18	17
Accuray	1	1	1	1	1	1	1	1	2	2	2	3
Repeatability	0	0	1	1	1	0	1	1	2	2	2	2

Display 3	Rating chromatic colors											
Task 1	4	5	16	2	6	12	3	8	11	17	1	18
Accuray	1	1	1	2	2	2	2	2	2	2	2	3
Repeatability	1	1	1	1	1	1	1	1	1	2	2	1

Display 4	Rating chromatic colors											
Task 1	1	4	12	8	16	11	5	17	2	6	3	18
Accuray	1	1	1	1	1	1	2	2	2	2	2	2
Repeatability	1	1	1	1	0	1	1	1	1	1	1	1



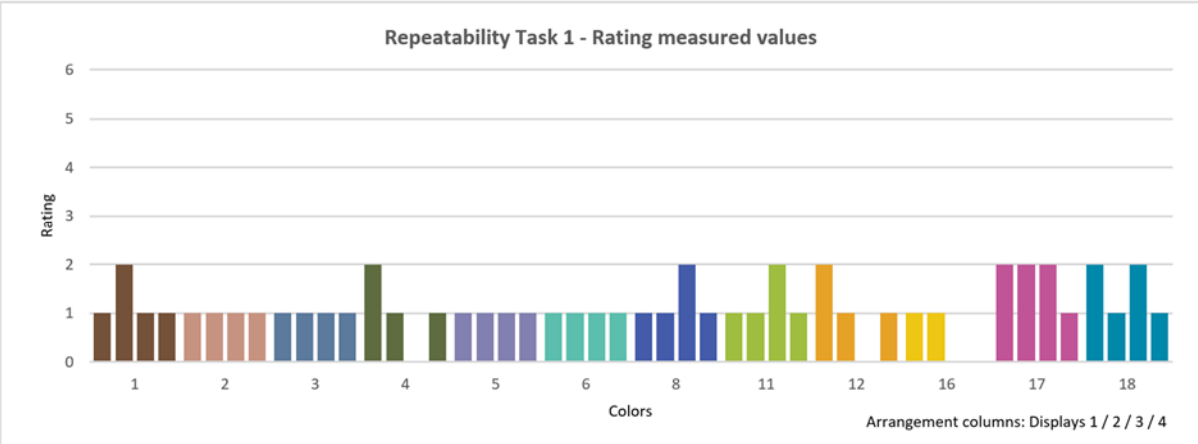


Figure XI : Résumé et visualisation des résultats obtenus par les participants ID 01, ID 03,

Conclusion

Malheureusement, le nombre de tests effectués ne nous permet pas encore de nous livrer à des déclarations qualitatives, mais diverses observations peuvent déjà être faites. Les écrans LCD renforcés par des QD utilisés présentent une représentation des couleurs très stable et précise. Cependant, les expériences de correspondance des couleurs réalisées par les participants montrent également que, dans les plages spectrales dominées par le bleu primaire de l'écran, la qualité de la représentation des couleurs diminue quelque peu. Cela est dû au fait que, dans la BLU, aucune extension QD n'est utilisée pour la composante spectrale bleue, et que c'est donc le spectre d'émission des LED BLU bleues utilisées qui détermine la représentation spectrale. Celle-ci s'avère être un peu plus large en comparaison, car les propriétés des QD utilisés pour le rouge et le vert, afin de représenter une lumière avec une émission étroite et un excellent contrôle de la longueur d'onde, n'entrent pas en jeu ici. Parmi toutes les correspondances de couleurs des participants, les réglages effectués pour la valeur de la couleur bleue entraînent les plus grandes imprécisions ou déviations de la valeur cible, parmi les couleurs cibles représentées en comparaison. En revanche, la définition spectrale très précise des primaires rouge et vert rendue possible par l'utilisation de QD conduit à de très bons résultats, avec de faibles déviations.

Comme prévu, la grande quantité de couleurs représentables a également constitué un défi pour les participants. Les résultats disponibles montrent que les utilisateurs expérimentés ayant des connaissances en traitement d'images numériques maîtrisent nettement mieux la situation. Ils ont obtenu de bons résultats de manière constante, indépendamment de l'écran. Cela montre l'importance de la qualité de la représentation des couleurs de la technologie d'affichage utilisée pour la production de résultats de haute qualité, en particulier en termes de production de médias standardisés. Dans ce domaine, les LCD renforcés par des QD offrent une valeur ajoutée significative par rapport aux autres technologies d'affichage. L'importance du calibrage et du profilage des écrans, pour une production standardisée, est de nouveau soulignée par les résultats obtenus. La représentation des couleurs en fonction de l'appareil et son influence sur la correspondance des couleurs obtenue montrent clairement l'importance de la qualité des profils d'affichage utilisés, qui est largement déterminée par le dispositif de calibrage de l'écran. La comparaison des performances effectuée avec quatre appareils tout-en-un standards de l'industrie montre des différences en fonction de l'appareil, mais aussi des résultats bons à très bons. Le choix délibéré d'un tel appareil, en fonction de l'écran utilisé, permet une représentation stable, reproductible et précise des couleurs.

En particulier chez les participants inexpérimentés, l'augmentation des couleurs représentables conduit à une intravariabilité notable des résultats, qui est très fortement déterminée par la représentation des couleurs des écrans en fonction de l'appareil. En résumé, les tendances déjà présentées ici sont visibles, mais pas entièrement transférables à chaque participant.

L'individualité de la perception des couleurs est évidente. Dans le sens d'une production médiatique standardisée de l'avenir, en accord avec le développement constant des technologies utilisées, une discussion doit également avoir lieu ici sur la manière de traiter cette individualité. Cela pourrait être envisagé dans un profil spécifique à l'utilisateur, pour un affichage défini, qui lierait la représentation des couleurs dépendant de l'appareil avec la perception individuelle des observateurs.

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List of terms and abbreviations

AGLP = (GNU) Affero General Public License

ASTM = American Society for Testing and Materials

ASV = Advanced Super View

ATC = Advanced Television Committee

ATSC = Advanced Television Systems Committee

BLU = Backlight Unit

BPLC = Blue Phase Liquid Crystal

CCT = Corelated Color Temperature

CGATS = Committee for Graphic Arts Technologies Standards

CF = Color Filter

CMC = Color Measurement Committee

CMM = Colormanagement Module

CIE = Commission Internationale de l'Eclairage

CRT = Cathode Ray Tube

DCI = Digital Cinema Initiatives

EBU = European Broadcast Union

ECI = European Color Initiative

EQE = External Quantum Efficiency

FFS = Fringing Field Switching

FWHM = Full Width Half Maximum

GaN = Gallium Nitride

HD = High Definition

HDR = High Dynamic Range

IEC = International Electrotechnical Commission

ICC = International Color Consortium

InGaN = Indium Gallium Nitride

IPS = In-Plane Switching

ITU = International Telecommunications Union

LC = Liquid Crystal

LCD = Liquid Crystal Display

LCM = Liquid Crystal Module

LGP = Light Guide Plate

LED = Light Emitting Diode

LUT = Look Up Table

MD = Measurement Device

MEMS = Micro-Electro-Mechanical-Systems)

MR = Measurement Run

MVA = Multi-domain Vertical Alignment

n-FFS = Negative-Fringing Field Switching

nm = Nanometer

NTSC = National Television Systems Committee

PS-BPLC = Polymer-Stabilized Blue Phase Liquid Crystal

OLED = Organic Light Emitting Diode

OSD = On-Screen Display

pc-WLED = Phosphor Converted White Light Emitting Diode

PCS = Profile Connection Space

p-FFS = Positive-Fringing Field Switching

PLQY = Photoluminescence Quantum Yield

PSL = Passive Streaming Layer

PVA = Patterned Vertical Alignment

PWL = Peak Wavelength

PWM = Pulse With Modulation

QD = Quantum Dot

QDEF = Quantum Dot Enhanced Film

QDCC = Quantum Dot Color Conversion

QDCF = Quantum Dot Color Filter

QDPR = Quantum Dot Photo Resist

RGB = Red Green Blue

RMS = Root Mean Square

RoHS = Restriction of Hazardous Substances

S-IPS = Super In-Plane Switching

SDC = Society of Dyers and Colorists

SMPTE = Society of Motion Picture and Television Engineering

SPD = Spectral Power Distribution

TFT = Thin Film Transistor

TFT-LCD = Thin Film Transistor Liquid Crystal Display

TLE = Total Light Efficiency

TN = Twisted Nematic

TRC = Tone Reproduction Curve

UHD = Ultra High Definition

UV = Ultraviolet

VA = Vertical Alignment

WLED = White Light Emitting Diode

YAG = Yttrium Aluminium Garnet

Preface

Today's world of digital media is experiencing rapid development. The increasing number of different digital devices, all with different display sizes and display technologies, poses a great challenge. At the same time, however, these developments also present great opportunities. This chapter serves as an introduction to the research field of color vision and display technologies and provides an overview of the development of scientific fundamentals, standardization, and display technologies.

From light to color

In the human visual system, the eyes are the sensory organ that perceives light and colors. James Maxwell formulated equations for electrodynamics in 1864. Using these equations, he concluded that light itself is an electromagnetic wave. The human eye perceives an electromagnetic wave with a wavelength of 380 nanometers as visible violet light, and we distinguish red light with a wavelength of 780 nanometers. Light rays contain information that we perceive and process with our visual system. Visual perception cannot be explained physically because everything we see is immediately interpreted by the brain. Color is a translation of the information contained in the light rays. [1–10]

Isaac Newton made a significant contribution to our current understanding of human color perception. He studied light refraction and showed that a prism can split white light into a color spectrum and that a lens and a second prism can split the multicolor spectrum back into white light. More than a hundred years after Newton, Thomas Young developed his theory of trichromatic color vision. In his experiments with three-color light of variable intensity, Young succeeded in determining the wavelength of the light. Its basic acceptance is based on the fact that the retina of the human eye has only three receptors for the three primary colors (red, green, and blue). This theory was further developed by David Brewster, who drew very precise three-color sensitivity curves and proved that all colors can be mixed with the three primary colors. Hermann von Helmholtz took the next step in 1850; based on Young's research, von Helmholtz formulated the trichromatic theory, which is the basis of modern color reproduction and color rendering. Every color can be mixed with the colored light of the three primary colors red, green, and blue, because there are only three different types of receptors in the human eye. These contain spectrally different pigments with different characteristic absorption properties: S-cone (blue), M-cone (green), and L-cone (red). [1, 3–8, 10–15]

In 1885, Ewald Hering formulated the opponent process theory. This began with the assumption that visible light falls on the light-sensitive retina and is divided into three different channels, while the luminance channel (black and white area) results from the input of all three cones. In 1905, Johannes von Kries formulated the theory of retinal rods and cones. Color perception works on two levels. In our perception, colors are created on the first level by spectrally different pigments in the cones that absorb light of a certain wavelength range. On the second level, color channels are created by the three groups of cones (photoreceptors). They absorb light of a short wavelength (S, blue), a medium wavelength (M, green-yellow), or a long wavelength (L, red). The two color channels are red-green and blue-yellow based on the combination of these signals. This additional level of color vision opens up the entire visible spectrum. [1, 10, 11]

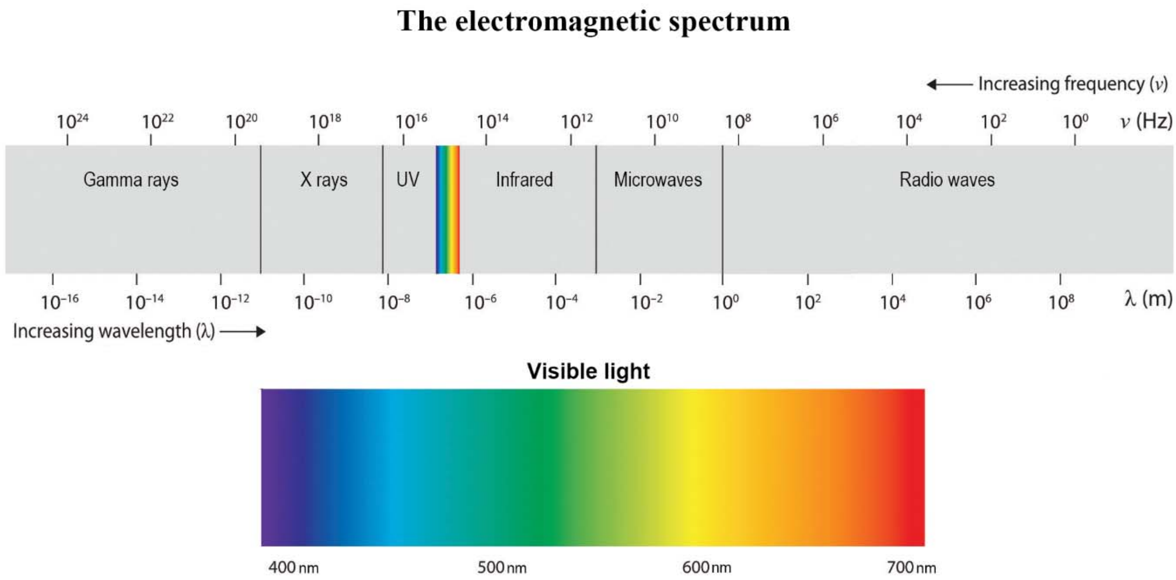


Figure 1. Visible light as part of the electromagnetic spectrum. [1, 3, 16]

Development of color representation

Our media is full of color. Print is traditionally referred to as the art of printing. Modern four-color printing technology was developed in the early 1930s. After World War II, industrial production of color books, magazines, and catalogs began. While reliable color reproduction was initially limited to special closed systems in prepress, this has changed dramatically due to technical advances in photography and electronics. The arrival of the computer and associated digitization changed the entire printing industry and ushered in a new media world. In particular, much has changed in the area of color reproduction in prepress. [16–18]

Today's printing industry adopts standardized workflows in open systems with many partners and many different input and output devices. Basic knowledge and experience are the prerequisites for perfect color reproduction using a color management system. Color management is the color matching of all input and output devices involved in the production workflow. This makes it possible to obtain color-correct output at any point in the production process. That said, the colors that can be determined and displayed by the input and output devices vary greatly. In modern color management, it is necessary to link different devices via the intermediate step of a neutral color space. The device-dependent color descriptions are converted into each other via the device-independent exchange color space. This step enables different output devices to represent colors in approximately the same way. However, identical representation is not possible. [16–18]

Modern device users want to see all the colors in nature replicated on their output devices. We expect color consistency from perception to output. Since colors have no units, colors must be defined; a number system is needed to accurately describe colors. Colors must be detectable by measuring devices. Depending on the technical application, we use different color systems in the production workflow. However, none of these meets the requirements of all applications, nor can they serve as a central model. These color systems are usually represented in three dimensions. All colors within the color system are assigned unique numerical values as color locations. Mathematical formulae and geometric models describe the human visual system that correlates colors. A color space is the practical application of a color system and should contain as many colors as possible within the color system. This is the so-called gamut, which defines absolute values for colors. A device color space contains the range of colors that a device used in the workflow can capture or output. [16–18]

The RGB (Red, Green, Blue) color model is a three-dimensional color space that represents color perception through additive color mixing of the primary colors red, green, and blue. It is based on trichromatic theory and is used for self-luminous systems such as screens, displays, and projectors. All colors are written and stored with three values for RGB. The CMYK (Cyan, Magenta, Yellow, Key) color model, meanwhile, is a generic color system that describes the technical mixing ratios. The description is independent of the base color used. It was developed from the CMY color model for printing; the K was designed as an additional color (black). Theoretically, printing the three basic colors cyan, magenta, and yellow results in black on top of each other. In practice, however, there is not enough black. This is mainly due to the technical composition of the color ink. None of the pigments used has the optical properties of an optimum color. [16–18]

In 1931, the CIE (International Commission on Illumination) published the CIE 1931 color space as one of the first international standards based on the definition of color as a visual function. Through a series of experiments with different participants, subjective color perception was regressed to general tristimulus values. The true monochromatic colors spectral red (700.0 nm), green (546.1 nm), and blue (435.8 nm) were used as reference stimuli. The result of the standardization was the CIE 1931 XYZ color space, based on the color matching functions of the CIE standard observer. The CIE 1931 color space chromaticity diagram was used to create a more descriptive and manageable two-dimensional diagram. Due to the loss of one dimension, however, it is no longer possible to determine brightness. [1, 11, 16–19]

In 1976, the CIE introduced the CIELAB color space, intended to address the deficiencies of the CIE 1931 XYZ color space with the help of mathematical transformations. In practice, however, problems arose in determining the tolerances for the color type defined by x and y. To explain, the color type is defined by the difference between two color types. In the case of the CIELAB color space, this deviation could be calculated from the difference between the two vectors but often failed to correspond to the visually perceived deviation. The CIELAB color system is an infinite three-dimensional color space with the three coordinate axes L* (luminance), a* (green-red axis), and b* (blue-yellow axis). The chroma diagram is the simplified two-dimensional description of the a*b* level for L* as a constant brightness level. [1, 11, 16–19]

From CIELAB to color management

Color management has its origins in prepress color reproduction. It evolved rapidly from the transition of electronic color reproduction to desktop publishing due to a technological shift in the 1980s and 1990s. All these technological changes sought to ensure the interchangeability of digital color information. In 1993 and 1996, respectively, the ICC (International Color Consortium) and ECI (European Color Initiative) standardization bodies were established. This marked the beginning of color management: both committees developed open standards for color profiles of input and output devices as the first steps toward a functioning color management system. [1, 16–19]

ICC color management is an important part of color reproduction. Its aim is to ensure the best possible color consistency between different input and output devices during the production workflow. The color management system works with a device-independent color space called PCS (profile connection space). Each device in the production workflow has a specific standardized technical device profile, which contains the definition of the device-dependent color space. Whereas the device-dependent color spaces often differ greatly in their reproducible color scale, by using a device-independent color space (media-neutral), they are decoupled from each other. It is therefore possible to convert image data into different technical color gamuts with high color consistency. [1, 16–19]

Color management has witnessed a shift away from traditional print products to digital output devices and mobile displays as media use changes rapidly across society. Smartphones and tablets are becoming increasingly important; use of such mobile devices is now largely taken for granted. This trend also applies to the media industry, where tablets have already achieved a strong presence and widespread use in the graphic arts industry. This significantly increases the need for coordinated color management solutions. The printing industry is once again playing a leading role in this development. Printed proofs have long been at the heart of [17]communication between the customer and the print department, and this role is increasingly being taken over by soft proofing systems (monitoring proofing). However, this poses a major challenge to all partners in the printing industry since soft proofing systems rely on calibration, profiling, and color management to provide an accurate representation of images as they will actually be printed. Many factors can contribute to the fact that despite the smallest metrological color differences and the best available hardware and software, the representation of an identical image file may vary considerably from display to display. Thus, the sum of all influences on the overall system must be standardized. [16–18]

Soft proofing is the display of color data on an accurately calibrated and high-resolution display with the goal of producing the color image of the colors described by the data for specific lighting and environmental conditions. Such accurate color representation requires colorimetric database definition and accurate color management software to represent the exact hue and brightness of the data. Crucial to image quality is a uniform color representation across the entire screen (homogeneity). The color gamut of a display is determined by the technology used and depends on the device. Essentially, the gamut must at least be large enough to represent all necessary colors. Here, one aspect of the color gamut is the brightness contrast, which is expressed in the luminance ratio of white and black points and should be at least 200:1. Absolute brightness requires a luminance of 150–200 cd/m^2, which should be achieved after calibrating the display to the desired white point (typically 5,000 K in the media industry). Another important requirement is temporal and spatial stability, as the reproduced colors must be consistent across the entire screen area and with tight tolerances. [16–18, 20]

Digital display devices

Displays are the visual interface for media productions, so their function in the production process is vital. Currently, liquid crystal displays (LCDs) are typically used in media production and offer a vast range of displayable colors. The classic LCD display is the most important display technology today; LCDs are used in all types of flat panel displays and are the predominant technology in mobile devices. [21, 22]

The function of this display technology is based on the fact that LCs (liquid crystals) influence the polarization direction of light when a defined electrical voltage is applied. A pixel consists of two glass plates coated on their opposite sides with a transparent electrode layer. In each cell, linearly polarized light interacts with a nematic LC. Between the glass plates, the LCs are arranged in a helical array, and the polarizing filters are glued to the outside of the glass plates. Illumination elements (so-called backlight) are then mounted on the back, and color filters are placed in front of each subpixel. The light from the backlight is transmitted and (selectively) fully or partially colored for each pixel. The ability to rotate the polarization direction of the light is based on optical anisometropy, which is the key physical mechanism. [21, 22]

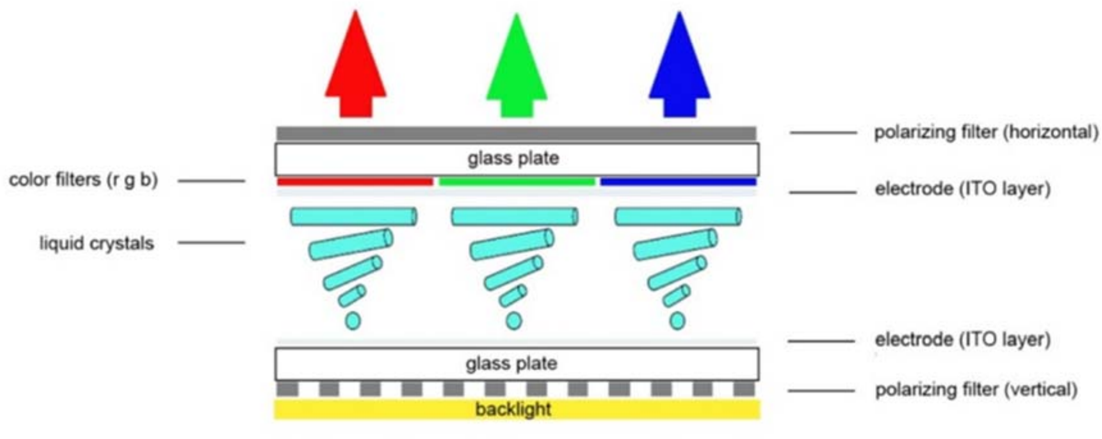


Figure 2. Schematic diagram of an LCD screen pixel. [21, 22]

Various panel technologies are used for the color rendering of an LCD. These have a strong influence on display properties, such as color representation or viewing angle dependency. LCDs with in-plane switching (IPS) panels are very well suited to media production. They offer very low viewing angle dependency, which is essential to common widescreen displays. Although IPS panels have lower brightness contrast than alternative panel technologies, they are more than adequate for true color representation. Other important requirements include the largest possible displayable color gamut, homogeneity, and temporal and spatial stability of the display. Due to the technological principle, LCD displays are passive and therefore not self-illuminating. Rather, they emit or reflect only the light that is fed into the display by an additional light source. The technology in which the light is emitted uniformly from the back and projected onto the full LCD display over a wide area is called backlighting. LEDs (light-emitting diodes) are typically used as light sources for backlighting. LED backlighting consists of many LEDs, which are integrated into the panel in different technical variants. [21–24]

Today, QDs (quantum dots) play an important role in the further development of LCD technology and are increasingly becoming the technology of choice for displays with a wide color gamut. QDs offer an amazing, high-tech performance boost for LCDs through a unique application of quantum physics. By incorporating the LCDs into the backlight, they produce highly saturated primary colors, very high color purity, and a color display with a wider color gamut, making it very pleasing to the eye while improving brightness and energy efficiency. QDs are also tunable, meaning they can produce the exact colors needed for high image and color accuracy. QDs have already been used in computer monitors and televisions, as well as biological and medical imaging equipment. [25–28]

Backlighting is a critical part of LCDs because it affects color gamut, optical efficiency, dynamic range, and viewing angle. QD-enhanced backlighting offers excellent characteristics with a simple device configuration: its central emission wavelength can be adjusted by the size of the nanoparticles. The full width at half maximum (FWHM) is about 20-30 nm, which is mainly determined by the size uniformity and high photoluminescence efficiency. Various materials have been synthesized and studied as part of this technology. These are typically divided into two categories of heavy metal-based QDs and heavy metal-free QDs. Heavy metal-free or low-carbon QDs are now the focus for current and future display applications. Different QD backlight geometries are used to configure the display unit. The quantum dot enhancement film (QDEF) technology is currently the most commonly used geometry. [25–29]

Various display manufacturers are now focusing on the emerging OLED (organic light emitting diode) technology. This is based on the fact that certain polymers emit light as soon as they enclose conductive layers and a voltage is applied. OLEDs consist of several organic layers with semiconductor behavior. An extremely thin, transparent, electrically conductive layer of ITO (indium tin oxide) is applied to a flexible, transparent film. This is followed by the actual light-emitting organic layer, which is sandwiched between a hole transport layer and an electron transport layer. Above this is the second electrode (cathode), and the OLED illuminates when current flows through the sandwiched layers. Since each sub-pixel itself becomes the light source, no backlight is required. The ability to turn light emission on or off hides certain organic

molecules in a natural combination; as such, they behave as semiconductors and are therefore suitable for transporting electrical charges. Polymers must not come into contact with water or oxygen, as they react with these substances and are thus destroyed. As a result, it is necessary to protect the organic elements from external influences by encapsulating the display. [21, 24]
OLEDs consist of small molecules or polymer materials and require only a single substrate. OLEDs can therefore be manufactured as extremely thin layers. The development of suitable conductive, transparent plastic substrates paves the way for flexible displays. Due to their thin-film structure, OLEDs achieve excellent optical properties (high contrast and brilliant colors) and high-precision light emission with low viewing angle dependency, while their energy consumption is very low. [21, 24]

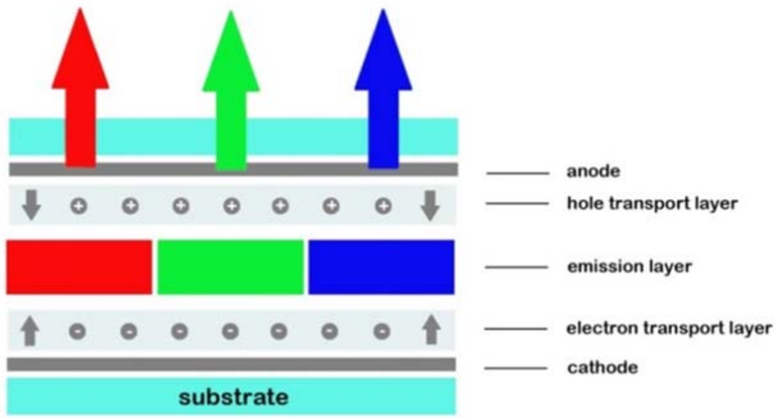


Figure 3. Schematic diagram of an OLED screen pixel. [21]

Mobile devices such as tablets and smartphones are becoming increasingly important tools in everyday life. Modern displays are becoming increasingly powerful and efficient. This is also necessary because quality requirements have increased significantly. On the one hand, many manufacturers prefer to use IPS LCD technology, which offers many advantages, such as low viewing angle dependency, which is very important for short viewing distances and frequent movements of the display. Due to the LED backlight, the power consumption of these devices is also very low, resulting in excellent battery life, while the IPS LCD technology is very sensitive to touch, enabling a very short response time. In addition, the device color gamuts of different IPS LCDs look relatively similar because they are more or less oriented to the sRGB color gamut. .[21–23, 30]
On the other hand, active matrix organic light-emitting diode (AMOLED) technology is also often used in mobile devices. Simple in design and enabling fast switching times, AMOLED displays are much thinner than LCDs and can be manufactured far less expensively. Other

advantages over LCDs include lower power consumption and very high luminosity. However, since the materials used have a shorter lifespan, AMOLED displays must be hermetically encapsulated because the materials they contain can oxidize quickly and lead to defects.[21–23, 30]

1 Introduction

Color vision is a complex phenomenon in optics and photonics that encompasses three basic components of color: light sources, object illumination, and observers. Color perception has always been an area of interest and a source of fascination for scientists, with studies dating back hundreds of years. Display and visualization devices are interfaces between digital information and human perception, where information is transported by light. These interfaces should be optimized for human vision and visual perception capabilities. An important goal, therefore, is to exploit the properties of the human visual system to meet today's technological challenges. These challenges include the various display technologies and their respective color gamuts, colorimetric characterization and calibration of digital displays, measurement devices, color management systems, and actual software applications. [21, 31–33]

In order to be able to evaluate and subsequently optimize self-luminous color displays, a wide variety of characteristics of human color perception must be taken into account. Among other things, the photoreceptor structure of the retina, color vision and color difference perception, as well as the spatial and temporal contrast sensitivity of the visual system are particularly important. However, various aspects of ergonomics as well as different color phenomena that may occur in the course of visual information processing must also be considered. [33]

Interindividual variability in color vision is also an important topic. Furthermore, it is also necessary to study specific characteristics of display technologies as they relate to certain color vision properties. Image quality is a major issue, especially the accurate representation of colors. For this purpose, the number of colors that can be represented must be optimized to cover as large a color gamut as possible, which can also be accompanied by a higher color depth. In addition, a colorimetric characterization of the display must be carried out and profiling performed. It is important here that a color representation model is used that takes into account an adaptation to the human visual system. [21, 33–36]

1.1 Approach

The technology of focus for this research is quantum dot (QD)-enhanced LCDs. TFT-LCDs are still the dominant flat panel display technology today; they are in the process of being revolutionized and reinvigorated by the integration of quantum dots into the backlight. This

unique application of quantum physics enables amazing performance gains in displayable color gamut and color saturation while improving display brightness and energy efficiency. [27, 37]
QD-enhanced LCDs produce highly saturated primary colors like those of OLED displays. Recent research shows that QD-enhanced LCDs perform more efficiently than current OLED displays due to their wider color gamut: this technology currently delivers up to 50% more color gamut and remains the display technology that at least comes close to the Rec.2020/BT2020 color gamut. It also provides high peak brightness, enabling support for high dynamic range (HDR) displays. QDs enable precise tuning and control of light emission, resulting in pure, clean whites and accurate, lifelike colors and improved color accuracy. [27, 37]
This research directly discusses and correlates two main topics: color vision and QD-enhanced LCDs. It is based on the following three overarching questions:

1. How do QDs change the color reproduction capabilities of LCDs, with a focus on the visual perception of the spectrum produced by these nanoparticles?
2. How do QDs expand the application possibilities of displays with a focus on media photonics?
3. What are the prospects for QD technology in the future?

To answer these questions, various colorimetric tests are carried out that allow conclusions to be drawn about the performance of the technology. Several displays from different manufacturers are used for this purpose, and the performance of different display calibration devices commonly used in the industry is measured. The focus here is on different color matching experiments; on the one hand, these serve to develop a deeper understanding of the color vision of the individual viewer. On the other hand, it is also important to determine how well the color representation of the displays is adapted to the requirements of the human visual system and the results this adaptation entails.
The following objectives for this research work were derived from the defined overarching questions and the selected focal topics:

1. Analysis of QD technology and its prospects in the field of media photonics;
2. A comparative study of current display calibration devices;
3. A comparative study of the impact of QD-enhanced LCDs on visual perception;
4. Evaluation of the expected improvements in media-related applications regarding a desired standardization of production processes.

2 An overview of color vision and color science

This chapter presents the essential basics and theories of color vision and the associated color sciences. First, an overview of the anatomy and function of the human visual system is provided, followed by a review of the basic theories of color perception. Various physiological sources of individual differences in color adaptation are then discussed. Finally, an introduction to colorimetry is given, including the CIE standardized and generally accepted colorimetric system.

2.1 The anatomy of the eye

The eye is the most important and also the most complex human sensory organ. Various demands are made of it: it should be mobile and quick to react, enable sharp close-up vision and television, follow movements without vibrations, perceive dangers, and function during the day and at night. The first important studies on the anatomy of the eye were carried out by Hermann Ludwig von Helmholtz (1924) and described in his book *Handbuch der Physiologischen Optik*. Many other studies on anatomy, color processing mechanisms, and physiology have since been conducted and published in a wide variety of publications. [1, 6]

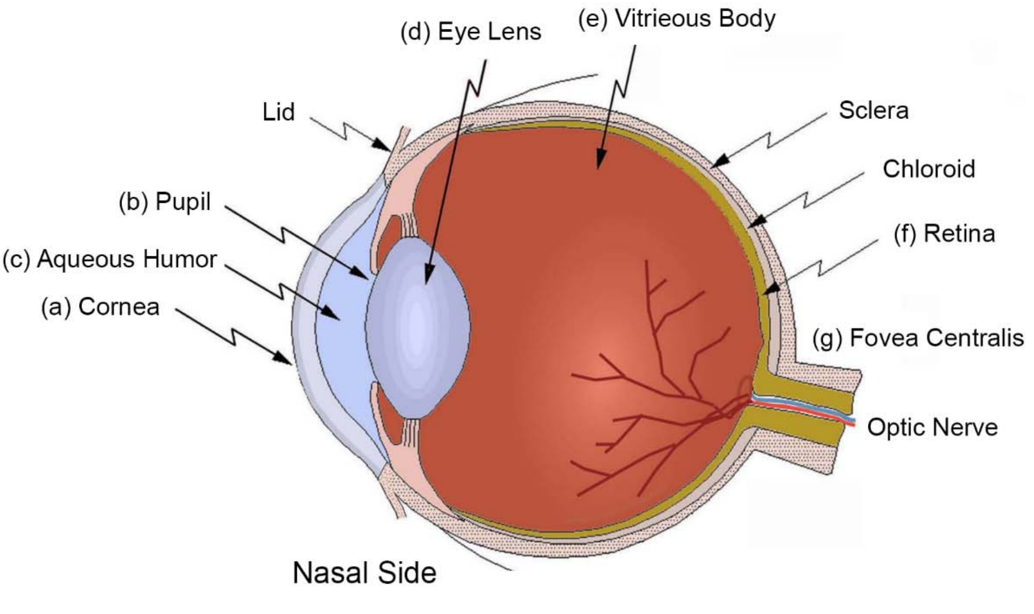


Figure 4. Human eye schematics.[1]

The eye consists of many important optical components (see Figure 4), all of which must work together in optimal harmony. The (a) *cornea* takes the form of a transparent tissue located at the front of the eye. Due to its high refractive power of around 43 diopters, it provides the largest share (about two-thirds) of total optical power. Its ideal shape is near-spherical; minute deviations from this result in refractive errors. The (b) *pupil* is a circular opening in front of the lens, surrounded by the iris, which controls the amount of light entering the eye. Adapting to the existing light conditions, the pupil increases or decreases in diameter (about 1–8 mm) under the control of the autonomic nervous system. The ratio of the amount of light admitted by the pupil with its smallest and largest aperture is around 1:15. [1, 6, 21, 38–47, 20]

The (c) *aqueous humor* is needed to control intraocular pressure and thus maintain the structural integrity of the eye. This fluid is essentially water and is located between the cornea and the lens. The remaining third of the total optical power of the optical apparatus is provided by the (d) *lens*. This is suspended in the vitreous body and is held in place by the ciliary muscles. Since the lens is very flexible and elastic, the ciliary muscles can change their shape and thus their refractive properties. This process of accommodation allows objects at different distances from the eye to be focused on the retina. [1, 6, 21, 38–47, 20]

Total length	24.75 mm
Average pupil diameter	3.5 to 4.0 mm
Effective focal length	22.89 mm
Total power (unaccommodated)	58.6 diopters
Lens power (unaccommodated)	19 diopters
Corneal power	43 diopters
Corneal radius of curvature	7.98 mm
Aqueous humor refractive index	1.336
Lens refractive index: center	1.406
Lens refractive index: edge	1.386
Vitreous refractive index	1.337

Table 1. Average optical constants of the human eye. [1]

The (e) *vitreous body* fills the space between the lens and the retina and thus stabilizes as constant a shape as possible of the eye in the eye socket. It consists of a fine framework of collagen fibers and an embedded hydrogel. Although this mass is not uniformly transparent, incident light nevertheless reaches the retina on the inside of the eye almost unimpeded. However, a significant amount of short-wave radiation is absorbed. The (f) *retina* is the light-sensitive surface of the posterior wall of the eye. It consists of a thin, multilayer neuronal element measuring around 0.1 mm in thickness. The innermost layer, which is in contact with the vitreous humor, is formed of cells and fiber nerves, while the farthest back layer contains the light-sensitive elements. When light hits the retina, biochemical changes stimulate an electrical response. Nerve endings located in the retina transmit these electrical signals to the brain via the optic nerve. An important area of the retina is occupied by the *macula lutea* (yellow spot). This is very strongly pigmented yellow, produced by the so-called macular pigment. The macula acts as a yellow filter and protects the (g) *fovea centralis* from exposure to short-wave energy. The fovea centralis is a small zone near the optic axis. It contains no blood vessels, only cones as photoreceptors in a dense, random arrangement. It is the area of sharpest vision. The yellow pigment of the macula causes those of the cones in the fovea to be permanently stimulated with less blue light. To compensate for this, the blue-sensitive cones inside the macula are significantly more sensitive than outside it. [1, 6, 21, 38–40, 42–47, 20]

2.2 Functionality of the eye

Incident light passes through the cornea to the inside of the eye. For protection, it is covered with a very thin film of tear fluid formed by the lacrimal glands. Due to its curvature, it refracts light with a refractive power of 43 diopters into the anterior eye socket, which is filled with aqueous humor. In the center of the cornea is the pupil, which is surrounded by the iris, made up of many fine muscle tracts that can contract or expand. The size of the pupil can thus be adjusted to light conditions. The darker it is, the more light is needed to see; the pupil becomes correspondingly larger in the dark and smaller in very bright light. Behind the pupil, the light is refracted again by the lens, which has a refractive power of around 19 diopters. Since the flexible lens handles accommodation (i.e., adjusting the focal point of the lens), its refractive power varies depending on the distance to the perceived object. This is due to the ciliary muscles on which the lens is suspended in a ring around the zonular fibers. The ciliary muscles control the curvature of the lens and thus the refractive power. To see far into the distance, the lens is in a relaxed state, meaning it is flat and extended. In a tense state, the lens takes on a more bulbous, spherical shape to enable close-range vision. At this point, the light has now passed through the dioptric apparatus. It then enters the almost transparent vitreous body, which consists of a gel-like, clear liquid, before hitting the retina on the inside of the eye. The retina comprises various cell layers and contains the photoreceptors (rods for light-dark vision, cones for color vision). These photoreceptors convert the light impulse into an electronic nerve impulse. The light information is bundled in receptive fields, amplified, and transmitted to the brain via the optic nerve. The area of the retina where the light information is bundled is the fovea centralis. [1, 6, 21, 38–40, 42, 44–47, 20, 48]

2.2.1 Retina and photoreceptors

The light-sensitive layer of the retina contains approximately 120 million light-sensitive photoreceptors. These are divided into rods and cones, which work cooperatively to realize vision. The rods are responsible for vision at low illumination (scotopic vision), while the cones are responsible for color perception and the fine details of vision at high illumination (photopic vision). As a result, color vision has a much higher resolution than night vision. The rods and cones have similar structures but differ in their finer details. For both, the outer segment contains light-sensitive pigments stacked in vertical layers, while the inner segment contains metabolic systems and neuronal connections. A typical rod is cylindrical, whereas a typical cone is tapered and has its largest diameter at the bottom of the inner segment. Rods and cones differ in their density distribution across the retina. Around 7 million cones are mainly located in or near the fovea, where there are no rods. The density of rods increases in line with the distance from the fovea. Blue cones are almost completely absent in the foveal region; the probability of light absorption is therefore at its lowest for the short-wavelength spectral region in this area. Blue cones have spatial properties that distinguish them from red and green cones. Among other things, they do not contribute to contrast discrimination, so they cannot detect image boundaries. Rather, they are important for the discrimination of hue and chroma (mainly yellow-blue). [1, 6, 21, 33, 38–40, 44, 45, 20, 48–60]

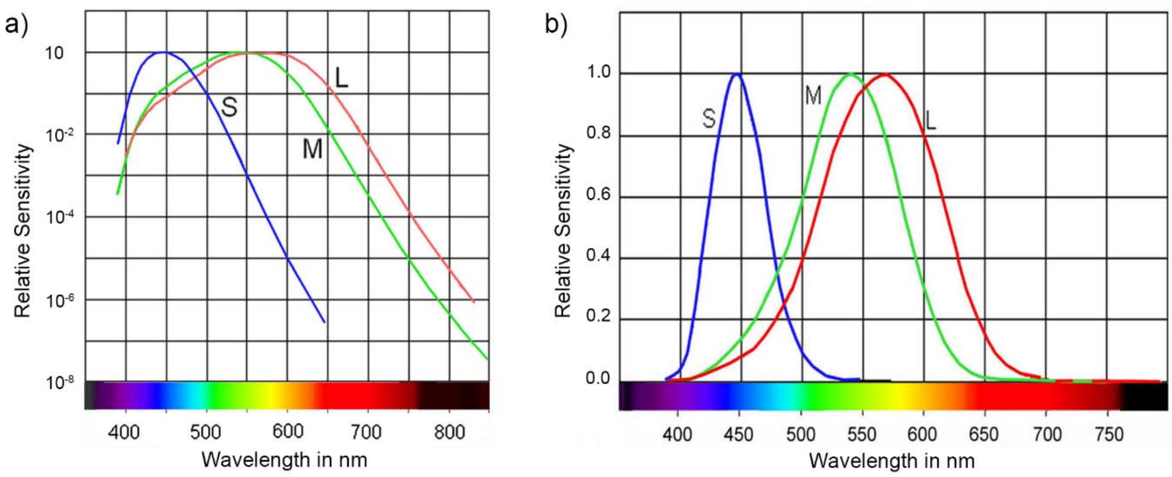


Figure 5. Relative spectral sensitivities of the three types of cones in a logarithmic scale (a) and in a linear scale (b). [1, 53–55]

The three types of color-sensitive cones are typically referred to as R, G, and B cones. However, this terminology is not particularly accurate since the maximum values of their sensitivity curves do not properly correspond to the R, G, and B spectral colors. For example, red cones have their highest sensitivity in the yellow range. It is hence more accurate to describe the three types of cones as L (long-wavelength), M (medium-wavelength), and S (short-wavelength) photoreceptors. The distribution of these three differently sensitive ones is more or less random in the retinal mosaic. There are also marked differences in number, with an estimated ratio for L, M, and S cones of 40:20:1, respectively. The peak sensitivities of the three cone types are in the blue (about 420 nm), green (about 530 nm), and yellow-green (about 560 nm) parts of the spectrum. Because of the overlapping spectra of the three types of cone pigments, there is a unique combination or triplet of absorption probabilities for each wavelength. By comparing the absorption rates in the three types, the eye can distinguish the wavelength. [1, 6, 21, 33, 38–40, 44, 45, 20, 48–57, 60]

2.3 Theories of color vision

2.3.1 The trichromatic theory (Young–Helmholtz–Maxwell)

Human color vision is trichromatic. This property originates in the retinal photoreceptor structure, which consists of three types of photoreceptors that are active at daylight intensity: L, M, and S cones. At the beginning of the 19th century (1802), Thomas Young presented his trichromatic theory (also called the three-color theory). This was based on the assumption that the retina contains three types of nerve fibers that can be stimulated to a greater or lesser extent by the different wavelengths. However, Young's theory gained little public attention. This remained the case until the German physicist Hermann von Helmholtz extended the trichromatic theory in 1852 through his investigations with subjects with deficient color vision (dichromats). A short time later (1860), James C. Maxwell succeeded in empirically proving that every color of the spectrum corresponds to three monochromatic primary colors: red, green, and blue. [6, 10, 12, 33, 43, 61–63]

The trichromatic theory offers a clear, simple explanation of color vision. It is based on the fact that color vision emerges from additive color mixing. Thus, there must be three types of photoreceptors that perceive red, green, and blue colors, and any color can be obtained by mixing appropriate amounts of only three appropriately selected primary wavelengths. This means that a color is accordingly characterized by the degree of response of these photoreceptors. On this basis, the CIE defined standard observer functions in 1931 and 1964.

On the contrary, trichromatic theory has its weak points, especially when taking a closer look at the color effect. For example, it cannot be explained why there are no reddish-green colors or bluish-yellow colors, nor why an additive mixture of red and green stimuli is perceived as yellow since there is no similarity to the two primary colors after all. Indeed, the trichromatic theory is unable to explain mixed color stimuli. [6, 10, 12, 38, 43, 61–66]

2.3.2 The opponent process theory (Hering)

These unresolved questions about the appearance of colors were addressed by Ewald Hering in his 1878 hypothesis, which posited that three opposing processes are generated in color perception. These act in two opposite directions: red vs. green, blue vs. yellow, and black vs. white (achromatic stimulus). The premise is that opposite colors are never perceived together. As a result, there is no such thing as 'greenish red' or 'yellowish blue', and more red necessarily means less green. Thus, all colors are characterized by the degree of response of these three processes, while the three types of cones have some overlap in the wavelengths of light to which they respond. Likewise, differences between the responses of the cones are easier to detect and process than the individual response in each case. This explains the high efficiency of the visual system. [6, 10, 38, 43, 44, 61, 62, 67, 68]

The opponent process theory was barely considered until the 1950s. Rather, the trichromatic theory based on the research of Young, von Helmholtz, and Maxwell remained the only physiological hypothesis applied to explain color perception. It was not until 1957 that the opponent process theory came to the fore again, when D. Jameson and L. M. Hurvich succeeded in proving the existence of Hering's opposing processes. In their experiments on hue suppression, wavelength pairs with opposite hue responses were superimposed, and their relative energies were adjusted until a ratio could be determined at which no hue could be perceived. [6, 10, 38, 43, 57, 61, 62, 67, 68]

2.3.3 The Kriess theory of color vision (von Kriess)

Neither the trichromatic theory nor the opponent process theory alone can satisfactorily explain the various phenomena of color vision. On the one hand, both are empirically based and can explain various phenomena of color vision without contradiction. On the other hand, both theories are compatible and can be merged. According to the Kriess theory of color vision, both theories are realized in human color vision at different processing levels: the trichromatic theory corresponds to the fundamentals of color vision at the photoreceptor level, and the opponent process theory is realized in the opponent color neurons of the retina and the subsequent stations of the visual pathway (i.e., in neural processing). Thus, the theory posits that in the first zone, three types of independent cones (with different photopigments) initiate color vision by absorbing light and sending responses in the form of electrical signals. In other words, the experimental data for color matching is acquired in this first zone. In the second zone, the signals sent by the cones are encoded in the neural network. Here, three new signals are generated: an achromatic signal and two chromatic signals. These chromatic signals follow the opponent processes proposed by Hering. Müller (1930) and later Judd (1930) explained the concept of Kriess's theory of color vision. [6, 10, 43, 57, 61, 67]

2.4 Color appearance: chromatic effects

As described earlier, color is tri-variant. Humans can use the visual system to distinguish three different descriptors in an isolated color stimulus: hue, lightness, and saturation. If one looks at a related color that is part of a scene or an overall image, the descriptors refer to the environment; we then speak of hue, lightness, and chromaticity. Each color can also be defined using three physical variables that correspond to these three perceptual variables: wavelength to hue, luminance to lightness, and colorimetric purity to saturation (see Table 2). [43]
However, these relationships do not exhibit absolute independence; rather, there is interference between the parameters. Even varying a single parameter affects not only the assigned perceptual attribute but the other two as well. Moreover, environmental changes also affect the color. These chromatic effects cannot be explained by a linear model. Many studies have been conducted on this subject, and various different nonlinear chromatic effects have been described. [1, 43, 47, 60, 61]

Chromatic stimuli	Isolated color	Related color
Wavelength (nm)	Hue	Hue
Luminance (cd/m²)	Brightness	Lightness
Colorimetric purity	Colorfulness	Chroma

Table 2. Physical and perceptual color descriptors for isolated and related colors. [43]

2.4.1 Bezold Brücke effect

"A variation in luminance can change the tone and thus change the color." [43] Bezold and Brücke (1873 and 1878) discovered this effect independently, describing how at high luminances, reddish and yellowish green became yellow, while greenish blue and violet became blue. However, they also confirmed that three specific hues do not differ: yellow (571 nm),

green (506 nm), and blue (474 nm). This effect underlines that hue and brightness attributes are not completely independent of each other. [43, 60, 69]

2.4.2 Aubert Abney effect

"Adding white to a purple or monochromatic color not only reduces saturation, but hue changes occur." [43] This effect describes a perceived hue shift that occurs when white light is added to a monochromatic light source. To human perception, this acts as a desaturation of that light source and an apparent change in hue. It is seen in Munsell's Atlas color patterns, with the same tone and different chroma in the xy diagram. [20, 43, 61, 70, 71]

2.4.3 Helmholtz Kohlrausch effect

"With heterochromatic matching and identical luminance, the brightness varies with the chromaticity of the stimulus." [43] At identical luminance, the perceived brightness increases with saturation and is influenced by the hue. Achromatic colors exhibit lower luminance than chromatic colors, so a chromatic image appears brighter than a monochromatic image. For any match of a white with any color, therefore, $(L_{white} / L_{color}) > 1$. [19, 33, 43, 60, 61, 72]

2.4.4 Simultaneous contrast

Two adjacent colors can influence and change the perception of these colors. For example, colors with the identical spectral composition are perceived as different when they are in front of a different chromatic background. A dark environment will make a gray appear brighter than another with a white environment. This effect can be observed both with different hues and with different brightness. [19, 20, 33, 43, 60]

2.4.5 Crispening effect

This refers to an increase in the difference between two stimuli when the background is similar to the stimuli. For similar stimuli, their difference in brightness is perceived more strongly when the value of the background brightness is between those of the stimuli. In this case, the brightness difference threshold is lower. This is due to the fact that the perception of the brightness of a stimulus depends not only on its properties, but also on the environment of the stimulus. [19, 43, 73–75]

2.5 Interindividuality in color perception

Visual perception differs from person to person. This individuality is based on many different factors. The individual physiology of the eye has just as much influence as the mental condition and age or, for example, the angle of vision and other environmental influences. Considering the physiology of the eye, the genotype plays a particularly important role, as it determines how colors can be perceived. [19, 33, 43, 53, 55, 60, 76]

Individual differences can even be found within normal trichromatic color vision. These are typically due to the structure of the retina, especially the retinal mosaic consisting of L, M, and S cones. The subsequent neuronal color signal processing must also not be neglected. Likewise, certain people experience abnormal color vision, also known as color vision deficiency. In a milder form, this is due to a paucity of cones of one type in the retina. This is called protanomal, deuteranomal, or tritanomal color vision. If cones of a certain type are completely missing from the retina, they are called protanopes, deuteranopes, or tritanopes. [19, 33, 38, 43, 53, 55, 60, 76, 77]

2.5.1 Metamerism

Metamerism in colorimetry is a perceived correspondence of color stimuli with different, non-matching spectral power distributions. This means that different spectral color stimuli in a defined colorimetric system can have identical tristimulus values. Such coincident color stimuli are called metamers or metameric color stimuli. This term is attributed to the German chemist Wilhelm Ostwald (1853–1932), who gives the following definition: *"Two samples with identical tristimulus values for a given reference illuminant and reference observer are metameric if their spectral power distributions within the visible spectrum are different."* The spectral power distribution describes the proportions of the total light emitted by a color sample at each visible wavelength. This can be emitted, transmitted, or reflected light. A reduction is made to the tristimulus values X, Y, Z. [1, 11, 19, 20, 60, 78]

The reason for metamerism is that each type of cone responds to incident light energy from a wide range of wavelengths. Therefore, it is possible that divergent combinations of light from all wavelength ranges can produce an equivalent cone response and thus identical tristimulus values and color sensations. Such metameric matches are indeed very common, especially in the range of near-neutral gray or whitish colors and neutral dark colors. With increasing brightness or saturation, the range of possible metameric matches decreases significantly. [1, 19, 20, 52, 60]

Metamerism is an important aspect that should not be neglected when analyzing display technologies. Without metamerism, the display of color images on image display devices with only three narrow-band primary colors (red, green, and blue) would not be possible since the exact same spectral distribution present in the object cannot be displayed in this way. Thus, based on the known spectral power distribution of the image display device, metameric colors are generated that are very similar to the real object; the basis for color image reproduction processes is the ability to produce such metameric color matches. [1, 19, 20, 52, 60]

2.5.2 Individual variations at receptor level

As described above, the three cone types in the retina (L, M, and S cones) have different spectral sensitivities. However, to characterize a color stimulus, these spectral sensitivities are not used; instead, three defined color matching functions have been designed to be representative of a standard observer (the CIE 1931 standard colorimetric observer) under typical viewing conditions for the average population. To describe a color stimulus with tristimulus values, qualitatively accurate color matching functions must be available. The available standard calculations are sufficiently accurate for most applications. [19, 21, 38, 39, 43, 52, 66, 77, 79–83]
However, several factors limit the accuracy of predicting individual color matches for a standard color gamut. Numerous studies show that different observers can have individually deviating color matching functions. These can be attributed to individual differences in three major components in the eye that relate to color perception: lens pigment, macular pigment, and photopigments. Lens pigment and macular pigment act as pre-receptor filters, while the three photopigments are the sensors in our eyes. All three components are spectrally selective and form a set of three response functions called cone bases, also known as the L, M, and S color matching functions. [19, 21, 35, 38, 39, 43, 52, 77, 79–84]

2.5.2.1 Lens pigment

The lens pigment acts as a preceptoral filter. Light entering the eye is focused onto the retina through the cornea and the yellow pigmented lens. The filtering function of the lens pigment causes incident light, especially light of short wavelengths, to be absorbed. Various studies clearly indicate large individual differences in the density of lens pigments. It is also apparent that the optical density of the lens increases with age, leading to systematic differences in the color perception of observers of different ages. A mathematical model based on this research was derived and included in the 2006 CIE physiological observer. [35, 39, 41, 42, 51, 52, 77, 84, 85]

2.5.2.2 Macular pigment density

The macula (or macula lutea) is a narrowly circumscribed area in the posterior, central region of the retina through which the visual axis passes. In this area, the distribution of color-sensitive cones reaches its greatest density. Before the incident light reaches the photoreceptors, the macular pigment acts as another filter. However, its spectral absorption shape differs from that of the lens pigment. The macular pigment also absorbs light of shorter wavelengths over a wide spectral range centered at 460 nm. The shorter the wavelength of the light, the higher the contained energy that emanates from it. The macular pigment therefore also performs an important protective function. Research shows significant individual differences in the density of the macular pigment of observers. This is due to the fact that it is unevenly distributed across the retina; the highest concentration is found in the central fovea, while density gradually decreases towards the outer regions. From this, it can be deduced that the maximum optical density of the macular pigment depends on the field size. Again, based on research work, a mathematical model was derived and included in the 2006 CIE physiological observer. [39, 52, 77, 79, 84, 86–92]

2.5.2.3 Photopigments

The absorption spectra of the photopigments of the L, M, and S cones have different maxima of 559.1 nm, 530.6 nm, and 420.8 nm, respectively. These absorption spectra depend, among other things, on the maximum optical density (Beer's law). This is determined by the size of the external field and the photopigment concentration within this field. These factors are individually variable from observer to observer. Evidence shows that as the eccentricity of the retina increases, the size of the outer field decreases, as does the optical density of the axial photopigment. A change in optical density alters the width of photopigment spectral response: a higher optical density broadens the spectral response, and a lower optical density narrows the spectral response of photopigments. A model as a function of field size and the above absorption spectra was included in the 2006 CIE physiological observer. [19, 39, 52, 54, 77, 84, 93–97]

Various microspectrophotometric recordings and molecular genetic studies outline several variants of the human L and M cone. This diversity is referred to as cone polymorphism. These genetic polymorphisms result in a shift of several nanometers in the spectral sensitivity of the L-cone photopigment. In applications where precise knowledge of the spectral sensitivity of an individual’s cones is important, genotyping can now help provide important information. Observers may have more than one variant of the L- or M-cone photopigment gene. The fact that the long-wavelength sensitive photopigment exists in two variants that are approximately evenly distributed in the normal population cannot be ignored, as it modifies color matches and photometric matches. [19, 35, 39, 52, 54, 77, 93–97]

2.5.3 Color vision deficiencies

Most people see color in the same way; this is called normal chromatic vision. Normal-sighted people are trichromats, which means that all three types of cones are functioning correctly. Fully functional color vision in a healthy person is also called polychromacy. However, certain people's vision can behave abnormally. A fully color-capable person has three different receptors (cones) for daytime vision, hence their labeling as trichromats. The three color receptors mediate the primary colors red, green, and blue, and the mixture of these receptor excitations gives the sensory impression of color. For example, the color yellow is produced in the brain by the excitation of the receptors for red vision and green vision. In color vision deficiency, the function of at least one of these receptors is impaired. In most cases, individuals are able to distinguish colors, but their chromatic vision is much worse than that of a person with normal vision, and many colors that are clearly different to a normal observer will be perceived to be the same to a person with chromatic deficiency. In most cases, color vision deficiency is genetic (i.e., congenital). [20, 21, 38, 39, 60, 77, 98–104]

Ishihara color charts, named after the Japanese ophthalmologist Shinobu Ishihara, are often used to determine color vision deficiencies. Various test images typically used are shown in Figure 6. [98]

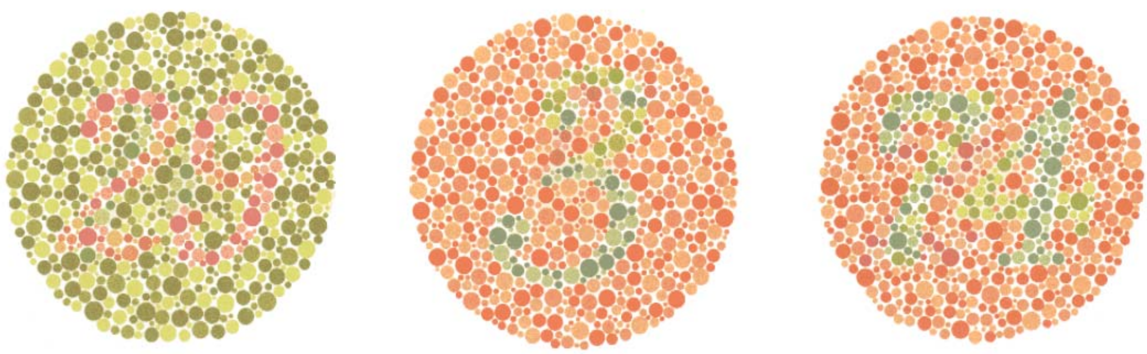


Figure 6. Ishihara color charts for the diagnosis of disorders of color weakness. People with normal vision see the numbers 29 (left), 3 (middle), and 74 (right). [98]

Different color vision defects are classified as follows. When only one type of cone is functioning, individuals are called monochromats; they cannot see differentiable colors but only in shades of gray. People with no cone type at all are known as achromats, and dichromats are those who lack one cone type or have only two functioning cone types; they suffer from dichromacy. Given the three types of cones (L, M, and S), there are also three types of dichromacy: protanopia, deuteranopia, and tritanopia.[21, 38, 39, 20, 43, 60, 77, 98–104]

Protanopia refers to an absence of L cones in the retina, which are sensitive to the long-wave range of light. Since the light that excites the L cones is mainly in the red spectral range, this is also called red blindness. This form of refractive error is relatively rare. People who suffer from deuteranopia are called green-blind. In this case, the M cones, which are responsible for the green spectral range, are not present. Green blindness affects approximately 1% of men and 0.01% of women. Tritanopia refers to an absence of S cones, which are responsible for the blue spectral region. Blue blindness affects about 0.002% of men and 0.001% of women. [20, 21, 38, 39, 43, 60, 77, 99–104]

	Type of cones	Type of chromatic vision
Normal vision	L M S	Normal
Defective vision		
Protanopia	- M S	Defective (R / G confusion)
Deuteranopia	L - S	Defective (R / G confusion)
Tritanopia	L M -	Defective (B / Y confusion)
Monochromatism	- - S	No chromatic vision
Achromatism	- - -	No chromatic vision
Anomalous vision		
Protanomaly	L‘ M S	Irregular (R / G confusion)
Deuteranomaly	L M‘ S	Irregular (R / G confusion)
Tritanomaly	L M S‘	Irregular (B / Y confusion)

Table 3. Types of color vision depending on the cones. [43]

A further anomaly in color perception is observed when people have all three cone types, but one of them has a slightly offset curve response for that pigment, thereby harming color discrimination significantly. These cases are called protanomalous, deuteranomalous, and tritanomalous. Protanomalous means the maximum absorption of the L cones is not at 560 nm; it is slightly shifted to shorter wavelengths and thus moves closer to the M cones. As a result, sensitivity for the red spectral range decreases significantly. In deuteranomalous cases, the sensitivity of the M cones shifts towards the L cones. The maximum absorption is no longer 540 nm but shifts towards a higher wavelength. The tritanomaly has hardly been observed scientifically thus far. [20, 21, 38, 39, 43, 60, 77, 99–104]

2.6 Colorimetry

As described above, human color vision is trichromatic due to the retinal photoreceptor structure. Three different photoreceptors are active at daylight intensity: L, M, and S cones. The spectral sensitivities of the three cone types are shown in Figure 5. These have been calculated across many different studies, meaning that a large amount of data is available to describe the characteristic functions of color perception. In the process of perception, three initial color signals are recorded by the L, M, and S cones according to their sensitivity curves. From these, the retina computes two chromatic signals, L - M (red-green opponent channel) and S - (L + M) (yellow-blue opponent channel), and one achromatic signal, L + M (luminance channel). Figure 7 shows that the maxima of the L, M, and S sensitivity curves are at 566 nm, 541 nm, and 441 nm, respectively. [1, 19, 21, 33, 47, 49, 52–54, 58, 60, 61, 77, 79]

The goal of colorimetry is to describe the color of a particular visual stimulus in detail using quantitative data. These data are based on the spectral power distribution of the stimulus in a single (standard) viewing condition. However, it is also important to describe the difference between two visual stimuli. According to the trichromatic theory, it is possible that many color stimuli can be balanced by additive mixing of three fixed primaries, taking into account different basic conditions. By adding linearity laws like symmetry, transitivity, proportionality and additivity, a strong quantitative framework is defined. [1, 19–21, 33, 47, 49, 52, 58, 60, 61, 77, 79]

2.6.1 Grassmann laws

The Grassmann laws are particularly helpful in developing a better understanding of the CIE color system. In February 1853, the mathematician Hermann Grassmann, who attributed many of his ideas to Maxwell (1857, 1860), published an article in *Poggendorffs Annalen der Physik und Chemie* entitled "Zur Theorie der Farbenmischung", which describes the principles for adding colors as well as experiments on color matching. Based primarily on his own experiments and observations, Grassman formulated the following four principles, known as the Grassmann laws of additive color mixing. [1, 19, 20, 105]

"Each color impression is completely described by three basic values: base color, color intensity and white intensity." [1, 10]

Although Newton had already recognized that every color can be described as a mixture of spectral colors together with a degree of whiteness, Grassmann preferred to use base color (spectral color), color intensity, and white intensity as his three basic values. This law is applicable to three primary colors, such as the CIE primary valences or RGB, with the prerequisite that the primary colors used cannot be represented among themselves. [1, 10, 19, 21, 52, 60, 79, 105, 106]

Mathematical description:

$$\{C\} \equiv r\{R\} + g\{G\} + b\{B\} \text{ bzw. } \{C\} \equiv \begin{pmatrix} R \\ G \\ B \end{pmatrix} \quad (1.1)$$

"If one modifies a shade of color continuously and mixes it with a second color, but leaves it unchanged, the shade resulting from additive color mixing also changes continuously." [1, 10]

With this principle, Grassmann describes the (mathematical) homogeneity of the color space, independent of which hue change is made to a color; the mixed product follows analogously. Through the continuous change of the basic color, Grassmann understands the change of the wavelength. [1, 10, 19, 21, 52, 60, 79, 105, 106]

Mathematical description:

Two colors

$$\{C_1\} \equiv \begin{pmatrix} R_1 \\ G_1 \\ B_1 \end{pmatrix} \text{und } \{C_2\} \equiv \begin{pmatrix} R_2 \\ G_2 \\ B_2 \end{pmatrix} \quad (1.2)$$

result in the following color after additive color mixing

$$\{C\} \equiv \{C_1\} + \{C_2\} \equiv \begin{pmatrix} R_1 + R_2 \\ G_1 + G_2 \\ B_1 + B_2 \end{pmatrix} \quad (1.3)$$

"The hue of a color produced by additive color mixing depends only on the color impression of the initial colors, but not on their physical (spectral) compositions." [1, 10]

This law states that the mixing behavior of colors can be described exactly on the basis of their color impression. This also applies to metameric colors, that is, colors whose visual color impression matches even though they have a different spectral or physical composition. However, this also means that no direct conclusions can be drawn from the mixing behavior for the spectral composition of a color. [1, 10, 19, 21, 52, 60, 79, 106, 105]

Mathematical description:

$$\{C'\} \equiv k\{C\} \equiv \begin{pmatrix} k\,R \\ k\,G \\ k\,B \end{pmatrix} \quad (1.4)$$

"The total intensity of an additive color mixture is the sum of the total intensities of the colors involved in it." [1, 10]

Grassmann’s fourth law is also known as "additivity of brightness" or "Abney's law" and is used today for the definition of luminance. According to David L. MacAdam, this law applies only to the special case of an idealized source reduced to a point but not to more extended color fields. Grassmann had only dealt with the special case mentioned above. [1, 10, 19, 21, 52, 60, 79, 105, 106]

Mathematical description:

$$T(A+B) \equiv T(A) + T(B) \quad (1.5)$$

(with T as the equivalent of the total intensity or luminance of a color impression).

These laws are the basis of all mathematical procedures that are later established in colorimetry. However, some important conditions must be taken into account. For example, all color matches must be made under similar conditions. In addition, care must be taken to avoid prior exposure of the eyes to light affecting the matching condition and influencing the spectral sensitivity of the eye. It is also possible that a failure of the proportionality law may be detected if a field diameter greater than 10° is used in a color match. [1, 10, 19, 21, 52, 60, 79, 105, 106]

2.6.2 CIE Color Specification System

The CIE system considers a defined visual spectrum whose wavelength range extends from 380 nm to 780 nm. Colors are described according to the additive color model. The necessary objectivity is ensured by including the effect of the spectral color stimuli. In colorimetry practice, however, the spectral sensitivities of the three cone types are not used to characterize a color stimulus; rather, three defined color matching functions describe the sensitivity of a standard observer to the defined wavelength range. For this purpose, a given geometry is considered. For color stimuli perceived within a viewing angle of 1°–4°, the color matching functions of the CIE 1931 standard colorimetric observer are used. These are designated $x(\lambda), y(\lambda), z(\lambda)$ and form the basis of standard colorimetry. [1, 19–21, 33, 47, 60, 61, 66]

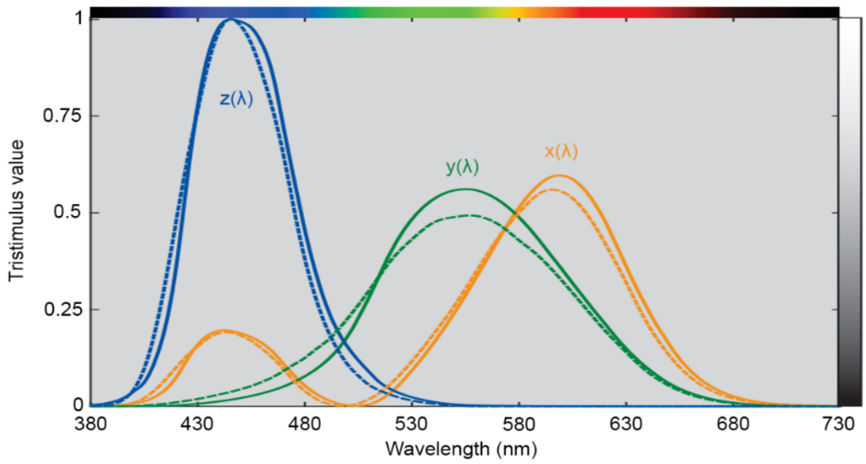


Figure 7. Standard spectral value curves for the 2° (solid lines) and the 10° standard observer (dashed lines). [16, 33, 60, 92]

To describe the color matching for longer stimuli (i.e., for viewing angles larger than 4°), the CIE 1964 standard colorimetric observer is recommended. Its color matching functions are denoted by $x_{10}(\lambda), y_{10}(\lambda), z_{10}(\lambda)$. These three primary functions are used to weight the spectral information emanating from an object by reflection or transmission. However, these real functions must be modified to ensure that only a positive complement of weighted spectral power is possible considering the virtual primary colors X, Y, Z. The CIE thus has defined practical rules and standards for color and color difference measurement. [1, 19–21, 33, 47, 60, 61, 66]

In the CIE system, the following formulae are used to define the CIE tristimulus values $CIE\ XYZ$:

$$X = k\ \sum_\lambda \phi_\lambda(\lambda)\bar{x}\,(\lambda)\Delta\lambda \qquad (1.6)$$

$$Y = k\ \sum_\lambda \phi_\lambda(\lambda)\bar{y}\,(\lambda)\Delta\lambda \qquad (1.7)$$

$$Z = k\ \sum_\lambda \phi_\lambda(\lambda)\bar{z}\,(\lambda)\Delta\lambda \qquad (1.8)$$

Here, X, Y, Z denote the CIE tristimulus values and $\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda)$ d denote the CIE color matching functions. $\phi_\lambda(\lambda)$ denotes the spectral distribution of the color stimulus function: $\phi_\lambda(\lambda) = d\phi(\lambda)/d\lambda$. k is a defined normalization constant. [1, 19, 20, 33, 47, 61, 66]

To calculate the X, Y, Z tristimulus values, the measured spectral radiation distribution of a color stimulus $L(\lambda)$ must be multiplied by one of the three color matching functions $\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda)$ integrated in the entire visible spectrum (360–830 nm):

$$X = k\ \int_{360}^{830} L(\lambda)\ \bar{x}\,(\lambda)\ d\lambda \qquad (1.9)$$

$$Y = k\ \int_{360}^{830} L(\lambda)\ \bar{y}\,(\lambda)\ d\lambda \qquad (1.10)$$

$$Z = k\ \int_{360}^{830} L(\lambda)\ \bar{z}\,(\lambda)\ d\lambda \qquad (1.11)$$

For reflective color samples, the following applies:

$$L(\lambda) = \frac{R(\lambda)E(\lambda)}{\pi} \qquad (1.12)$$

The spectral radiance of the stimulus $L(\lambda)$ corresponds to the spectral reflectance of the sample $R(\lambda)$ multiplied by the spectral irradiance of the light source illuminating the reflecting sample $E(\lambda)$. [1, 19, 20, 33, 47, 60, 61, 66]

k is usually chosen as in equation 1.13 below:

$$k = \frac{100}{\int_\lambda L(\lambda)\bar{y}(\lambda)\ d\lambda} \qquad (1.13)$$

As can be seen from this equation, for the reflection of color samples, the constant k is chosen to correspond to $Y = 100$ for ideal white objects with $R(\lambda) = 1$. For self-luminous objects, the value of k can be set at 683 lm/W. The value of Y then corresponds to the luminance of the self-luminous object. [1, 19, 20, 33, 47, 60, 61, 66]

The chromaticity coordinates (x, y, z) are defined by equation (1.14): [1, 19, 20, 33, 47, 60, 61, 66]

$$x = \frac{X}{X+Y+Z} \qquad y = \frac{Y}{X+Y+Z} \qquad z = \frac{Z}{X+Y+Z} \tag{1.14}$$

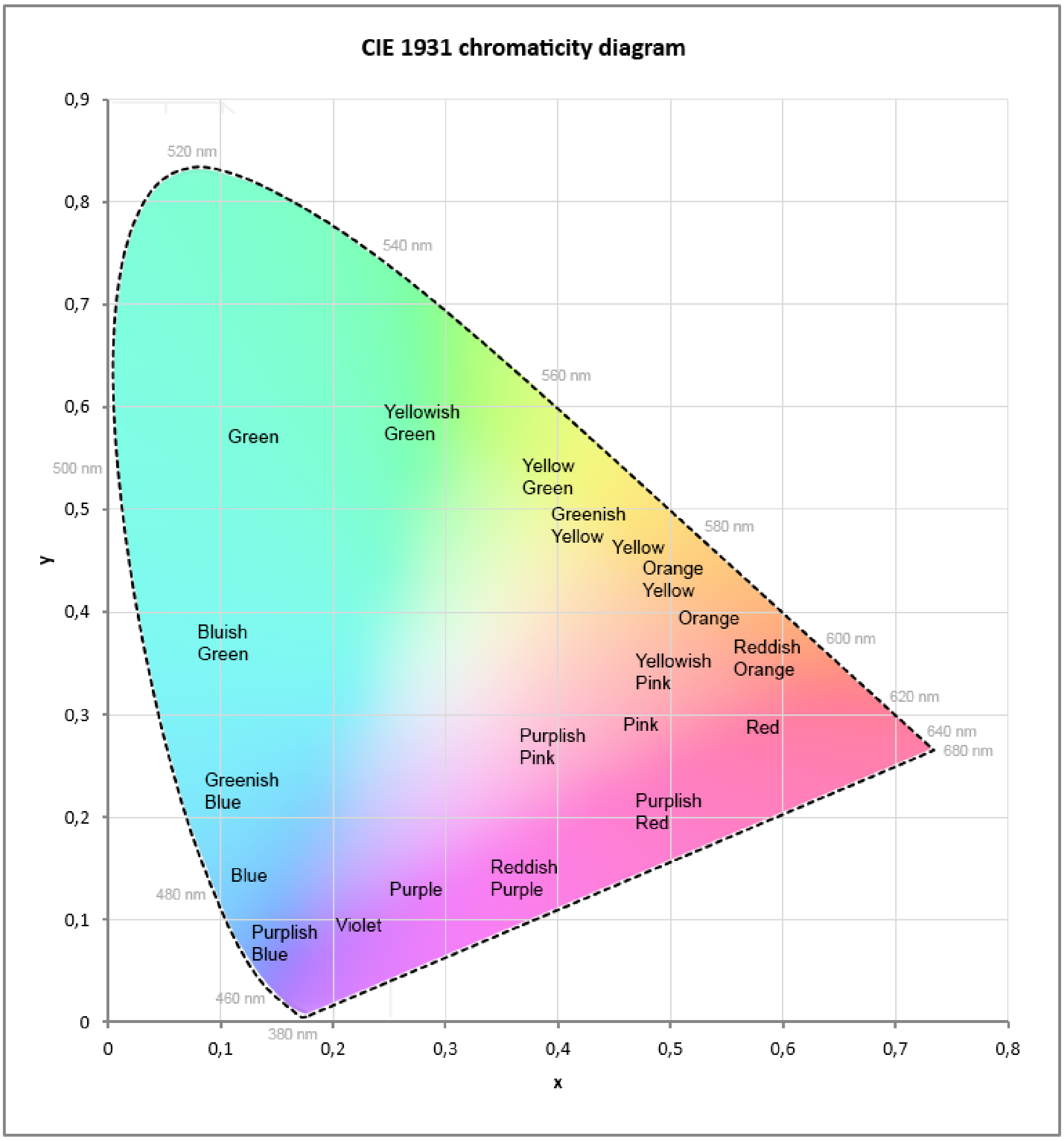


Figure 8. CIE 1931 chromaticity diagram with assigned visual sensation qualities of the colors. [1, 20, 33, 107, 108]

2.6.3 Uniform color spaces

Crucially, the description of color stimuli in the system of tristimulus values (X, Y, Z) leads to an inconsistent and unsystematic representation of the corresponding color perceptions. More specifically, the relevant psychological properties of perceived colors (i.e., perceived brightness, screen brightness, redness-greenness, yellowness, hue, chromaticity, saturation, and colorfulness) cannot be expressed directly in XYZ values. To model color perception effectively, it must be possible to derive numerical correlates from the XYZ values of the stimulus for each attribute. [1, 19, 20, 33, 47, 60, 61, 66]

Hue is the attribute of a visual sensation according to which a color stimulus appears to be similar to the perceived colors red, yellow, green, and blue, or a combination of two colors. Brightness is the attribute of a color stimulus according to which it appears to emit more or less light; it is the brightness of a color stimulus measured against the brightness of a similarly illuminated reference white. Chromaticity is the attribute of a color stimulus according to which the stimulus appears to exhibit more or less chromatic color. For a given chromaticity, chromaticity usually increases with luminance. The perceived attribute chroma refers to the chromaticity of the color stimulus, which is judged proportionally to the brightness of the reference white. Saturation is the chromaticity of a stimulus in relation to its intrinsic brightness. [1, 19–21, 33, 47, 60, 61, 66]

These properties of color perception must be modeled via correlates that are uniform in perception. This means that equal numerical differences should also correspond to equal perceptual differences; it is only in this way that they can be meaningful and useful in a practical application. Using the calculated numerical correlates, the color stimuli can be arranged in a three-dimensional color space. Through the defined axes of the color space and the possibility of calculating certain distances and angles within it, psychologically relevant meanings can be calculated and displayed in direct connection with the perceived color attributes. [1, 19–21, 33, 47, 60, 66]

The CIE 1931 chromaticity diagram is perceptually inconsistent. This means that a numerically equal difference of Δx, Δy, and ΔY of two colors does not correspond to the same visually perceived difference, as proven by MacAdam and illustrated via the MacAdam ellipses. These limitations led to further development. To predict the perceived color difference between two colors, CIELAB and CIELUV, the CIE 1976 uniform color spaces provide two three-dimensional coordinate systems. Both color spaces aim to make differentiations between object colors of the same size and shape comparable and linear. Here, logarithmic eye responses are simulated. The calculations of the numerical correlates of the perceived color attributes are based on the XYZ values of the color stimulus and the XYZ values of a given reference color stimulus (X_n, Y_n, Z_n). Both color spaces can be used with the CIE standard colorimetric observers depending on the viewing angle. If the viewing angle is between 1° and 4°, the standard observer CIE 1931 is used. If the viewing angle is larger, the colorimetric standard observer CIE 1964 should be used. [1, 10, 19–21, 33, 47, 60, 61, 66]

2.6.3.1 CIE 1976 (L*u*v*) color space, CIELUV color space

The CIELUV color space is defined with the following equations:

$L^* = 116\, f\, (Y/Y_n) - 16$ (1.15)

$u^* = 13L^*(u' - u'_n)$ (1.16)

$v^* = 13L^*(v' - v'_n)$ (1.17)

where

$f(Y/Y_n) = (Y/Y_n)^{1/3}$ if $(Y/Y_n) > (24/116)^3$ (1.18)

$f(Y/Y_n) = (841/108)\,(Y/Y_n) + 16/116$ if $(Y/Y_n) \le (24/116)^3$ (1.19)

u', v' correspond to the CIE 1976 UCS coordinates of the test stimulus, while u'_n , v'_n correspond to those of a defined white color stimulus. From u^* and v^*, it is clear that a given color difference is reduced by a factor L^* as the color becomes darker. This allows the perceptual fact that a given difference in chromaticity represents an increasingly smaller perceived color difference when its value of Y/Y_n is reduced. The constant 13 is included to determine the perceptual significance of the L^*-, u^* -, and v^* scales. A special feature of the CIELUV color space is that not only chroma and hue can be defined, but also a correlate of the saturation in the u', v'diagram can be calculated. [1, 19–21, 33, 47, 60]

CIELUV saturation: $s_{uv} = 13[(u' - u'_n)^2 + (v' - v'_n)^2]^{1/2}$ (1.20)

CIELUV chroma: $C^*_{uv} = (u^{*2} + v^{*2})^{1/2} = L^* \cdot s_{uv}$ (1.21)

CIELUV hue angle: $h_{uv} = \arctan\,(u^*/v^*)$ (1.22)

The CIELUV chromaticity angle h_{uv} shall be between 0° and 90° when u^* and v^* are both positive, between 90° and 180° when v^* is positive and u^* is negative, between 180° and 270° when v^* and u^* are both negative, and between 270° and 360° when v^* is negative and u^* is positive.[1, 19–21, 33, 47, 60, 61, 66]

2.6.3.2 CIE 1976 (L*a*b*) color space, CIELAB color space

The CIELAB color space is defined with the following equations:

$L^* = 116\, f\, (Y/Y_n) - 16$ (1.23)

$a^* = 500[f\,(X/X_n) - f\,(Y/Y_n)]$ (1.24)

$b^* = 200[f\,(Y/Y_n) - f\,(Z/Z_n)]$ (1.25)

with

$f(X/X_n) = (X/X_n)^{1/3}$ if $(X/X_n) > (24/116)^3$ (1.26)

$f(X/X_n) = (841/108)\,(X/X_n) + 16/116$ if $(X/X_n) \le (24/116)^3$ (1.27)

and

$$f(Y/Y_n) = (Y/Y_n)^{1/3} \quad \text{if} \quad (Y/Y_n) > (24/116)^3 \qquad (1.28)$$

$$f(Y/Y_n) = (841/108)\,(Y/Y_n) + 16/116 \quad \text{if} \quad (Y/Y_n) \leq (24/116)^3 \qquad (1.29)$$

and

$$f(Z/Z_n) = (Z/Z_n)^{1/3} \quad \text{if} \quad (Z/Z_n) > (24/116)^3 \qquad (1.30)$$

$$f(Z/Z_n) = (841/108)\,(Z/Z_n) + 16/116 \quad \text{if} \quad (Z/Z_n) \leq (24/116)^3 \qquad (1.31)$$

Here, X, Y, Z describe the tristimulus values of the considered color stimulus of the test object. X_n, Y_n, Z_n correspond to the tristimulus values of a precisely defined color stimulus, starting from a white object. In this case, X_n, Y_n, Z_n are the tristimulus values of the light source with Y_n equal to 100. [1, 20, 19, 21, 33, 47, 60, 61, 66]

The output values of the perceived color attributes are L^* (CIE 1976 lightness of equation 1.23), C^*_{ab} (CIELAB chroma), and h_{ab} (CIELAB hue angle). In the CIELAB color space, the positive a^* axis points approximately in the direction of red color stimuli, the negative axis points approximately in the direction of green stimuli, the positive b^* axis points approximately in the direction of yellow stimuli, and the negative b^* axis points approximately in the direction of blue stimuli. L^* is coupled to the luminance of the stimulus. L^*, a^*, and b^* form the three orthogonal axes of the CIELAB color space. The following equations show how to calculate C^*_{ab} and h_{ab} with the information a^* and b^*. [1, 19–21, 33, 47, 60, 61, 66]

CIELAB lightness: L^* as defined in equation 1.23 (1.32)

CIELAB chroma: $C^*_{ab} = [(a^*)^2 + (b^*)^2]^{1/2}$ (1.33)

CIELAB hue angle: $h_{ab} = \arctan\,(b^*/a^*)$ (1.34)

The CIELAB hue angle h_{ab} should be between 0° and 90° when a^* and b^* are positive, between 90° and 180° when b^* is positive and a^* is negative, between 180° and 270° when b^* and a^* are both negative, and between 270° and 360° when b^* is negative and a^* is positive. [1, 19–21, 33, 47, 60, 61, 66]

2.6.3.3 CIE 1976 color difference formulae

The color difference ΔE allows the quantifiable description of visual color differences between two color stimuli. In the CIELAB and CIELUV color spaces, Euclidean distances can be used to approximate these perceived color differences between two color stimuli (ΔE^*_{ab} and ΔE^*_{uv}):

$$\Delta E^*_{ab} = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2} \qquad (1.35)$$

$$\Delta E^*_{uv} = [(\Delta L^*)^2 + (\Delta u^*)^2 + (\Delta v^*)^2]^{1/2} \qquad (1.36)$$

The brightness, chroma, and hue angle differences of two color stimuli (ΔL^*, ΔC^*_{ab} and Δh^*_{ab}) can be calculated by subtracting the color stimuli to be compared. Hue differences (ΔH^*_{ab}) must not be confused with hue angle differences (Δh^*_{ab}). Hue differences include the fact that the same hue change results in a large color difference for large hues and a small color difference for small hues. However, CIELAB and CIELUV color differences exhibit perceptual differences depending on the region of the color space (e.g., reddish or bluish colors), the color difference magnitude (small, medium, or large color differences), and various viewing parameters such as sample separation, texture, and background color. Hue differences can be calculated using the following equations. These quantities must be calculated indirectly due to the relativity of a hue angle. [1, 19–21, 33, 47, 60, 61, 66]

$$\Delta H^*_{ab} = [(\Delta E^*_{ab})^2 - (\Delta L^*)^2 - (\Delta C^*_{ab})^2]^{1/2} \quad (1.37)$$

$$\Delta H^*_{uv} = [(\Delta E^*_{uv})^2 - (\Delta L^*)^2 - (\Delta C^*_{uv})^2]^{1/2} \quad (1.38)$$

ΔE^*_{ab}	Valuation
< 0.2	Color difference not perceptible
0.2 to 1	Very small color difference
1 to 3	Small color difference
3 to 6	Mean color difference
6 to 12	Large color difference
> 12	Very large color difference

Table 4. Interpretation and evaluation of color differences. [19]

As a result, the CIE recommended both color spaces for further testing. In the industry, however, the CIELAB formula in particular has been accepted and tested and has also become the standard today. [1, 19–21, 33, 47, 60, 61, 66]

The CIELAB color space exhibits relatively large deviations, especially in magenta and red tones, which results in an excessively high evaluation of the color difference for saturated colors compared to neutral gray tones. This has led to ongoing work on the development of further color difference formulae, which are typically not Euclidean. This means that color differences cannot be represented as simple distances in a three-dimensional space. In various ways, the saturation difference of the colors has been weighted less than their brightness difference. For this purpose, factors are used to decrease the difference value as the saturation of the measured color pair increases. Three of these further developed formulae are described below. [1, 19–21, 33, 47, 60, 61, 66]

In 1984, the Color Measurement Committee (CMC) of the Society of Dyers and Colorists (SDC) introduced the CMC formula, published by Clarke, McDonald, and Rigg. In 1995, this became the ISO standard for textile applications. [1, 19–21, 33, 47, 60, 61, 66]

In this formula, the color difference $\Delta E^*{}_{CMC}$ is evaluated as follows:

$$\Delta E^*{}_{CMC}(\mathrm{l:c}) = \left[\left(\frac{\Delta L^*}{lS_L}\right)^2 + \left(\frac{\Delta C^*_{ab}}{cS_C}\right)^2 + \left(\frac{\Delta H^*_{ab}}{S_H}\right)^2\right]^{1/2} \quad (1.39)$$

where

$$S_L = \frac{0.0409075L^*}{(1+0.01765L^*)} \quad (1.40)$$

unless $L^* < 16$ when $S_L = 0.511$

$$S_C = \frac{0.0638C^*_{ab}}{(1+0.0131C^*_{ab})+0.638} \quad (1.41)$$

$$S_H = S_C\,(Tf + 1 - f) \quad (1.42)$$

where

$$f = \left[\frac{(C^*_{ab})^4}{(C^*_{ab})^4+1900}\right]^{1/2} \quad (1.43)$$

and

$$T = 0.36 + |0.4\cos(h_{ab} + 35)| \quad (1.44)$$

unless h_{ab} is between 164° and 345° when

$$T = 0.56 + |0.2\cos(h_{ab} + 168)| \quad (1.45)$$

This formula is used to vary the relative weights of the contributions of the differences in L^*, C^*_{ab}, and H^*_{ab} according to the position of the color in the CIELAB color space. l and c are selectable linear parametric factors for controlling the relative sensitivity to differences in lightness and color. S_L is the weighting function of lightness. This depends on the lightness and reduces the effect of a lightness difference with increasing lightness. S_C is the weighting function of chroma. This reduces the effect of significantly increasing chroma difference values with increasing chroma in an a^*, b^* diagram. S_H is the most complex weighting function and is used to weight the hue. To do justice to the general size dependence of the chroma and irregularities due to the hue angle, variants of the hue angle h_{ab} and chroma C^*_{ab} are used here. [1, 19–21, 33, 47, 60, 66]

The mathematical form of the CMC formula shows an essential deviation from the CIELAB formula. In CIELAB, the color difference is the vector length between the two points in the color space. This vector definition is no longer valid in the CMC formula because weights are applied to the vector components and thus the calculated color difference is no longer represented as a vector in a coordinate system. [1, 19–21, 33, 47, 60, 66, 109]

In 1994, the CIE introduced another color difference formula: CIE94. A technical working group carried out this optimization of the CIELAB formula mainly on the basis of new experiments. The result is very similar to the CMC formula and also follows its basic form.

However, it provides only one of the features of the CMC formula, making it less complicated. As the color chroma C^*_{ab} increases, the weighting of the differences ΔC^*_{ab} and ΔH^* decreases. In addition, this formula establishes fixed viewing conditions via the parameter k = 1. [1, 19–21, 33, 47, 60, 66, 109]

The formula CIE94 is:

$$\Delta E^*_{CIE94} = \left[\left(\frac{\Delta L^*}{k_L S_L}\right)^2 + \left(\frac{\Delta C^*_{ab}}{k_C S_C}\right)^2 + \left(\frac{\Delta H^*_{ab}}{k_H S_H}\right)^2\right]^{1/2} \tag{1.46}$$

where

$$S_L = 1 \tag{1.47}$$

$$S_C = 1 + 0.045 C^*_{ab} \tag{1.48}$$

$$S_H = 1 + 0.015 C^*_{ab} \tag{1.49}$$

Here, we can see that the weighting functions S_L, S_C and S_H differ in their definition from the CMC (1:c) formula. k_L, k_C and k_H are parametric factors that describe results obtained by changing the specified reference conditions (k = 1). [1, 19–21, 33, 47, 60, 61, 66]

Use of the CIE94 color difference formula is no longer recommended by the CIE. Further work by the CIE has since led to the recommendation of the CIEDE2000 formula for color difference evaluation. This formula incorporates improvements to the division terms used in the CIE94 formula, all based on new data from various studies, along with a hue rotation term to allow interaction between the hue and chroma terms in the blue region of the color space. It has been observed that most ellipses representing color differences tend toward the origin of the CIELAB color space. However, the ellipse tilt in the blue region is counterclockwise and away from the direction of the constant hue angle. To account for this effect, a rotation function is applied to the weighted hue and chroma difference that affects only high chroma, blue, and color differences. [1, 19–21, 33, 47, 60, 61, 66]

Consequently, a stretching of the a^* axis of the CIELAB system takes place when calculating the chroma C_{ab}. a^* becomes a', the calculated chromas become C' or $\Delta C'$, and the hue differences become $\Delta H'$. To compensate for the inequalities from CIE94, the weighting factor S_H or the hue difference is now calculated as a function of the chromaticity angle. The weighting factor S_L for the lightness difference is no longer fixed at 1 but can vary between 1.0 and 1.75 depending on the location of the ΔH^* values. A subtractive corrector is also added for colors located in the fourth quadrant (+a^*/-b^*). [19–21, 33, 47, 60, 61, 66]

The formula CIEDE2000 is:

$$\Delta E_{00} = \left[\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{k_C S_C}\right)\left(\frac{\Delta H'}{k_H S_H}\right)\right]^{1/2} \quad (1.50)$$

where

$$L' = L^* \quad (1.51)$$

$$\Delta L' = L'_b - L'_s \quad (1.52)$$

$$\Delta C' = C'_b - C'_s \quad (1.53)$$

$$\Delta H' = 2(C'_b C'_s)^{1/2} \sin(\Delta h'/2) \quad (1.54)$$

and

$$\Delta h' = h'_b - h'_s \quad (1.55)$$

The indices b and s indicate that the value applies to the selected color and to the default color, respectively. [19–21, 33, 47, 60, 61, 66]

The CIELAB axes are then transformed in such a way that

$$L' = L^* \quad (1.56)$$

$$a' = a^* (1 + G) \quad (1.57)$$

$$b' = b^* \quad (1.58)$$

where

$$G = 0.5\left\{1 - \left[\frac{\overline{C}_{ab}^{*7}}{(\overline{C}_{ab}^{*7} + 25^7)}\right]^{1/2}\right\} \quad (1.59)$$

The bar symbol above C' means that the value is the arithmetic mean for a color pair. It is used comparably also for L' and h'.

Modified values for chroma C' and hue angle h' are calculated by:

$$C' = (a'^2 + b'^2)^{1/2} \quad (1.60)$$

$$h' = \tan^{-1}\left(\frac{b'}{a'}\right) \quad (1.61)$$

The weighting functions are given by:

$$S_L = 1 + \frac{\left[0.015\left(\overline{L}' - 50\right)^2\right]}{\left[20 + \left(\overline{L}' - 50\right)^2\right]^{1/2}} \quad (1.62)$$

$$S_C = 1 + 0.045\overline{C}' \quad (1.63)$$

$$S_H = 1 + 0.015\overline{C}'T \quad (1.64)$$

where

$$T = 1 - 0.17\cos\left(\overline{h}' - 30°\right) + 0.24\cos\left(2\overline{h}'\right) + 0.32\cos\left(3\overline{h}' + 6°\right) - 0.20\cos\left(4\overline{h}' - 63°\right) \quad (1.65)$$

To account for the anomalies in the blue region of the CIELAB color space, a rotation parameter R_T is still required:

$$R_T = -\sin(2\Delta\theta)\, R_C \quad (1.66)$$

with

$$\Delta\theta = 30\exp\left[-\left(\frac{\left(\overline{h}' - 275°\right)}{25}\right)^2\right] \quad (1.67)$$

$$R_C = 2\left[\frac{\overline{C}'^7}{\left(\overline{C}'^7 + 25^7\right)}\right]^{1/2} \quad (1.68)$$

As a result, CIEDE2000 significantly outperforms the previous formulae; CMC (1:c) and CIE94 should therefore be discarded. [19–21, 33, 47, 60, 61, 66]

3 Quantum Dot enhanced Liquid Crystal Displays

This chapter considers the current QD-enhanced LCD technology in greater detail. It explains the meaning behind the term *quantum dot* and discusses the properties that make QDs so interesting for modern display technologies. Current technical configurations and new developments are also presented.

3.1 Modern display technologies

The image quality of modern display devices has reached a very high level due to intensive research and development efforts. Driven by the goal of producing displays that reproduce all the colors of the natural world, manufacturers are continuously developing their display technologies. Improving color gamut is one of the key strategic goals of most, if not all, major display manufacturers. Some are trying to achieve this using new platforms such as OLED technology, while others are incorporating QDs into their existing platform, LCD technology. [27, 37, 110–112]

At the time of writing, the dominant flat-panel display technology is the thin-film transistor liquid crystal display (TFT-LCD). These are used in small technical device displays, in mobile devices (smartphones, tablets, etc.), in computer monitors, and in wide-screen TVs. However, this market leadership is increasingly being challenged by the continuous development and improvement of the innovative and versatile OLED technology, which offers numerous advantages. Indeed, the debate is ongoing as to which display technology—LCD or OLED—will dominate the future marketplace. In the meantime, many scientific studies have compared the various performance metrics of these technologies. On the one hand, OLED technology is a self-light-emitting technology, which means that it offers significant advantages over LCD technology in terms of module thinness and flexibility, as well as in the response times of the individual subpixels; testing also shows comparable results in terms of ambient contrast ratio and viewing angle. On the other hand, when considering service life, power consumption, resolution density, and costs, LCD technology performs better. [112–122]

Two major challenges persist for LCD technology: the improvement of response times and the displayable color gamut. With the former, the progress of polymer-stabilized blue phase liquid crystal (PS-BPLC) materials and device structures is particularly noteworthy. Currently, fringing field switching (FFS) technology is still typically used for touch panels, whereas multi-domain vertical alignment (MVA) technology is used for TV sets. More recently, in-plane switching (IPS) based BPLC technology has combined the advantages of IPS (wide view, low color shift, and pressure resistance) and MVA (high contrast ratio, fast response time) and thus offers a potential total solution for all types of display devices. [119, 121, 123–137]

To achieve wider color gamuts and accurate color reproducibility, colloidal semiconductor nanocrystals or QDs are now being used by various manufacturers. Today, they are typically used to optimize LCD backlight units (BLUs), enabling a new generation of more efficient, brighter displays with a much wider color gamut. LCD technology has hence been revitalized and stands in direct competition with the more recent OLED technology. [27, 28, 110, 112, 116, 117, 120–122, 125, 138, 139]

The quest to improve color gamut has also been beset by enormous pressure on the standards front following the introduction of the BT.2020/Rec.2020 video standard, an International Telecommunications Union (ITU) standard recommended in 2012 and approved in 2015. The BT.2020/Rec.2020 color gamut covers 99.8% of the colors from the natural world, or nearly 60% of the spectrum visible to the human eye. By contrast, displays built to the high definition TV (HDTV) standard can only reproduce 58% of the BT.2020/Rec.2020 color gamut. LCD-based ultra HD TVs (without QDs) fare better, with most achieving around 70% coverage, while OLED TVs today reach up to 74%. Higher still, photo-enhanced QD displays currently on the market can handle 85–90% of the color gamut specified in the standard. Photo-emissive QD color conversion displays in development reach 93.3%, while initial prototypes of electro-emissive QD display technology achieve around 90%. [27, 112, 116, 140, 139, 141–143]

However, the number of reproducible colors as measured by the BT.2020/Rec.2020 color standard are only one performance indicator. Sufficient clarity, which requires neither visible pixels nor motion blur or ghosting at typical viewing distances, is also necessary. This is significantly influenced by the resolution and the response time of the display. High dynamic range (HDR) is another key term. A sufficiently high peak brightness and a sufficiently low black value is necessary to convey the desired visual experience. [112, 116, 140–143]

3.2 Quantum dots (QDs)

When it was recognized in the 1980s that the color of semiconductor particles at nanometer scales depends on their physical size, QDs became the subject of intense scientific and industrial research. Theoretical and experimental concepts of quantum confinement were developed to exploit their then novel electronic, electrical, optical, and catalytic properties, as dictated by their size, shape, and quantum physics arising at the nanoscale. Quantum confinement effects in QDs lead to discrete electron and hole states that can be precisely tuned by varying the particle size. Efforts to exploit this quantum tunability of QDs have led to many interesting ideas for optical and optoelectronic devices and applications that have revolutionized our way of life. Many materials are being studied and advanced, and more and more new structures with quantum mechanical effects are being developed. Colloidal semiconductor nanocrystal QDs are one of these structures. Since the effective bandgap of these QDs within or near the visible spectral range can essentially be matched with a material system, semiconductor QDs have an important place in photonics. In addition, the optical properties of these materials can be further controlled by tuning their size and size distribution. [27, 37, 112, 116, 120, 122, 138, 139, 144–151]

While displays are currently the largest commercial application for QDs, their physical properties have also transformed a number of other scientific fields. Applications in medicine, imaging, laser technology, quantum computing, or photovoltaics seem limitless. As the size of materials gets smaller and smaller, classical mechanics are no longer sufficient to explain the material properties; instead, the control mechanisms are based on the principles of quantum physics. The same physical principles apply to nanocrystalline semiconductor QDs. [27, 37, 112, 116, 120, 122, 138, 139, 144–151]

3.2.1 Fundamentals of quantum dots

QDs are nanometer-sized semiconductor particles that are affected by quantum confinement effects determined primarily by their size. They possess a number of very attractive properties, such as high photoluminescence quantum yield (PLQY), solution processability, and highly tunable bandgaps. These special properties make quantum dots very well suited to use in optoelectronic devices such as light-emitting diodes and semiconductor lasers (as emitters) or in photodiodes and solar cells (as light absorbers). [27, 111, 112, 116, 122, 120, 139, 149, 152–154]

When considering a bulk semiconductor, the number of atoms is very large and the overlap of this high number of atomic orbitals forms a continuum of closely spaced ‘molecular’ orbitals that form the valence and conduction bands. This changes when the semiconductor is reduced to a nanoscale size, which in turn greatly reduces the number of overlapping atomic orbitals. Quantum confinement effects begin to dominate the physical properties; the valence and conduction bands are now no longer continuous but are instead formed from discrete electron energy levels, affected by both the material property and the particle size. Thus, even the addition or subtraction of just a few atoms to/from the QD has the result of changing the boundaries of the bandgap. This will always be energetically larger in a quantum dot because electrons must occupy a larger distance energetically. This makes it possible to specifically influence and control the absorption and emission behavior of the semiconductor material by changing the particle size. For the use of QDs, the very precise control of this bandgap is particularly important. This phenomenon of quantum mechanics offers incredible opportunities for the use of QDs in display technologies. Each QD is a super-small semiconductor that can convert short wavelength light (450–495 nm) into almost any color of the visible spectrum. This means that when excited with blue or ultraviolet (UV) light, QDs can glow with a precisely defined color. [27, 111, 112, 116, 120, 122, 152]

3.2.1.1 Quantum confinement effect

The QDs used in displays today typically have dimensions of 1 nm to 10 nm. Because the electrons and holes are confined in such small particles, quantum confinement effects dominate their physical properties. When a QD absorbs a photon, it creates an electron-hole pair that recombines to form a new photon. Such an electron-hole pair is called an exciton, an elementary excitation of the solid and a quasiparticle that can move through the crystal. In doing so, the exciton transports its excitation energy through it without charge transport because it is electrically neutral. Excitons have an average physical separation between the electron and the hole, called the exciton Bohr radius, which is different for each material. Typically, the dimensions of semiconductor crystals are much larger than the exciton Bohr radius. However, if the size approaches the exciton Bohr radius of the material, then the electron energy levels can no longer be treated as continuous and must be treated as discrete, meaning that there is a small and finite separation between the energy levels. This phenomenon is called quantum confinement and the semiconductor material no longer resembles mass; it can instead be called a quantum dot. This has a significant impact on the absorption and emission behavior of the semiconductor material. [27, 112, 113, 120, 122, 146, 145, 147, 152, 155]

The electron energy levels of QDs are discrete and affected by both the material property and the particle size. There is thus a great deal of freedom in tailoring emission peaks. The addition or subtraction of only a few atoms to/from the QD has the effect of changing the bandgap boundaries. The bandgap in a QD will always be energetically larger, which is why the radiation from QDs is 'blue shifted' (i.e., shifted to lower wavelengths), reflecting the fact that electrons must be energetically spaced farther apart and thus produce radiation at a shorter wavelength. In QDs, the size of the bandgap is controlled by changing the dot size. Since the transmission frequency of a dot depends on the bandgap, it is possible to control the output wavelength of a dot with high precision. Thus, it is possible to determine the bandgap of a dot and thus adapt its 'color' to the requirements of an application. [27, 112, 113, 120, 122, 146, 145, 147, 152, 155–160]

This system can be described by a finite quantum well problem, and the effective bandgap that determines the energy (and hence the color) of the fluorescent light can be approximated by the Brus equation for effective mass approximation. This assumes that an effective mass of electron and hole is confined in a spherical potential well of the crystallite:

$$E^* = E_g + \frac{h^2\pi^2}{2R^2}\left[\frac{1}{m_e} + \frac{1}{m_h}\right] - \frac{1.786e^2}{4\pi\varepsilon R^2} - 0.248\, E_{Ry}, \quad (2.01)$$

where E_g is the bandgap of the bulk semiconductor, R is the particle radius, and m_e and m_h are the effective mass of the electron and hole, respectively. The effective bandgap and hence the fluorescence light of a QD system depend on the particle size. Thus, referring to equation 2.01, the optical properties of QDs can be varied by changing the particle size. The spectral power of QDs and hence the wavelength of the emitted photons are determined by the energy level of the QD, which depends on its size. Larger dots emit longer wavelengths (620–750 nm), while smaller dots emit shorter wavelengths (380–450 nm). This is due to the tight electron confinement of the semiconductor material, which requires more energy for a smaller volume, so smaller QDs emit higher energy wavelengths. The narrower the particle size distribution, the narrower and purer the resulting colors, which is a prerequisite for displays with a wide color gamut. In principle, any color in the visible spectrum can thus be produced by controlling the particle size during the synthesis process. A larger R results in longer wavelength emission. However, it remains difficult to find a high quality fluorescent material at a specific wavelength. Today's best performing dots emit light with over 99% quantum efficiency and produce a very narrow spectral distribution of less than 25 nm FWHM. [27, 111–113, 116, 120, 122, 145–147, 152, 155, 159–163] QDs thus make it possible to obtain any specific color emission by varying the particle size using the same material system. This feature offers a great deal of design freedom. For example, the emission spectrum of QD can be designed to match color filters to increase optical efficiency while expanding the color space. The emission of a QD sample is the convolution of the fluorescence emission of each QD in a population. Therefore, the linewidth is determined by inhomogeneous broadening of the QD particle size distribution. Sophisticated chemical synthesis techniques can precisely and uniformly control the particle size of QDs. Current chemical synthesis techniques show excellent controllability over the particle size distribution. Batches of QDs with > 10 particles can be produced, all within +/- 1 atom of thickness variation. The FWHM of cadmium (Cd)-based QDs is approximately 30 nm. Current developments suggest that 25 nm FWHM QDs in green and red will soon be available off-the-shelf. In addition, new colloidal particles in the form of platelets exhibit 10 nm FWHM. Such a narrow emission linewidth would undoubtedly produce an exceedingly broad color space. [27, 112, 113, 116, 120, 122, 144–147, 149, 152, 155, 162, 164–168]

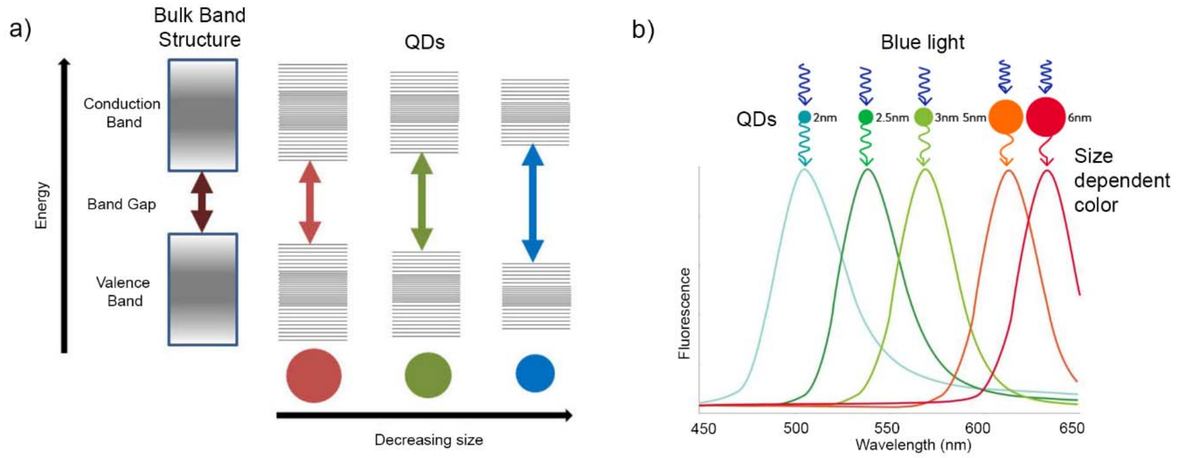


Figure 9. Division of energy levels into quantum dots due to the quantum confinement effect. The semiconductor bandgap increases with the size of the nanoparticle. [27, 139, 169, 170]

3.2.1.2 The structure of quantum dots

The most important properties of QDs are their excellent quantum yield and stability, as well as bright and stable luminescence. While the optical absorption properties are not so strongly dependent on the surface condition, it has a very strong effect on the luminescence. This is due to the large surface-to-volume ratio (about 20%), which leads to a high proportion of atoms on the QD surface. It is therefore necessary to prevent non-radiative recombination paths, which are normally associated with the confinement of electrons or holes. Surface defects such as dangling bonds should thus be reduced since they are particularly active in the charge-trapping process. One solution to improve surface properties is to coat the core with larger bandgap shell materials, resulting in a core/shell system with much higher quantum efficiency and stability. Type-I core-shell structures are used for QDs. The crystalline wide gap shell helps confine the electron and hole wave functions to the core and prevents the confinement of charges at or near the QD surface. Thus, the core of a QD is covered by a shell with a wider bandgap and then surrounded by organic ligands. Like the shells, these also act as a protective layer; they also provide excellent surface passivation and eliminate harmful surface conditions. The core-shell structure effectively limits the wave function of excitons within the core, resulting in a high recombination rate and improved emission quantum efficiency. In addition, they also provide the necessary processability. This advancement has improved both efficiency and lifetime compared to core-only systems. [27, 112, 116, 120, 122, 144–147, 149, 152, 155, 158, 164–168, 171–173]

3.2.2 QD materials

Thanks to intensive research, a variety of QD materials can be produced today. Especially over the last decade, the ability to grow thick and uniform shells has been significantly improved. Chemically graded and alloyed shells have reduced strain at the core-shell interface and further improved structural perfection and luminescence quantum efficiency. In the context of this study, the materials studied are as follows: II–VI semiconductors (zinc oxide [ZnO], zinc(II) sulfide [ZnS], zinc selenide [ZnSe], cadmium selenide [CdSe], cadmium sulfide [CdS], cadmium telluride [CdTe]); III–V semiconductors (gallium nitride [GaN], gallium phosphide [GaP], gallium arsenide [GaAs], indium phosphide [InP], indium arsenide [InAs]); ternary semiconductors (copper indium sulfide [CuInS]); and doped materials such as manganese-doped zinc selenide [ZnSe:Mn]. These can essentially be divided into two overarching groups: heavy metal-based QDs and heavy metal-free QDs. However, only a few of these materials are suitable for use in displays since they must absorb blue photons, efficiently convert blue to narrow red and green photons, scale accurately, process efficiently, and remain stable for many hours of application while still being cost-effective. QDs for display applications are generally made from II–VI elements such as CdSe or III–V elements such as InP. These require an inorganic shell (e.g., of zinc sulfide) for sufficient quantum efficiency and stability. They are typically synthesized via solvent chemistry in high-boiling solvents using precursors and ligands that bind to the surface of the QDs. Due to the possible precise control of different synthesis conditions (e.g., precursor and ligand concentrations) as well as the temperature and time of the reaction, QDs of different sizes can be prepared. The photoluminescence emission and absorption wavelengths can be fine-tuned, which is ideal for optoelectronic applications. The two key metrics for evaluation are the FWHM and the PLQY, which is the efficiency with which a blue photon is converted to another color. The narrower the emission peak width, the better the color quality. The higher the quantum efficiency, the more efficient and brighter the display. [27, 78, 111, 112, 122, 147, 149, 152, 157, 158, 163, 171–181]

3.2.2.1 Heavy metal-based quantum dots

The II–VI semiconductor CdSe is the most advanced and best characterized QD material system, with a bulk bandgap of 1.73 eV (λ = 716 nm). According to Equation 2.01, the emission spectrum can be tuned to cover the entire visible range by adjusting the particle size. Currently fabricated Cd-based QDs exhibit a narrow FWHM (20 ~ 30 nm) and very high luminescent quantum efficiency (> 95%). Thus, 90% of the BT.2020/Rec.2020 UHD reference color space can be realized. Thanks to these results, such a high quality QD material seems to be a perfect choice for display applications and has accordingly been used by various manufacturers in different display devices. However, cadmium is toxic and, like other heavy metals, falls under the EU's Restriction of Hazardous Substances (RoHS) Directive. This limits the maximum cadmium content to 100 ppm in all consumer electronics products, with the ultimate aim of banning heavy metals permanently. One focus of QD research is therefore the development of new heavy metal-free materials for future display applications. [27, 112, 116, 122, 143, 144, 149, 152, 182–188]

3.2.2.2 Heavy metal-free quantum dots

Existing research has identified InP-based QDs as the most promising and viable alternative to Cd-based QDs. Their quantum efficiency is most comparable to the best CdSe QDs. However, their emission linewidth is still slightly wider. To achieve the same emission wavelength, the core size of InP QDs must be smaller than that of CdSe. Smaller bandgaps and particle sizes lead to a much stronger quantum confinement effect, making their emission spectrum more susceptible to particle size changes and thus their FWHM is somewhat wider (> 40 nm). As a result, only around 70–80% of the Bt.2020/Rec. 2020 UHD reference color space can be realized, depending on the color filters used. In addition, quantum yield and stability are slightly lower than Cd-based QDs. These characteristics are also due to the fact that the chemical synthesis method of InP QDs is not yet mature enough. If their FWHM can be further reduced and their lifetime increased, they should become more attractive for display manufacturing. Research and development are in full swing and almost all display manufacturers are now using Cd-free BLUs. As mentioned above, the RoHS Directive sets the upper limit for heavy metal-based QDs. Although InP is not currently on the list, it may be re-evaluated in the future. Therefore, other environmentally friendly QD materials need to be developed. Studies are underway on metal-free graphitic carbon nitride [C_3N_4], while a QLED prototype has already been presented using g-C_3N_4 QDs as a blue emitting layer with promising performance. Yet another technology based on halegonide perovskite QDs is also increasingly coming into focus. [27, 111, 122, 145, 152, 157, 175, 177, 180, 183, 185, 188–195]

3.2.2.3 Perovskite quantum dots

Perovskite QDs are a promising new class of light emitters. In particular, halide perovskite semiconductors are becoming increasingly important. This is due to their role as low-cost, high-efficiency absorbers in photovoltaic cells. Perovskite QDs are easily fabricated using a very simple yet robust synthesis compared to traditional QD synthesis. Recent research has shown that these materials can be formed in-situ during polymerization of a polymer, further simplifying the process. In addition to solution processability, they also offer the properties of established QDs, such as accurate bandgap tunability and high PLQY. In contrast to the colloidal QDs used today, their bandgap tunability is based not only on the size of the particles but is mainly controlled by the chemical composition, which allows the generation of very narrow spectral emission lines. Established InP QDs have a bandwidth of 35–45 nm, compared to 30 nm for CdSe QDs. Metal-halide perovskite QDs with a FWHM of > 25 nm have already been developed, halving these results with an impressive bandwidth of 12–18 nm for green (similar to a blue LED linewidth). At the same time, the highest possible quantum efficiencies of > 95% are achieved, promising very high peak brightness for a display. The very high intrinsic absorption of metal halide perovskite QDs thus makes them a very suitable candidate for the next generation of wide color gamut displays. [163, 196–210]

However, for all the positive results, certain problem areas persist. For one, almost all metal halide perovskite QDs contain lead. In current applications, these still fall well below the RoHS limits, but highly concentrated form factors such as color filter replacements or color conversion layers in micro-LEDs could exceed them. Another problem, also known from photovoltaic applications, is a certain level of instability depending on the material structure and chemical composition. This results in susceptibility to elevated temperatures and light currents. Such elevated temperatures and luminous fluxes affect the lifetime of the material, and color options are still limited. Metal-halide perovskite QDs are compositionally matched, and atoms are substituted for color matching; under the influence of heat or light, they are very mobile and tend to move, resulting in a shift in the emission spectrum, or color shift. Research is ongoing on this topic, and promising results have already been obtained and numerous strategies developed to improve stability. [163, 184, 196–210]

3.3 Liquid crystal display technology

The three most important components of an LCD are the backlight unit (BLU), the liquid crystal module (LCM) and the color filters (CFs) in front of the individual subpixels. When the display is in operation, the BLU is on and provides uniform illumination of the LCM. The backlight consists of LEDs, which are either installed at the edges of the display (edge LED) or distributed over the entire display surface (direct LED). In addition to the LEDs, the BLU contains several layers of optical plates to emit the light with uniform brightness over the entire display surface. [21, 27, 112, 121, 122, 125, 211, 212]

The LCM consists of individual LC cells, the number of which is defined by the screen resolution. Each of these cells consists of two polarizers and two glass substrates surrounding a thin (~3 µm) layer of LCs. These have the ability to affect the polarization direction of the light. In the simplest configuration, the two polarizers are aligned with their polarization planes at right angles. If the LC cell is not turned on, the light transmitted by the first polarizer can pass through unaffected and is blocked by the second polarizer. When the LC cell is turned on (i.e., an electric field is applied), the LCs change position depending on the strength of the voltage, thereby rotating the plane of polarized light so that it can pass through the second polarizer. The way the LCMs work depends on the panel technology used. [21, 27, 112, 121, 122, 125, 211, 212]

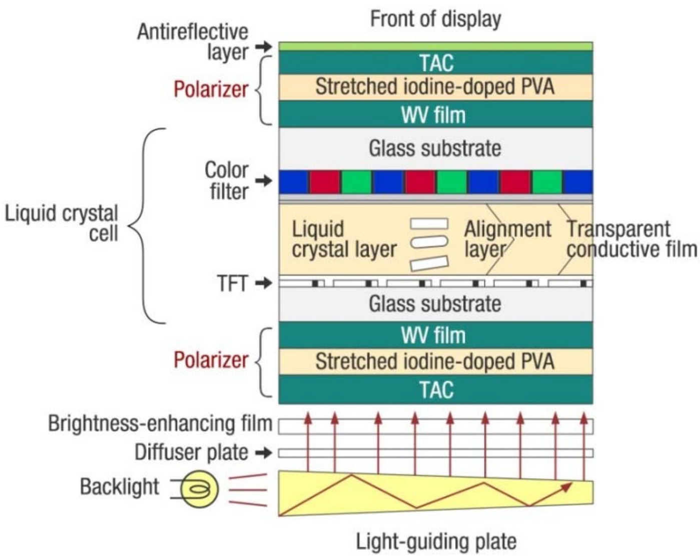


Figure 10. Cross-sectional view of a typical LCD. [125]

As outlined above, the human eye contains only three types of color-sensitive cones, each of which responds to a different peak wavelength of light. These wavelengths correspond to the colors red, green, and blue. For this reason, in a display today, each screen pixel is typically divided into red, green, and blue sub-pixels, which are coated with color filters of the corresponding color. Varying the relative brightness of each subpixel allows the human visual system to see different colors. This is done by controlling the amount of time each subpixel is open and allows light to pass through. Thus, any color that can be represented from a combination of red, green, and blue can be displayed at any pixel position. By additively mixing these three primary colors in various ratios, it is thus possible for a display to produce over a billion unique hues. In turn, the quality or accuracy of these colors is a direct function of subpixel color quality, depending on the quality of the light from the BLU and the color filter on the subpixel. To enable precise color mixing, the light spectrum exiting each subpixel must be as narrow as possible. This requirement presents some difficulties for LCD technology. Two existing methods can be used to ensure that the light spectrum coming from each subpixel is narrow. The first uses very strict CFs that allow only a narrow spectrum in each of the primary colors of red, green, and blue to pass through. The second is to create a white background light in which each of the three primary colors has a spectral distribution with a sharp and narrow emission peak. [21, 27, 112, 121, 122, 125, 211, 212]

3.3.1 The backlight unit

The BLU is one of the most important technical components in LCDs. It significantly influences the color gamut of the display, as well as its optical efficiency, dynamic range, and viewing angle. Due to the technological principle, LCDs are passive and therefore not self-illuminating; they emit or reflect only the light fed into the LCD via an additional light source. The technique by which the light is projected evenly over the entire display from behind is called backlighting. Typically, LEDs are used today as light sources for backlighting, offering fast switching times at very low energy consumption. The LEDs can be installed in the panel in different ways. A distinction is made between edge LEDs and direct LED packages. With edge LED, the LEDs are located at the edges of the display and must be very well distributed over the diffuser and light guide layer mentioned above. The LED strips can be mounted on the side or top and bottom, or on the side and top and bottom. With direct LED technology, the LEDs are located directly behind the TFT and LC layers on the display surface. This facilitates light distribution via the diffuser and the light guide layer is illuminated more evenly. [21, 27, 29, 119, 121, 125, 211–217]
Backlighting based on phosphor-converting white LEDs (1pc-WLED) is still the standard. This is due to their high efficiency, long lifetime, low cost, and simple optical configuration. However, they cannot meet the ever-growing demand for more vivid colors. Mostly blue LEDs are used, covered with a yellow phosphor to produce the desired white light. One of the most commonly used technologies for white LEDs is based on yttrium aluminum garnet (YAG) phosphor pumped from a gallium nitride (GaN) blue source. The phosphor acts as a downconverter, downconverting the blue light from the LED into different visible wavelengths. The CFs in front of the subpixels separate their component color from the white light of the BLU. All other colors that lie between the primary colors of the filters are blocked. To achieve high-quality coloration, either the filter function must be very narrow, resulting in significant

attenuation and a noticeable loss of efficiency, or the spectra in the BLU white light corresponding to the color filter should be narrow and well matched to the desired punctual color. The problem here is that the LED light source at the heart of the BLU does not provide these filters with enough of the colors they need to truly shine. [21, 27, 29, 112, 118, 119, 121, 125, 211–221]

The white light produced by these LEDs has a narrow blue spectrum and a broad yellow spectrum, while the red and green light content is very weak and the spectra are broad. As a result, when this light is filtered into red, green, and blue components, there is often not enough energy at the required wavelengths of red and green to produce a bright image. The filters compensate for this lack of energy by allowing broader color palettes to pass through. With such imperfect colors, it is impossible for the subpixels to mix the light from the three primary color components into the exact colors the user wants to see. The result of this trade-off between brightness and color accuracy leads to displays that are inefficient and inaccurate. In response, an ideal backlight source for an LCD would be three discrete colors that could match the color filters to provide the best possible color purity. In this way, one could not only achieve the best color gamut, but also the best efficiency. Expectations, and therefore bases for evaluation, have shifted significantly on this point: more advanced backlight technologies are in demand, and various approaches are being investigated. Using discrete RGB LEDs is one effective way to expand the color gamut. Another possibility is the use of two phosphor-converted WLEDs (2pc-WLEDs). [21, 27, 29, 111, 112, 118, 119, 121, 122, 125, 211–223]

However, the most promising alternative is QD enhanced backlighting. QD technology can be an ideal light source for LCDs due to their narrower FWHM nature and ease of tunability at peak wavelength (PWL). Their absorption and emission characteristics make them ideal for use as subpixels. Compared to YAG phosphors, QDs exhibit narrow emission with excellent wavelength control, allowing the exact color to be preselected based on size and composition. This means that the majority of the photons generated can pass through the color filters rather than being blocked; the photons are therefore used much more efficiently. When QDs are layered over an LED backlight, they effectively filter the light and also convert unwanted wavelengths into pure red, green, and blue peaks instead of filtering them out. This results in a reduction in the amount of energy required to produce an image at a given brightness, meaning efficiency is significantly improved. Increased color reproduction enables more realistic reproduction of lifelike colors. [21, 27, 111, 112, 118, 121, 122, 125, 168, 211, 212, 214, 219, 224–226]

The fact that QDs are particularly suitable as optical downconverters is due to the structure of their absorption spectra. The absorption spectra of organic molecules typically contain one or more absorption bands. The absorption of QDs at short wavelengths increases independently of the emission color. This enables the use of QDs as an optical downconverting material that efficiently absorbs blue light emitted from, for example, a high-efficiency InGaN LED. The QDs then convert the blue light to other wavelengths depending on their size. The downconversion process typically involves far-field coupling between reemitting QDs and the light source. The efficiency of the downconversion process is determined by the luminescence quantum efficiency of QDs. The key technical challenge is to maintain this high luminescence efficiency of QDs under real operating conditions. Another important parameter is the efficiency of coupling the emitted light from the device. This usually depends on the refractive index of the medium in which QDs are dispersed. The efficiency of light decoupling can be increased by using dielectric mirrors with high reflectivity in the emission band of QDs. Several important technologies can thus benefit from the use of QDs as optical downconverters.[147, 168, 219, 226–228]

3.3.1.1 Performance of the backlight

The results of many investigations confirm the excellent suitability of QDs for use in LCD backlighting. The tunable narrow emission spectra enable vivid colors and an exceptionally wide displayable color gamut. Among other things, the Gaussian equalization method plays an important role here. The emission spectrum of QDs and typically used InGaN LEDs is Gaussian, so equalization is performed to extract the peak wavelength and FWHM. The pure emission peaks thus allow the use of broadband CFs. This makes it possible to achieve not only a large balanced color gamut (color filter effect), but also a balanced efficiency and thus a significant increase in luminous efficacy. A large color gamut not only helps to produce vivid colors but also to reduce power consumption. This is due to the so-called Helmholtz Kohlrausch effect, where a display with saturated color is perceived as brighter. [26, 27, 112, 229–231]

To evaluate the performance of a backlight, the classic system configuration of an LCD panel must be considered. The incident light $S_{in}(\lambda)$ is divided into three channels: R (red), G (green), and B (blue), corresponding to the color filters. The total emission consists of three peaks and the spectral power distribution (SPD): [27, 28, 79, 112, 143]

$$S_{out}(\lambda) = S_{out,R}(\lambda) + S_{out,G}(\lambda) + S_{out,B}(\lambda) \qquad (2.02)$$

The TFT aperture ratio, the LC layer, the applied voltage, and the CF used must be taken into account, as these determine the optical efficiency and color saturation of an LCD panel as a total system. [27, 28, 79, 112, 143]

Two metrics are commonly defined to evaluate backlight performance: total light efficiency (TLE) and color gamut. TLE indicates how much emitted light from the backlight passes through the LCD panel and is finally converted into the brightness perceived by the human eye. This means the relative sensitivity of the human eye at different wavelengths must be taken into consideration. This varies significantly over the perceptible spectral range of 380–750 nm. Therefore, the human eye sensitivity function $V(\lambda)$ is also considered to calculate the TLE. This is normalized for the peak at λ = 555 nm since this is where the human eye reaches maximum sensitivity, meaning that the human eye is more sensitive to green/yellow light. TLE thus includes the overall efficiency of the backlight and considers almost all influences in the display system, such as the spectrum of the light source, the transmission of color filters, LC layer and polarizers, and the aperture ratio of each color channel: [27, 28, 79, 112, 121, 122, 143]

$$S_{out}(\lambda) = \frac{683 \frac{lm}{W} \int S_{out}(\lambda)\, V(\lambda)\, d\lambda}{\int S_{in}(\lambda) d\lambda} \qquad (2.03)$$

The color gamut specifies the color palette that can be reproduced by the LCD display. It can be defined in either the CIE 1931 or CIE 1976 color space: [27, 28, 79, 112, 143, 232]

$$Color\ gamut = \ Area\ encicled\ by\ RGB\ primaries \qquad (2.04)$$

3.3.2 Liquid crystal display panel types

Currently, three different panel types are produced commercially. Each differs in the way the LCs are aligned between the glass plates: twisted nematic (TN) panel, vertical alignment (VA) panel, and in-plane switching (IPS) panel. The panel technology shapes its display characteristics and thus its usability. TN panels are the cheapest, fastest, and therefore also the most common LCD panels. IPS or patterned vertical alignment (PVA) panels are used for high-quality requirements, for example in graphics. For mobile displays such as tablets and smartphones, IPS panels are preferred due to their performance in terms of viewing angle, color shift, and pressure resistance for touch panels. In particular, the further developed fringing field switching (FFS) mode offers excellent performance, including a high transmittance at very low power consumption. [112, 121, 129, 233–236]

TN includes the term ‘nematic’, which describes a state or phase in which all the rod-shaped molecules of a liquid crystal screen are arranged in one direction. In this case, the LCs are brought between crossed polarizers and, when voltage is applied, align themselves with the electric field applied perpendicular to the glass surface. Here, the longitudinal field is used to align the twisted rod-shaped liquid crystal molecules. This mode has a simple structure with a high transmittance, and power consumption is also low. However, the viewing angle is limited. Currently, TN is mainly used in displays that do not require high image quality. The LCs in VA panels are initially aligned vertically in the de-energized state. After voltage is applied, the longitudinal electric field controls the LC tilt angle from vertical to the glass surface to horizontal to display different brightness levels. This enables a high contrast ratio and relatively fast response times. Associated technologies include multi-domain VA (MVA), patterned VA (PVA), and advanced super view (ASV). In both MVA and PVA technologies, the LCs of each pixel are divided into two to four sub-areas and controlled separately. This in turn ensures a comparatively high viewing angle of 160° and above. [21, 27, 112, 121, 125, 212, 234–237]

In IPS technology, the electrodes are arranged next to each other in one plane. This means they sit parallel to the screen surface. In the de-energized state, the liquid crystal molecules are homogeneous and aligned parallel to the optical axis of the polarizer. When voltage is applied to the electrodes, the electric field aligns the LCs parallel (in-plane) to the panel surface or polarization layer. As a result, the contrast is far less viewing angle dependent than with TN panels. However, the viewing angle dependency of the color display is only reduced with the improved S (Super) IPS and dual-domain IPS technology. Switching times were initially very long due to the weak fields, but current variants can definitely keep pace with fast TN panels. Current modifications of the IPS mode provide further improvements, while FFS mode provides a significant increase in transmittance and thus in luminous efficiency. In addition, FFS offers the best pressure resistance compared to all LCD modes and is therefore often used for mobile or touch displays. Both negative (n-FFS) and positive (p-FFS) dielectric anisotropic liquid crystal molecules are used. Studies show that p-FFS offer higher effective transmittance and significantly lower crosstalk than n-FFS due to a faster response time. [112, 123, 125, 129, 136, 137, 233, 238–243]

In the IPS-BPLC (blue phase liquid crystal) mode, polymer-stabilized blue phase liquid crystal molecules are used. These appear optically isotropic in a voltage-free state, resulting in a very good dark state. As soon as an electric field is applied, the induced birefringence lies along the direction of the electric field. Macroscopically, such an isotropic/anisotropic transition can be described by the extended Kerr effect. This LCD mode has several attractive features. For example, the response time of the BPLC is in the sub-millisecond range, and the viewing angle is very wide with negligible color shift. In addition, the simplicity of the required BLU as well as the large cell gap tolerance and touch insensitivity make it very attractive for a wide variety of display applications. [112, 127, 130, 131, 134, 135, 244–247]

In principle, backlighting enhanced with QDs can be used with all these panel technologies. This always enables a very large color gamut, but the actual optical efficiency varies greatly depending on the panel used. Different QD backlight configurations can be used to realize different panel sizes. Compared to MVA, IPS, and p-FFS, n-FFS has a much higher luminous efficiency. Considering the different configurations, QD enhanced n-FFS panels in particular offer attractive performance with high transmittance, wide viewing angle, and negligible color shift. In addition, an extremely wide color gamut can be displayed, which together results in excellent image quality, especially outdoors, making these panels particularly suitable for mobile devices. QDs also improve the luminous efficiency and color performance of the IPS-BPLC panel, which is suitable for both mobile displays and TV sets. They also offer advantages in terms of lifespan, power consumption, resolution density, color gamut, and cost. [28, 112]

	TN	MVA	IPS & FFS	IPS-BPLC
Contrast ratio	Fair	Excellent	Good	Good
Transmittance (relative to TN)	100 %	~ 70 %	IPS ~70% p-FFS ~ 80%	~ 80 %
Viewing angle	Fair	Good	Excellent	Excellent
Color shift	Fair	Good	Excellent	Excellent
Response time	~ 20 ms	~ 5 ms	~ 20 ms	< 1 ms
Touch intensitivity	No	No	Yes	Yes
Potential to color sequential	No	No	No	Yes

Table 5. Comparison of different LCD modes. [112]

3.4 Photo-enhanced quantum dot displays

In this further development of LCD technology, the background light is processed by QDs integrated between the BLU and the CFs to improve color reproduction. Three different technical configurations for the BLU of these photo-enhanced QD systems are used. QDs can be dispersed in a polymer matrix, processed with existing optical film technology, and conveniently integrated into the LCD backlight system. [27, 110, 112, 116, 120, 138, 139, 153, 168, 248–250]
For the ‘in chip’ configuration (QD Dot), the QDs are embedded in the LED chip. This design consumes the least amount of QD material and is cost effective. It is also fully compatible with the current BLU, resulting in a much simpler optical design. The previously used phosphors are simply replaced by QD mixtures as an energy downconversion layer within the LED package. However, due to the high flux and temperature of the LED junction (150°C), the lifespan, stability, and quantum efficiency of the QDs can be significantly affected. The necessary encapsulation against environmental influences is also problematic. For the ‘on chip’ configuration (QD Rail), a QD rail is mounted in a mixing cup and then clamped between the blue LED strip and the light guide plate (LGP). The mixing cup is typically made of a highly reflective plastic. Its function is to serve as a support for the QD bar while directing the emitted light toward the LGP. However, the optical processing is very demanding since each component

should be strictly aligned. This design prompts an inherent trade-off between efficiency and color uniformity, so various parameters must be carefully designed for high effectiveness. This refers to the concentration of scattering particles in the QD matrix, the distance between the QD rail and LGP, or the size of the QD rail, among others. Compared to the on chip design, the lifespan of the QD rail used is significantly improved due to the distance to the inserted blue LED. [25, 27, 37, 110, 112, 116, 120, 138, 139, 249]

The usual technical design today is 'on panel' in the form of a quantum dot enhancement film (QDEF), which was developed to replace an existing film in the BLU called the diffuser. Red- and green-emitting QDs are combined in a thin, optically clear film that emits white light when stimulated by blue light. The red and green spectral components are generated by stimulating the QDs, while the blue spectral component is generated directly from the background light by transmitting corresponding components. The red and green QDs are developed according to precise specifications that depend on the display design. To achieve the widest possible color gamut, they must be perfectly matched to the CFs selected by the display manufacturer. An appropriate QD structure must therefore be developed that delivers exactly the right wavelengths of red and green to maximize color space coverage. [25, 27, 37, 110–112, 116, 120, 138, 139, 232, 249, 251, 252]

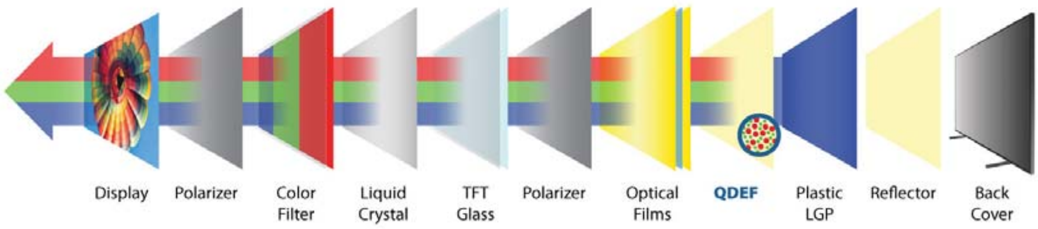


Figure 11. Schematic representation of the most frequently used QD display technology in current use and the integration of QDEFs. [37]

A typical approach is to use LEDs in the BLU that emit blue light at a wavelength of 450 nm. The QDEF contains QDs with a diameter of 1.5 nm that emit green light from a wavelength of 525 nm, while another group of QDs has a diameter of 3.0 nm and emits red light of wavelength 633 nm. With this formulation, more than 90% coverage of the BT.2020/Rec.2020 color space can be achieved. The QDEF is located above the LGP and is thus spatially decoupled from the LED heat source. The resulting operating temperature is therefore close to room temperature. Both the reliability and long-term stability of QDs are significantly improved as a result. To protect the QDs, two barrier layers are used in QDEFs, but they also increase production costs.

Therefore, an alternative approach is taken to combine the QDEF with the LGP. The glass of the LGP can serve as one barrier layer, whereas a second, low-cost encapsulation layer serves to protect the QDs during further processing. The optical stack is laminated to the TFT glass, encapsulating its components in glass. This reduces the cost of the QDEF. [25, 27, 37, 112, 116, 120, 138, 139, 249, 251]

This approach is called photo-enhanced because the QDs in this application are photopumped, and the color reproduction quality of an LCD is improved without fundamentally changing its design. This is because a QDEF is a simple, drop-in product that requires no production line retooling or process changes from display manufacturers. It can be easily integrated into current manufacturing operations, and the impact on device design is minimal. Manufacturers can relatively easily introduce this film into their processes, change their white LEDs to blue (the same LEDs but without phosphors), and begin producing LCD panels with accurate color, low power consumption, and improved brightness. [25, 27, 37, 110, 112, 120, 138, 139, 251]

3.5 Photo-emissive quantum dot color conversion displays

In a photo-emissive QD color conversion (QDCC) display, QDs replace the color filter arrangement. This means that the QDs are moved to another level of the display design. They are no longer integrated in front of the BLU but embedded on the front side in the liquid crystal cell itself, where they generate light directly at the level of the image reproduction. Currently, two different systems are in use: Quantum Dot Photo Resist (QDPR) and Quantum Dot Color Filter (QDCF). This approach is called photo-emissive because the QDs are photopumped and the design of the displays is very similar to that of typical emitting technologies such as OLED and plasma. [27, 37, 120, 138, 180, 251, 253–257]

The BLU only emits blue light. This can pass through the blue subpixel easily and without loss. Instead of an absorbing color filter, the green and red subpixels now each consist of a layer of green or red quantum dots and act as downconverters. They absorb energy from the blue light of the BLU and downconvert it to green or red light, respectively. They then emit precise colors of a defined wavelength, providing saturated primary colors. Since the light now no longer requires filtering, the light throughput of each subpixel is also significantly increased. This increased efficiency can be translated into higher brightness or cost savings by using fewer LEDs, or a combination of both. Viewing angle is also improved by this design: because the light from the red and green pixels originates at the front of the display (i.e., in front of the LC layer and the polarizers), it can also be seen in front of the display. The contrast is also improved because the light scattering that occurs in the color filter between the two polarization layers is eliminated. [27, 120, 138, 139, 153, 180, 251, 253, 255–257, 37]

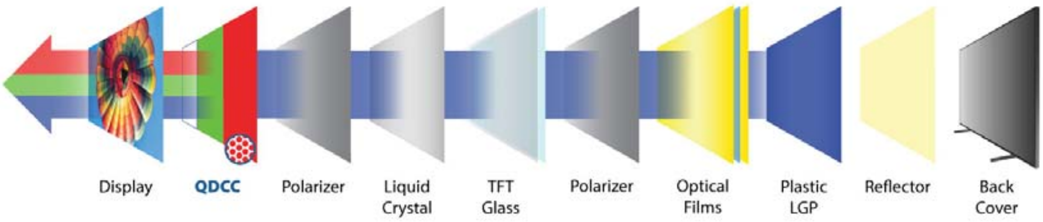


Figure 12. In a photo-emissive QD color conversion (QDCC) display, QDs replace the color filter arrangement. [37]

The production of such QDCC layers still poses certain challenges for manufacturers, while RoHS compliance also applies here. The requirements for the design and light management of the individual subpixels are high. In contrast to QDEF, where the QDs balance light conversion with light transmission, here they must absorb all the blue light from the LED. However, blue light leaking into the red or green subpixels would very quickly degrade color purity. To take full advantage of the efficiency benefits of this technology, it must be considered that QDs emit light isotropically, that is, uniformly in all directions. This means that part of the light from the red and green subpixels is emitted to the rear, (i.e., to the inside of the display). Solutions are needed here as to how to deal with this portion of light. The exposed position of the QDs on the front of the display must also be taken into account. Here, they could potentially be excited by incident ambient light. This means that blue ambient light in particular must be reduced even before it hits the CFs. Another issue is reducing and eliminating unintentional crosstalk between neighboring subpixels. [27, 37, 120, 139, 138, 153, 180, 251, 253, 255–257]

To be able to transfer the QDs to each subpixel, they are either integrated into a photoresist (subtractive process) or they must be printable using a method (additive process) that achieves the resolution and repeatability required for large-area displays. To use existing manufacturing processes, QDs must also be air processable and stable under the various thermal and chemical steps of the manufacturing process. Currently, the biggest challenge is the re-design of the LCD stack and the fabrication and integration of an internal polarizer for the LC cells. This is necessary because the QDs are placed in front of the LC and therefore the upper polarizer must be placed inside the cell and not as an optical film outside the cell. This is a requirement because QDs depolarize light. Subpixels require polarized light to function, and if QDs are used in the same position as current color filters, the LCD will not work. Other requirements for the QDCC layer are a maximum layer thickness of around 5 µm, a high external quantum efficiency (EQE), and a sufficient lifespan for a commercial product. This means component manufacturers must produce extremely thin films with very high QD concentrations so that they absorb nearly 100% of the blue light incident on each subpixel. In addition, structuring or printing must be implemented at the subpixel level, which imposes very different process requirements on QD/polymer composites. [27, 37, 111, 120, 122, 138, 139, 180, 251, 253, 255, 256]

Micro-LED displays are a very current and much discussed topic, as they offer outstanding features such as low power consumption, nanosecond response time, good sunlight readability, true black state, high dynamic range, and wide color gamut. These positive characteristics are due to the fact that micro-LED displays are an emitting display technology in which each individual red, green, and blue sub-pixel is an independently controllable light source. In this design, the display is built from a pure micro-LED array. Each pixel thus consists of a set of three micro-LEDs for each subpixel, which should be smaller than 10 x 10 µm. Different approaches are currently being taken to this setup. One is to incorporate one red, one green, and one blue micro-LED for each pixel, which are grown on different wafers and then transferred to the same TFT-based glass substrates. Careful alignment of each pixel is required. This design results in the need for different semiconductor processes and performance parameters for each color, as the light emission efficiency and degradation rate of RGB micro-LEDs are different due to the contrasting substrates for growing blue/green and red micro-LEDs. Another method is the monolithic integration of RGB micro-LEDs. These are grown together on a substrate and then transferred in batches to a backplane without the need to break them down into separate chips for each color. Neither of these manufacturing options is currently advanced enough to achieve good yields across all three colors over the millions of RGB pixels required. Pick and place manufacturing requires high precision in a huge number of operations where the smallest errors can result in dead pixels. For the monolithic approach, the challenge is to manufacture three different colors of LEDs on the same substrate, as different colors typically require different process conditions in manufacturing. [37, 111, 138, 142, 258–262]

Another approach relies on the use of monochromatic UV or blue micro-LEDs together with QDs as downconverters to produce the red and green subpixels. Very good results have already been obtained with specially designed CdSe-based QDs positioned on the top of a UV LED array. The process used is called aerosol jet technology. Atomizers and gas flow control are used here to spray the quantum dots in a confined space while maintaining uniform and controlled constrictions. A special full-color driver chip is used to drive each color of the micro-LEDs using pulse width modulation (PWM). Digital dimming is possible by adjusting the duty cycle of the current. High demands are made on the optical density of the applied QD layer: the QDs must have a high absorption coefficient to ensure complete color downconversion. To improve the light conversion efficiency of the QDs, a distributed Bragg reflector is used on the top surface, which leads to a poor contrast ratio, among other things. To achieve improvements here, another approach is to work with blue micro-LEDs, which first excite phosphors filled in funnel tubes to generate white light, which then excites the applied QDs, which is expected to increase the efficiency of light conversion. [37, 111, 142, 258–274]

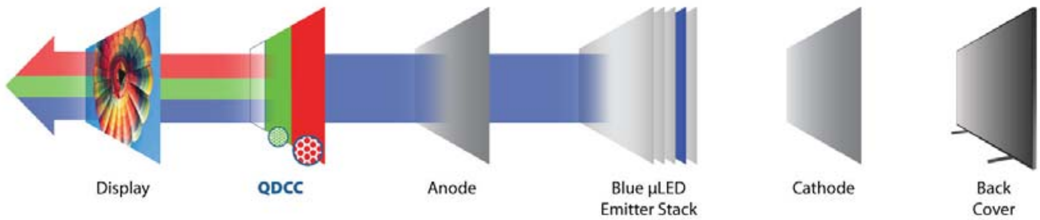


Figure 13. Micro-LED displays are an emitting display technology in which each individual red, green, and blue sub-pixel is an independently controllable light source. [37]

Various large companies and research institutions are currently working on this technology. However, the production and assembly of millions of super-sharp multicolor LED pixels is proving a major challenge. On the one hand, the fabrication of micro-LED chips sized < 10 x 10 µm remains a key technical challenge; the mass transfer of micro-LEDs from semiconductor wafers to glass substrates with high yield is also very problematic. The use of a wide variety of technologies is being investigated in response. These include polymer stamp transfer processes, flexo and semi-continuous printing processes, fluid transfer processes, or electromagnetic and electrostatic MEMS (micro-electro-mechanical-systems). [37, 111, 142, 258, 259, 261]

Photo-emissive QDs could help solve these problems. Manufacturing-wise, it is much easier to make a monochrome micro-LED display than an RGB micro-LED display. QDs could hence be applied in the form of an array, acting as the downconverters needed. That said, integrating the QDs in a precise and controlled manner remain a major technical challenge, especially as pixel sizes in next-generation micro-displays become even smaller. [37, 111, 142, 259, 261–274]

3.6 Electro-emissive quantum dot displays

Electro-emissive QD displays have the potential to become the next generation display technology. However, this technology is still at an early stage of development. It takes the name ‘electro-emissive’ because here the QDs serve as the emitter material, sandwiched between the anode and cathode, just like an OLED. Each subpixel would have either red, green, or blue QD material that is excited by electrons to emit photons at a desired wavelength. The subpixels are addressable and 'turned on' by stimulation with electrons, meaning they are powered directly. When a color is not needed, the dot that produces it is completely turned off, allowing no light to escape. As with photo-emitting QD displays, color filters are no longer required, nor are a BLU and LCM. As a result, the display would actually meet the requirements of a fully emitting display. [27, 37, 111, 116, 120, 138, 139, 180, 251, 257]

Manufacturing and technical processing also allow for an optimistic outlook. Since QDs are solution processed, advanced print manufacturing techniques can be used to produce these displays, making material use more efficient and improving yield and throughput. In addition, the promise of longer lifespan is more likely to become a reality through the use of inorganic materials such as QDs, as opposed to all organic materials, which have many intrinsic degradation pathways. Ultimately, this means a longer life for end devices without loss of performance. [27, 37, 111, 116, 120, 138, 139, 251, 257, 258]

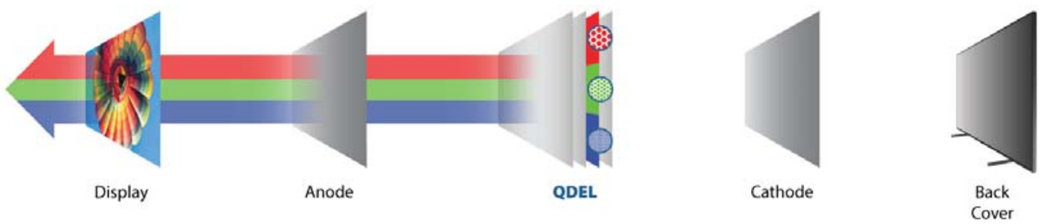


Figure 14. Electro-emissive indicates that the QDs serve as emitter material embedded between an anode and cathode, so that no backlighting is required. [37]

4 Colorimetric experiments

This research examines how QDs change the color rendering capabilities of LCDs, focusing on the visual perception of the spectrum that these nanoparticles produce in interaction with the backlight. In addition, new wide gamut display technologies and QD-enhanced LCDs make the question of observer metamerism more relevant than ever. Therefore, it is necessary to address this issue specifically and to develop a deeper understanding of the color vision of individual observers.

4.1 Organization and structure

To address the question posed, a research design with colorimetric experiments was developed and a suitable research environment was created. The technical setup consists of four test displays from various manufacturers, four current display calibration devices, a spectrometer for color and luminance measurement, and a computer with defined software applications for digital control of the various devices.

The colorimetric experiments are carried out in three discrete successive steps:

1) Performance benchmarking of the selected display calibration devices.
2) Performance benchmarking of the test displays
3) Color matching experiments with individual observers

First, colorimetric calibration and profiling of the test displays used are performed. This is an essential part of experimental methods in image processing and therefore of enormous importance. Calibration is performed using a display calibration device to establish a fixed defined condition for stable predictable color representation. Typical device characteristics that influence the stability of the color representation and thus also the characteristic color response, such as required warm-up time, must be taken into account. The aim of this definition is to ensure reproducible color representation for any further use of the display.

Since the quality of the calibration and the ICC profiles generated in the process are largely responsible for the quality of the color representation, a performance comparison of the four display calibration devices is first carried out. Four current measuring devices, which are widely used in the media industry in particular, are compared, followed by a detailed analysis of the results obtained. Based on this data, a decision is then made as to which measuring device will actually be used for the calibration and profiling of the selected displays as part of the planned studies to achieve the best possible color representation quality in the subsequent measurements and color matching experiments.

In the next step, performance benchmarking is conducted for all the displays used. The goal here is to test the performance and stability of the available displays and to establish comparability. For this purpose, the maximum luminance, the displayable color gamut, and the uniformity of the displays are measured, among other indicators. To be able to perform a qualified analysis, the measurements to be made are conducted over a defined period and repeated several times. Given that not only the performance but also the stability of the color reproduction over a longer period of use is to be evaluated, the measurements are conducted in defined time windows. Analysis of the results is carried out after completion of the defined test period, thus enabling an evaluation of the color representation properties and overall stability of the displays used.

For the concluding color matching experiments, colored test patches are used based on the colorimetric patches of the X-Rite ColorChecker. Here, the task for the observer is to match a color shown on the display in a defined size as closely as possible in an inserted mask. Ideally, no color difference should be visible or measurable after color matching. The tests are conducted with two different test geometries. First, the selected colors are displayed individually and one after the other. As soon as the test person is satisfied with the result of the color matching to be performed, their response is saved and the next color is then displayed. Once this task has been processed, the entire ColorChecker target is shown on the display and can then be edited. No order of the color patches to be edited is specified at this point, but the test person can proceed according to his or her own preferences. The digital values are saved for all colors, and then the spectral color stimulus emitted by the display is measured and also saved. [275, 276]

Analysis and evaluation of the results is conducted as standard in a reference system with a fixed observer. The data obtained thus provide insight into the relationship between individual visual color perception and real reproduced colorimetric values. By assigning the results obtained to the displays used, a qualitative statement can be made on the influence of the display technology used on the color perception of the observer. [19]

4.2 Methodology

The selected methods for implementing these tests are described in the following subsections. ASTM (American Society for Testing and Materials) Standard Practice E2214 serves as the basis for the implementation. Here, the following basic principles of the scientific method and measurement technique are central: [277, 278]

1) Repeatability—The focus is on how well an instrument can repeat identical measurements under the same conditions and within a certain defined period. This means that repeatability indicates the deviation that can occur due to a measuring instrument used in the examinations.
2) Reproducibility—Reproducibility indicates the deviation caused by one or more changes in the measurement conditions. It is important to document these changes.
3) Inter-instrument and inter-model reproducibility—These are special cases of repeatability in which instruments of the same design (inter-instrument) or different designs (inter-model) are compared.
4) Accuracy—Accuracy is used to indicate how accurately an instrument can meet the accepted value for a given sample. Accepted values are usually provided by a standards organization.

4.3 Research environment and technical setup

To conduct the planned research, a suitable research environment was created in the form of a newly designed laboratory at Offenburg University, which will also be integrated into the media technology teaching framework.

The technical setup consists of four test displays from different manufacturers, four display calibration devices, a spectrometer for color and luminance measurements, and two identical desktop PCs with specified software applications for digitally controlling the various devices. The selected test displays are current consumer devices from various well-known manufacturers. All four devices are QD-enhanced LCDs, but they use different BLUs and also differ in the QD materials used. Two devices with a screen diagonal of 32" and two devices with a screen diagonal of 27" are used. All test displays offer the option of making hardware-based calibration settings via the on-screen display (OSD). Two desktop PCs with identical configurations are used to control the displays and conduct the examinations. The operating system used is Windows 10 Enterprise; the graphics interface is an NVIDIA GeForce GTX 1060. The displays are controlled with 10-bit via a DisplayPort connection in the available version 1.4. The latest drivers are installed for operation. Four display calibration devices are used within the scope of the research. These are compact plug-in devices designed for functionality that are connected to the PC via USB and automatically recognized. They do not require an external power supply. A Konica Minolta CS-200 photoradiometer is used to verify the results obtained.

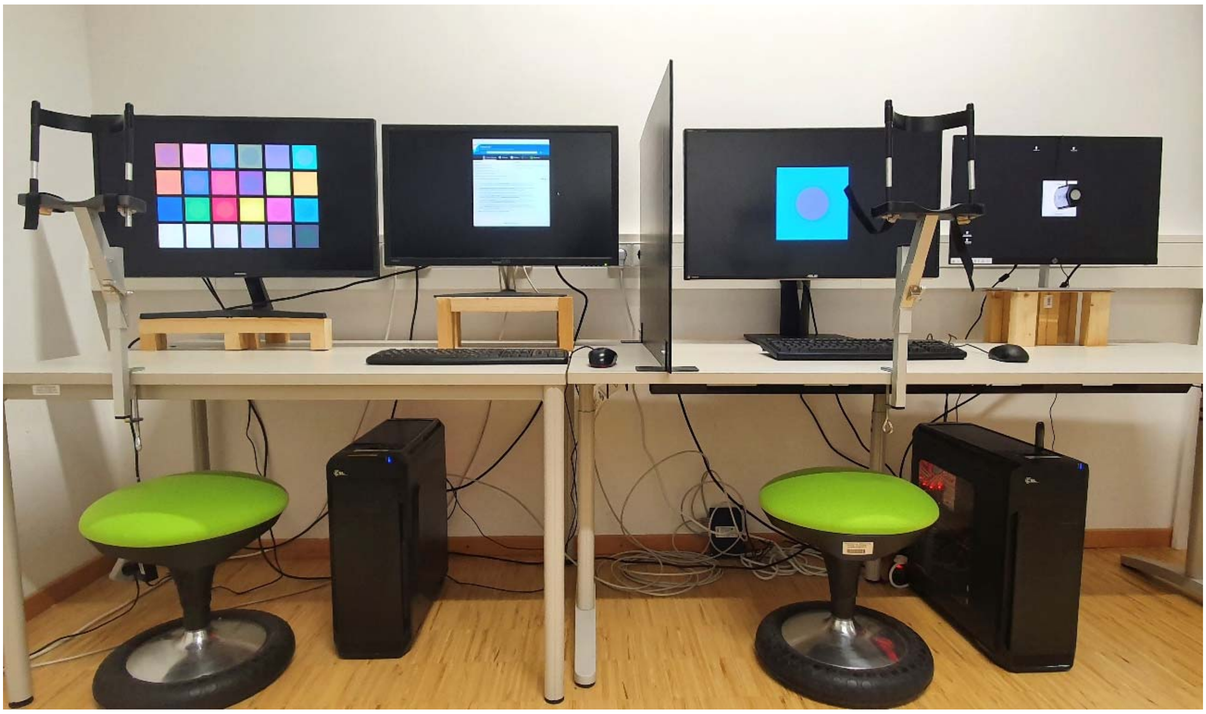


Figure 15. The experiments are conducted at two workstations separated from each other by a protective screen.

4.3.1 Defined measurement conditions

To ensure the repeatability of the measurements taken and thus the reproducibility of the results, the following basic measurement conditions are defined. These apply to all measurements and investigations to be carried out within the scope of this work.

Ambient light	0 Lux
Normal temperature	23°C
Preheating time displays	60 min
Preheating time measuring instruments	60 min

4.3.2 Displays

Four test displays are used for the examinations. The selected displays are current consumer devices from various well-known manufacturers. Two devices with a screen diagonal of 32" and two devices with a screen diagonal of 27" are used. All devices are QD-enhanced LCDs; that is, QDs are used to optimize the LCD BLUs to achieve a large color gamut. The technology used and the structure of the BLU differ from manufacturer to manufacturer, as does the performance achieved. The different technical specifications are shown in Table 6.

	Display 1	Display 2	Display 3	Display 4
Size class / Diagonal	32 in / 81.28 cm	27 in / 68.58 cm	31.5 in / 80.1 cm	27 in / 68.58 cm
Display area (w / h)	70.85 x 39.85 cm	59.67 x 33.57 cm	69.84 x 39.29 cm	59.67 x 33.56 cm
Aspect ratio	16:9	16:9	16:9	16:9
Panel type / bit depth	IPS / 10-bit	IPS / 10-bit	MVA / 10-bit	IPS PLS / 8-bit
Backlight	W-LED	W-LED	W-LED	W-LED
Colors	1073741824 / 30-bit	1073741824 / 30-bit	1073741824 / 30-bit	16777216 / 24-bit
Resolution (max.)	3840 x 2160 px	2560 x 1440 px	3840 x 2160 px	2560 x 1440 px
Pixel pitch	0.185 mm	0.233 mm	0.182 mm	0.233 mm
Pixel density	137 ppi / 54 ppcm	109 ppi / 42 ppcm	139 ppi / 54 ppcm	109 ppi / 42 ppcm
Brightness (max.)	350 cd/m²	250 cd/m²	270 cd/m²	400 cd/m²
Gamut coverage	AdobeRGB: 99,5 % sRGB: 100% DCI-P3: 90 % NTSC: n.s.	Adobe RGB: 116% sRGB: 156% DCI-P3: n.s. NTSC: 110%	AdobeRGB: 88% sRGB: 100% DCI-P3: 95% NTSC: n.s.	Adobe RGB: n.s. sRGB: n.s. DCI-P3: 93 % NTSC: n.s.
Contrast	Static: 1000:1 Dynamic: 100000000:1	Static: 1000:1 Dynamic: 100000000:1	Static: 3000:1 Dynamic: 100000000:1	Static: 1000:1 Dynamic: 5000000:1
Viewing angle (H/V)	178° / 178°	178° / 178°	178° / 178°	178° / 178°
Response time	4 min (grey to grey)	5 min (grey to grey)	4 min (grey to grey)	5 min (grey to grey)
Coating	Non-glare	Non-glare	Non-glare	Non-glare
Frequency (digital)	Horizontal: 30–135 kHz Vertical: 24–76 Hz	Horizontal: 31–89 kHz Vertical: 56–75 Hz	Horizontal: 30–135 kHz Vertical: 24–75 Hz	Horizontal: 30–100 kHz Vertical: 46–75 Hz
Power On	< 138.3 W	33 W	< 59 W	34 W
Power Saving	< 1.4 W	0.45 W	< 0.5 W	0.38 W
Power Off	< 0.5 W	0.27 W	< 0.3 W	0.25 W
Voltage	100–240 V / 50–60 Hz	100–240 V / 50–60 Hz	100–240 V / 50–60 Hz	100–240 V / 50–60 Hz

Table 6. Overview and comparison of the device-specific properties of the used displays (manufacturer information). [279–286]

4.3.3 Display calibration devices

Here, too, four devices are used. All four are compact colorimeters designed for functionality. Colorimeters are three-range measuring instruments: the colorimetric detection of light is performed by contact measurement using three or more sensors, which are adapted to the spectral value curves of the standard observer (spectral sensitivity of the L, M, and S receptors) with inserted color filters and thus directly supply colorimetric values (e.g., CIE XYZ). As a result, the spectrally weighted evaluation of the radiation can be integrally performed according to the three standard spectral value curves for the short, medium, and long wavelength ranges.

These values are then transferred to the instrument software for color profile calculation. Colorimeters have no integrated electronics for converting the color information obtained, nor do they have a measured value display. [17]

Manufacturers use modern filter and optical systems in their devices, which should enable a high measuring speed and guarantee repeatable measurements. The software required in each case is designed for user-friendliness. Detailed wizard-based process control enables simple calibration with optimized presets. However, manual control of all settings relevant to the process is usually also possible via an advanced mode. The actual calibration process and the creation of the display profiles are automated. The technical specifications of the devices used are shown in Table 7.

	Display calibration device 1	Display calibration device 2	Display calibration device 3	Display calibration device 4
Device type	Colorimeter	Colorimeter	Colorimeter	Colorimeter
All-in-one design	✓	✓	✓	✓
Measurement sensors	3 Channel	3 Channel	7 Channel	Lenticular Color Engine
Software	i1 Profiler V 3.1.1	Color Munki Display V1.1.5	Spyder5Elite V. 5.2	SpyderXElite 5.4
User interface	Wizard – Basic Mode; User Driven – Advanced mode, direct access workflow	Wizard – Easy and Advanced Modes	Wizard, Interactive help, Expert Console, suite of expert features	Wizard, Interactive help, Expert Console, suite of expert features
Supported display technologies	CCFL, White LED, RGB-LED, Wide Gamut, OLED	CCFL, White LED, RGB-LED, Wide Gamut	CCFL, White LED, RGB-LED, Wide Gamut	CCFL, White LED, RGB-LED, Wide Gamut, OLED
Windows	Windows 7 32-bit/64-bit and above	Windows 7 32-bit/64-bit and above	Windows 7 32-bit/64-bit and above	Windows 7 32-bit/64-bit and above
Macintosh	Mac OS X 10.7 and above	Mac OS X 10.7 and above	Mac OS X 10.7 and above	Mac OS X 10.10 and above
Display resolution	1024 x 768 pixels or higher	1024 x 768 pixels or higher	1024 x 768 pixels or higher	1024 x 768 pixels or higher
Graphics card	16-bit (24-bit recommended)	16-bit (24-bit recommended)	16-bit (24-bit recommended)	16-bit (24-bit recommended)
Memory	2 GB RAM	512 MB RAM (2 GB recommended)	1 GB RAM	1 GB RAM
Disposable hard disk space	2 GB (depending on components installed)	500 MB (depending on components installed)	500 MB	500 MB
Connectivity	Powered USB port	Powered USB port	Powered USB port	Powered USB port

Table 7. Overview and comparison of the device-specific properties of the used display calibration devices (manufacturer information). [287, 288]

4.3.4 Desktop PCs

Two desktop PCs with identical configurations are used to control the displays and perform the tests. The operating system used is Windows 10 Enterprise. The graphics interface is an

NVIDIA GeForce GTX 1060 with three DisplayPort ports. Controlling the displays with 10-bit is made possible through a connection via DisplayPort in the available version 1.4. The corresponding technical specifications are shown in Table 8.

Type	Desktop PC	**Operating system**	Windows 10 Enterprise
RAM	8 GB	Version	1709
System type	64-bit operating system, x64-based processor	System build	16299.1747
Processor	AMD Ryzen 7 2700X	**Graphics card**	GeForce GTX 1060
# of CPU cores	8	GPU engine family	NVIDIA
# of threads	16	NVIDIA CUDA cores	1280
Base clock	3.2 GHz	Base clock	1506 MHz
Max boost clock	Up to 4.1 GHz	Boost clock	1708 MHz
Total L1 cache	768 KB	Memory speed	8 Gb/s
Total L2 cache	4 MB	Processor boost	1708 MHz
Total L3 cache	16 MB	Standard memory config	6 GB GDDR5
Package	AM4	Memory interface width	192-bit
PCI Express version	PCIe 3.0 x 16	Memory bandwidth	192 GB/s
System memory type	DDR4	Interface	PCI Express x16 3.0
System memory specification	Up to 2933 MHz	Max digital resolution	7680 x 4320 @ 60 Hz
Memory channels	2	Standard display connectors	DP 1.4, HDMI2.0, DVI
Power consumption	65 W	Graphics card power	120 W
Max temperature	85°C	Max CPU temperature	94°C

Table 8. Overview of the technical specifications of the used desktop PCs, categorized by type, operating system, processor, and graphics card (manufacturer information).[289, 290]

4.3.5 Luminance and color meter Konica Minolta CS-200

The Konica Minolta CS-200 is a luminance and chromaticity measurement instrument that can be used to measure light sources of all types, especially modern displays such as LCDs and OLEDs.

The CS-200 has 40 sensors and performs calculations using spectral sensitivity characteristics (normal observer sensitivity curves) like those of the human eye. This method yields tristimulus values (XYZ for red, green, and blue) with a high degree of accuracy. Measurements can be made over a very wide luminance range: from 0.01 cd/m² up to high values of 20,000,000 cd/m² (with a measurement angle of 0.1°). The measurement angle can be switched depending on the target object to be measured. High-precision luminance and chromaticity measurements are possible, comparable to those of a spectroradiometer. The technical specifications of the CS-200 are shown in Table 9. [291, 292]

Konica Minolta CS-200	
Measurement range	0.01–200,000 cd/m^2 (measuring angle 1°) 0.01–5,000,000 cd/m^2 (measuring angle 0.2°) 0.01–20,000,000 cd/m^2 (measuring angle 0.1°)
Accuracy #1 (measuring angle 1°, standard illuminant A, temperature 23°C ± 2°C, relative humidity max. 65%)	150 cd/m^2 (illuminant A): L_v ± 2 % ± 1Digit; xy ± 0.002 0.01–0.5 cd/m^2 (illuminant A): L_v ± 0.02 cd/m^2 ± 1Digit 0.5–1 cd/m^2 (illuminant A): L_v ± 0.02 cd/m^2 ± 1Digit ; xy ± 0.007 1–10 cd/m^2 (illuminant A): L_v ± 2% ± 1Digit ; xy ± 0.004 10–200,000 cd/m^2 (illuminant A): L_v ± 2 % ± 1Digit; xy ±0.003 5.000 cd/m^2 (illuminant A): color filter (R, G, B); xy ± 0,006
Repeatability #2 (measuring angle 1°, standard illuminant A)	0.01–1 cd/m^2 (illuminant A): L_v ± 0.01 cd/m^2 ± 1Digit; (2σ/AUTO) 1–2 cd/m^2 (illuminant A): L_v ± 0.5 % ± 1Digit; xy 0.002 (2σ/AUTO) 2–4 cd/m^2 (illuminant A): L_v ± 0.5 % ± 1Digit; xy 0.001 (2σ/AUTO) 4–8 cd/m^2 (illuminant A): L_v ± 0.5 % ± 1Digit; xy 0.0005 (2σ/AUTO) 8–200,000 cd/m^2 (illuminant A): L_v ±0.1% ± 1Digit; xy 0.0004 (2σ/AUTO)
Measurement time	Automatic setting between 1 s and 60 s (AUTO) Automatic setting between 1 s and 3 s (LTD. AUTO) 0.5s/measurement (Super-FAST) 1s/measurement (FAST) 3s/measurement (SLOW) 12s/measurement (Super-SLOW)
Measurement method	Spectral method, Grating + linear photo diode array
Measuring angle	1° / 0.2° / 0.1° (switchable)
Minimum measuring area	0.5 mm 0.1 mm (close-up lens)
Minimum measuring distance	296 mm (distance from front edge of metal lens barrel)
Observer	2°/10°
Gamut	L_v x y, L_v u' v', L_v T Δuv, XYZ, dominant wavelength
Measurement synchronization setting range	Vertical synchronization frequency: 40–200Hz
Interface	USB 1.1
Power source	AC adapter or 4 AA-Size batteries
Battery life	Approx. 3 h (continuous measurement / fast mode / AA-size alkaline cells)
Size	95 mm (W) × 127 mm (H) × 330 mm (L)
Weight	1.8 kg (without battery)
Operating temperature/humidity range	0°C to 40°C, relative humidity 85% or less (at 35°C with no condensation)
Storage temperature /humidity range	0°C to 45°C, relative humidity 85% or less (at 35°C with no condensation)

#1 Lv = 0.01–10 cd/m2, SLOW, average of 30 measurements; Lv = 10 cd/m2 and above, SLOW, average of 10 measurements.

#2 At 0.2° measuring angle, the amount of received light is approx. 1/25 of that for 1°.
Therefore, the repeatability becomes the same as that for 1° with 25 times lower luminance.
At 0.1° measuring angle, the amount of received light is approx. 1/100 of that for 1°.
Therefore, the repeatability becomes the same as that for 1° with 100 times lower luminance.

Table 9. Overview of the technical specifications of the Konica Minolta CS-200 (manufacturer information).[291, 292]

4.4 Color representation on displays

Display and visualization devices are the most important interfaces between digital information and human perception, where information is transmitted by light. Expectations of the quality and accuracy of color representation are correspondingly high and influenced by the technical specifications of the different displays and depend on their performance. This problem requires the use of open color management systems to ensure the best possible consistency of color reproduction of identical digital content on such different displays. If such systems are not used, the same colors, understood as an ordered vector of the three color components R, G, and B, will be reproduced differently with respect to the color perception of an observer. [17, 19, 293]

Color management is the process of providing a standardized selected relationship between colors by converting the color information of an input device to the color information of a target device. The objective is to achieve the highest possible color consistency, which also means that the results are predictable and reproducible. However, it should be noted from the outset that colorimetrically identical color reproduction is not always possible since this is strongly device-dependent. Today, the ICC color management system is typically used. This open standardized framework was published in 1993 and allows cross-platform use. It is implemented at the operating system level and thus enables all necessary color information to be made available to all application programs in the same way. This information is provided in the form of a standardized color profile (ICC profile). This is a standardized data set with precisely defined specifications that contains all the displayable colors (gamut) of the input or output device described. Based on this color information, different devices can be compared with each other, and a color space transformation can be performed. For this purpose, a valence-metrically defined device-independent color space (CIE XYZ, CIE L*a*b*) is used as a profile connection space (PCS). With a color computer, the color matching module (CMM), the color space transformations, and color space adjustments from a source profile to a target profile are carried out in a standardized manner using mathematical algorithms. This standardized concept, developed by the ICC, is recognized by the International Organization for Standardization (ISO) as standard ISO 15076-1. [17, 19, 293–295]

Looking at the process as a whole, it can be seen that the color profiles are of particular importance. Indeed, they are the most important component of a functioning color management workflow, as only they can provide the necessary information for the color space transformations to be carried out. Color profiles are stored in the ICC workflow with the file extensions .icc or .icm. ICC profiles are divided into the following profile classes: input (scnr), display (mntr), output (prtr), device link (link), color space conversion (spac), named color (nmcl), and abstract (abst). The first three profile classes are also referred to as device profiles. ICC profiles are binary data stored in a standardized structure. They contain defined metadata as well as the required color information. The header contains general information about the profile in text form. The profile's table of contents (tag table definition) lists the tags, which are standardized identifiers of the color information. The actual color information is then contained in the form of conversion tables, matrices, tone reproduction curves, and so on, as tagged element data. [17, 19, 293–295]

Basically, device profiles are divided into matrix color profiles and look-up table (LUT) profiles. Matrix profiles contain 3 × 3 matrices and typically three curve definitions, known as tone reproduction curves (TRCs), which are used for the transformation of device-dependent RGB color data into a device-independent media-neutral color space. Normalized XYZ standard color values are assigned to the three RGB primary colors and stored in the tags of the color profile, so that the RGB to XYZ color space transformation can be performed with a 3 x 3 matrix calculation. The additionally stored TRCs are used to calculate the intermediate values (i.e., to adapt the brightness information to the output). LUT profiles, meanwhile, contain a significantly higher number of color values. The higher the number of saved color values, the fewer intermediate values have to be calculated, which benefits the accuracy of the profile. LUT profiles are mostly used when it comes to describing the non-linear color behavior of devices, as the actual gamut can be better described with the help of the data tables used. This is defined in the form of a color mapping table between permanently assigned RGB/CMYK values and measured XYZ or CIE Lab color values. [17, 19, 293–295]

Device profiles always contain a definition of the white point. In addition, ICC profiles can also contain calibration data of the profiled device. This is common especially for profiles of displays. Calibration data are values based on settings made on the hardware side to achieve definable target values. The created profile hence describes not the original, but the calibrated state of the display based on the settings made. The calibration made with the help of the display menu (or better, the OSD) is an additional process and does not replace the use of the actual ICC profile. [16, 17]

The current specification of the ICC for color profiles is version 4.3.0.0. However, many profiles in version 2 are still in use today. For example, the color profiles for the standard color gamuts sRGB IEC 61966-21 and AdobeRGB (1998) are created in version 2, while the much newer color profile for the standard color gamut DCI-P3 is a version 4 profile. Unfortunately, compatibility issues persist for version 4 profiles with various applications. [16, 295]

4.4.1 Display color spaces

A color space is a subset of the color range that can be perceived and identified by the human eye (e.g., the visible light spectrum). The term *display gamut* is used to describe the most important visual property of a display. It defines the number of colors that can be represented, that is, the native color gamut that can be generated and represented by the selected display. Device color spaces vary from display to display and depend on the technology used. Due to the continuous technical development from cathode ray tube (CRT) displays to the current OLEDs and QD-enhanced LCDs, the representable color gamuts have also evolved and increased significantly. [1, 19, 20, 33]

Depending on the technology used, a given display can only represent the colors that lie within a triangle defined by the three primary colors. These are always based on red, green, and blue and follow the spectral color sensitivity of the human visual system. The larger this triangle (i.e., the gamut of the display), the more colors can be represented. However, some display manufacturers also work with more than three primary colors. In such cases, the color gamut is represented by a polygon. However, the use of a fourth primary color does not serve to increase the displayable gamut here, only to increase brightness and efficiency. [1, 19, 20, 33]

4.4.1.1 Standard color space

The goal of all image-based applications is to reproduce the colors in the image content as accurately as possible. This is only possible if a well-defined color space is specified. Since the native color gamut of the multitude of available displays can vary significantly, so-called standard color spaces were defined very early in their technological development. These are essentially based on the technical possibilities offered by current displays available on the market. However, the needs of users and the applications they use, which often only require a certain suitable color palette, have also been incorporated into the standardization. [1, 19, 20, 33]

In principle, an infinite number of color spaces can be specified by defining the primary valences, the white point, and the gradation curve (gamma). The primary valences define the color triangle of colors that can be represented at low brightness levels. The white point defines the intensity ratio of colors to be represented with three identical color components (e.g., RGB = 255) and thus indirectly also the ratio of maximum red to maximum green to maximum blue. With the aid of a color management system, the native color gamut of the display used is adapted to the specifications of these standard color spaces. As technology has evolved, the displays, the standards, and the content have evolved together over time. A brief description of the most important color spaces is presented below. [1, 19, 20, 33]

Figure 16. Mapping of the standard color gamuts sRGB, AdobeRGB, DCI-P3, and Rec.2020 in the CIExy chromaticity diagram.

4.4.1.2 NTSC and SMPTE-C

The NTSC color space was developed by the National Television Standards Committee of the United States of America and is the first official standard for displays, introduced in 1953 at the beginning of US color television broadcasting. Its primary valences are derived from the emission spectra of the color phosphors used at that time:

- red: europium-doped yttrium vanadate (Eu^{+} YVO_4)
- green: silver-doped zinc cadmium sulfide (Ag^{+} ZnS/CdS)
- blue: zinc sulfide (ZnS).

The color range that can be represented according to the NTSC standard is like that of the AdobeRGB (1998) standard, but the red and blue values differ slightly. If the sRGB color gamut is used for comparison, it covers about 72% of the NTSC color gamut. [276, 296]

In reality, the NTSC color gamut was never used in the commercial production of color TVs: the primary colors chosen to define the color gamut were too saturated and could not be implemented by the consumer TVs of the time. Therefore, the classic NTSC color space was replaced in 1979 by the Advanced Television Committee (ATC) with the SMPTE-C color gamut of the Society of Motion Picture and Television Engineers (SMPTE). The SMPTE-C standard is based on phosphor colors used by the Conrac Corporation, which were actually used in early color televisions. It is not significantly different from today's sRGB/Rec.709 color space, which is around 13% larger than SMPTE-C. Many later gamut standards were based on SMPTE-C, including, for example, Rec.601 for digital standard definition TV. [276, 296]

4.4.1.3 sRGB/Rec.709

The sRGB color space was defined by the International Electrotechnical Commission (IEC) in 1998. The color scheme chosen is identical to the International Telecommunication Union (ITU) High Definition TV (HDTV) standard ITU-R BT.709-3, also known as Rec.709. The major difference between these two color spaces is that sRGB is an absolute color gamut, specifying only the chromaticity of the primary colors and white point, along with a gamma correction curve. In contrast, Rec.709 specifies far more aspects of image representation, including pixel numbers and frame rates. For many years, sRGB/Rec.709 has been the dual standard used for the production of most consumer digital content. sRGB has become the standard for Windows environments and is suggested primarily for applications where embedding a color profile is not practical in terms of file size or for compatibility purposes. Since all elements in a system are sRGB compliant, no time is lost in conversion. A favorite target is the Internet. Moreover, an extended color encoding standard has been defined for sRGB that supports multiple levels of precision while remaining compatible with the base standard. [276, 296, 297]

As mentioned above, the sRGB/Rec.709 gamut is 13% larger than the SMPTE-C color gamut. However, looking at the CIExy chromaticity diagram, it is noticeable that the color range that can be represented with the help of sRGB is rather small. In particular, the range of highly saturated colors is excluded. Indeed, representation in the exact CIE 1976 uniform color space shows how relatively small the green color area is, accounting for only 10% of the total color space. By contrast, the newer color gamuts AdobeRGB (1998), DCI-P3, and BT.2020/Rec.2020 all have considerably enlarged green color areas. [276, 296, 297]

4.4.1.4 AdobeRGB (1998)

AdobeRGB was defined by Adobe Systems in 1998. Initially, this color space was used under the designation SMPTE-240M for Photoshop users. After the SMPTE-240M standard committee decided on a smaller representable color range, the name AdobeRGB was established. This color space is very close to the original NTSC color space; it also uses the identical blue and red primary colors as sRGB but includes a much more saturated green primary color. It is therefore 17% larger than the sRGB/Rec.709 color space. [276, 296, 298]

The main aim of AdobeRGB was to adapt the CMYK color gamuts of color printers and printing presses to the RGB working color gamut of displays and other output media. This is why this standard is particularly important in the graphics industry. Today, for example, all high-end digital cameras allow the use of the AdobeRGB color space. Additionally, an ever-growing number of displays can now represent the largest range of the AdobeRGB color space, which is also used in all professional image processing applications. [276, 296, 298]

4.4.1.5 DCI-P3

The DCI-P3 standard color space was defined by the Digital Cinema Initiatives and published as the SMPTE EG 432-1 and SMPTE RP 431-2 standards. DCI-P3 is used primarily by the film industry in digital cinema, but it is also increasingly being used in the home due to the growing use of wide gamut displays. The home cinema sector and 4K ultra high definition (UHD) television play an important role here, where DCI-P3 is seen as an intermediate step before the implementation of the significantly larger BT.2020/Rec.2020. In DCI-P3, the blue primary color is identical to sRGB and AdobeRGB (1998), while the red primary color is light of the same color with a wavelength of 615 nm. However, the color gamut is 26% larger than that of the sRGB/Rec.709 color space: the saturated red range and especially the green color range have been expanded (by 52% compared to sRGB/Rec.709). In comparison with AdobeRGB (1998), the color space is similar but slightly shifted towards red. [296, 299, 300]

4.4.1.6 BT.2020/Rec.2020

The BT.2020/Rec.2020 standard is the next generation of standard color spaces. Published as the ITU-R recommendation BT.2020, it is impressively large and very wide, and the color saturation is extremely high. The basic RGB colors correspond to monochromatic light sources in the CIE standard color system of 1931 with the precisely defined wavelengths of 630 nm for red, 532 nm for green, and 467 nm for blue. BT.2020/Rec.2020 not only fully covers the sRGB and Adobe RGB (1998) color spaces but also all but a negligible proportion of up to around 0.02% of the DCI-P3 color gamut and the NTSC 1953 color gamut. In turn, the color gamut is 72% larger than sRGB/Rec.709 and 37% larger than DCI-P3, making it possible to represent almost all available content in true color. Although only minimal current content and very few displays on the market come close to covering the included color gamut, considering the progress that QD-enhanced LCDs and OLED displays are making, it is safe to assume that BT.2020/Rec.2020 will become an important new standard gamut within the next few years. [140, 296, 301, 302]

sRGB

	Primaries			White point
	R	G	B	(D65)
x	0.6400	0.3000	0.1500	0.3127
y	0.3300	0.6000	0.0600	0.3290
z	0.0300	0.1000	0.7900	0.3583

AdobeRGB (1998)

	Primaries			White point
	R	G	B	(D65)
x	0.6400	0.2100	0.1500	0.3127
y	0.3300	0.7100	0.0600	0.3290
z	0.0300	0.0800	0.7900	0.3583

DCI-P3

	Primaries			White point
	R	G	B	(D65)
x	0.6800	0.2650	0.1500	0.3127
y	0.3200	0.6900	0.0600	0.3290
z	0.0000	0.0450	0.7900	0.3583

Rec.2020

	Primaries			White point
	R	G	B	(D65)
x	0.7079	0.1700	0.1314	0.3127
y	0.2920	0.7970	0.0459	0.3290
z	0.0000	0.0330	0.8230	0.3583

Table 10. Colorimetric specifications of the most important RGB display color spaces. [297, 298, 300, 302]

4.4.2 Calibration and profiling of a display

The aim of calibrating and profiling a display is to ensure standardized accuracy, reproducibility, and repeatability of color representation on that display. It also allows colors to be communicated in such a way that they can be adapted for other different output devices. To achieve this desired color consistency, calibration and profiling are used in combination. In the first step, the display is calibrated to a desired display behavior; in the second, a color profile is generated that is used to communicate with other output devices. [303]

Depending on the intended use of the display, various approaches are available:

- Calibration to a working color space
- Perceptual linear calibration
- Soft proofing calibration
- User-defined (or no) calibration.

In the context of this study, the approach of calibrating to a working color gamut was selected since this allows the displays to be precisely adjusted to a desired display behavior with a high level of color accuracy.

Calibration and profiling should always be performed in the typical operating environment for daily use. After a preheating period of at least 30 min, the process can be started; this is the time typically required for a display to achieve the necessary stability in color representation. The entire process is controlled by user software. Different colorimetric working gamuts, such as sRGB, Adobe RGB (1998), DCI P3, or Rec.2020, are available. Basically, the selected standard color gamut should be covered completely or at least approximately by the native technical color gamut of the display. Possible differences between the target calibration and the actual reproduction are adepted in the display profile. [303]

The initial calibration here is crucial. Step 1 is the calibration of the display and involves a measurement and subsequent adjustment of the display behavior. The basic parameters of *gamma*, *white point*, and *brightness* are set and checked by the user. This adjustment is hardware-related via the OSD of the display. In principle, this could also be done via the output of the graphics card, but this should be avoided. In image processing, the term gamma generally refers to the brightness of the mid-tones (gray tones). A gamma value of 2.2 is typically used as the standard for displays. The Windows operating system also works with this standard gamma value. The color temperature is set via the white point setting. This refers to the color of light, which is the standard index used to control the color balance of the display. The color temperature is a standard for measuring the white tone and is specified as an absolute temperature in the unit K (Kelvin). The most common standard is D65 (6,500 K), which should roughly correspond to directly incident daylight. D65 also defines the white point of sRGB and AdobeRGB. The general brightness of the display is controlled via the luminance. A standard value often used in image processing for averagely bright rooms is 120 cd/m².

In step 2, the display is profiled with the help of the measuring device used. On the display to be calibrated, the application shows the area on which the calibration device is to be positioned for conducting the measurement process. The common measuring devices are usually equipped with a counterweight, which enables them to be placed in the specified position and to lie flat there. The measuring device used should be placed precisely and, above all, quietly, since any minor movement can influence the measurement result. The response of the calibrated display is then measured and described by an ICC profile created in this process. Once this process is complete, the created profile can be saved with a defined name. Optionally and for simplicity, the calibration can be saved in the profile, but both must still be used together to obtain correct results. Based on this profile, a re-calibration or check of the calibration can now be done, making these processes significantly less time-consuming.

It is possible to show an overview of the profile, which allows comparison of the display gamut with other profiles or with various standard color gamuts. An analysis of the display quality can also be performed: the software makes it possible to perform various tests for evaluating the color gamut, tonal value representation, brightness and contrast, white point, screen homogeneity, and color accuracy, and to output them as a report.

4.5 Performance benchmarking of display calibration devices

The quality of color representation on a display greatly depends on the colorimetric calibration process and thus on the quality of the measuring devices used and the profiles generated in the process. For this reason, a comparison is made of the performance of the four display calibration devices used. These four measuring instruments are all-in-one devices designed for simple functionality and operation. The actual measurement process is automated, and device-related manufacturer software is typically used to conduct the calibration. An assistant guides the user through the entire process. However, it is also possible to work with open-source, manufacturer-independent applications. All applications distinguish between initial calibration, re-calibration, and a check of the existing calibration for the sake of good usability.

In this study, a performance and measurement accuracy check of the devices used is conducted, as is an evaluation of the cross-device consistency of the colorimetric results obtained on a test display selected as a reference. This examination of the quality of the process is used to select the device that will be used for the important basic calibration of the displays used in the subsequent studies. The colorimetric performance of these devices is crucial for high-quality and reproducible image representation. To obtain the data required for the intended performance benchmarking of the measuring devices used, the necessary measurements are carried out in two sub-steps. The aim of sub-step 1 is to define a reference display; for sub-step 2, it is to conduct the performance benchmarking of the measuring devices with the use of this reference display. To obtain the data, profiles are first created using all the measuring devices; all required data are determined on the basis of these display profiles.

Thus, the measuring device benchmarking begins with the selection of a reference display. The premise here is to select the display with the best coverage of the AdobeRGB standard color space. To verify the available manufacturer specifications, all four available displays are first calibrated with each of the four measurement devices, and device profiles are created. The open-source software DisplayCal is used as the application tool for this process. The profiles created are based on the basic settings of the AdobeRGB color gspace: luminosity = 160 cd/m², color temperature = 6,500 K, gamma = 2.2. Subsequently, all measurements and profiles are compared with each other, and the reference display is selected on the basis of the available results; this is then re-calibrated with all four display measuring devices. The profiles created are checked via repeated control measurements with a defined test form, and the results obtained are analyzed in terms of intra- and inter-variability. This allows a statement to be made about the reproducibility and repeatability as well as the stability of the measurements performed. Finally, comparative measurements of different defined test colors are performed with the spectrometer Konica Minolta CS-200 so that a statement can be made on the accuracy of the measurement results of the calibration equipment used in comparison to a high-quality spectrometer.

4.5.1 User software for controlling the display calibration devices

The display calibration devices require appropriate user software to perform the calibration and profiling. The quality of the generated display profile—and thus also the quality of the colors reproduced and displayed—depend greatly on the capabilities and settings of the calibration software. These settings can vary depending on the display and screen calibration device used. Individual, customized settings are crucial here when seeking to achieve the most accurate results possible in terms of stable repeatable color quality. To ensure device comparability and the quality of the measurements performed, the manufacturer-independent application software DisplayCal version 3.8.9.3 is used in this thesis. To justify this decision, the application programs provided for the individual display calibration devices and the associated process are considered below, before DisplayCal and its diverse possibilities are discussed in more detail.

4.5.1.1 Device-related manufacturer software

The measuring devices used are all-in-one devices from two manufacturers. In the user software provided, an assistant guides the user through the entire process, and the actual measurement process is automated. Essentially, all programs offer the user a similar introduction to the process. First, a choice is offered between display and projector as the device to be calibrated. Once "Display" has been selected, the device to be calibrated must be specified. Here, the required inputs vary somewhat, but the outcome is always the selected device and the type of backlight used. The calibration can now be performed using a basic or advanced mode. Whereas the basic mode starts an automated process with default presets for color temperature, luminance, and gamma, the advanced mode permits individual settings according to the user's own preferences. Once these inputs have been made, the measurement process can be started. With the help of a rear sensor, the ambient light can also be determined here, whereupon the software once again makes a more precise recommendation. However, this setting is not necessary and can be deselected.

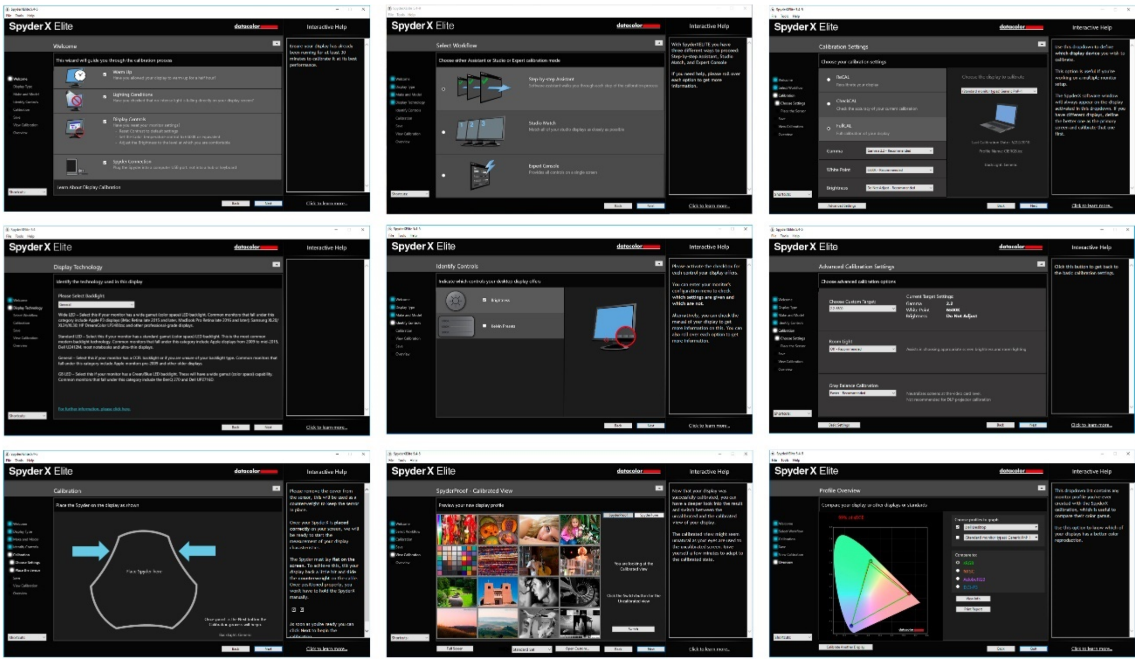


Figure 17. Example of menu navigation through device-related manufacturer software.

After the settings have been selected, the sensor must now be placed on the screen in the position specified by the application. If the screen can be tilted slightly, this will help the user to position the calibration device flat on the display. The measuring devices are equipped with a counterweight that is placed on the back of the screen. Once in place, the measurement process can be started. A progress bar at the bottom of the display shows the progress or duration of the measurements, while on the display itself one can observe how different colors are displayed and measured. First, the presets for color temperature and luminance entered by the user are checked with the help of various measuring fields. A request is then made to manually readjust the display's settings on the hardware side until the specified target values are reached within an accepted tolerance value and the software acknowledges this. Subsequently, the measurement is performed on the basis of a test form defined by the manufacturer, which contains a defined number of color patches to be measured. After the measurement process is complete, the created display profile can be named and saved. The profile is automatically stored in the data folder provided by the operating system and in the graphics card memory as

a color profile. The result of the calibration can then be evaluated on the basis of various test images. In addition, a before/after switch can be used in all software applications.
Significantly, the number of measuring fields used for profiling differs greatly across devices. This has a strong influence on the accuracy and thus the quality of the profile created. The application for measuring device 2 uses 40 color patches for calibration, whereas measuring devices 3 and 4 contain 74 color patches, based on the primary colors red, green, and blue, as well as neutral gray gradients from white to black. However, the most setting options are offered by the user software for measuring device 1, where it is possible to select between various standard test shapes, consisting of 119, 211, or 461 measuring fields. It is also possible to make different individual profile settings for chromatic adaptation, ICC profile version, and profile type.

4.5.1.2 DisplayCAL

DisplayCAL is a proven and versatile ICC-compatible display calibration and profiling solution based on the open-source color management system ArgyllCMS. This free application software may be used, redistributed, and/or modified under the terms of the GNU general public license as provided in version 3 of the license, or any later version as published by the Free Software Foundation. DisplayCAL has a very large active user community and is maintained and developed by developer Florian Höch. The software is written in Python and uses various third-party packages and Python extensions for Windows to provide Windows-specific functionality. This enables the use of this application in the built research setup. [304]
To use DisplayCAL, the color management software ArgyllCMS version 1.0 (or later) must be installed. This application is already integrated in the installation file. ArgyllCMS is an ICC-compatible color management system that is available open-source. Specifically, it is a collection of source code that assembles into a set of command line tools licensed under a GNU Affero general public license. ArgyllCMS also includes a general-purpose library for accessing the ICC V2 profile format (icclib) and another for characterization data for input and output in the CGATS (Committee for Graphic Arts Technologies Standards) file format. All these software packages are copyrighted by their respective authors. [304, 305]
The DisplayCAL software offers a variety of options for display calibration and profiling. A large number of measurement devices from different manufacturers are supported. All devices selected during the research are supported by DisplayCAL. Before the measurement devices can be used, any necessary generic colorimeter corrections that are part of the manufacturers' associated measurement value packages should be imported, as the measuring devices require

special adaptation to the different display technologies. This is usually done on the hardware side by the manufacturer of the measuring device; for example, the spectral sensitivities of the installed filters may be included in the hardware.

DisplayCal offers predefined settings that can be changed and adapted according to the set requirements. For this, the software interface is divided into different tabs that permit the input of individual settings in each case. In Tab 1 (Display & Instrument), settings are made for the hardware used; the display to be profiled and the measuring device used are selected here. With the help of an available control panel, it is also possible to carry out automatic device recognition, where the detected measuring device is displayed directly and a selection is not necessary. Directly connected displays appear in a drop-down list, and the inserted device can be selected. This is followed by the selection of the measuring mode.

In general, the two basic measuring modes are "LCD" and "Refresh". Some measuring devices support different measuring modes for different types of display devices or offer additional measuring modes where one mode is coupled with a predefined colorimeter correction. These are displayed for selection in a drop-down list. Further settings are possible, such as drift compensation for white and black levels or the display update delay. In addition, it is possible to select a colorimeter correction for a specific display, which can improve the accuracy of a colorimeter for a particular display type. These can be imported either from the manufacturer's own software or from an online database containing data sets provided by the user community.

In Tab 2 (Calibration), it is possible to enter individual settings and target values for the calibration process. For this purpose, "Setting the interactive display" must be activated. It is possible to set the colorimetric observer (and/or the color matching function). The default setting is the 2° observer according to CIE 1931. The target white point can be entered in Kelvin or as chromaticity coordinates, the target brightness of white in cd/m². The native black level is usually used as the black level to maximize the contrast ratio. The TRC (gamma) is usually an exponential curve (output = input gamma) and is set to 2.2 by default. However, four other predefined curves can also be used. The sRGB gamut TRC, which includes an exponential curve with a straight segment at the dark end, approximates an overall gamma response of 2.2. The L* curve corresponds to the TRC of the CIE L*a*b* color space for visual perception. In addition, the TRCs of the Rec.709 and SMPTE 240M standards are available for selection.

Tab 3 (Profiling) enables settings that affect the actual profile. Here, influence is taken on the quality and the level of detail of the resulting profile. As described earlier, a distinction is generally made between two types of profiles: LUT-based and matrix-based. For table-based LUT profiles, the size of the main look-up table and thus the quality of the resulting profile are determined. For matrix-based profiles, the level of detail of the curves per channel and the fitting effort are specified. When selecting a LUT-based profile type, advanced gamut mapping options become available to create perceptual and/or saturation tables within the profile in addition to the colorimetric tables that are always created by default. Advanced gamut mapping options are also available. A wide variety of predefined test charts are already available for profiling. At the same time, it is also possible to create individual user-defined test charts with the help of a test chart editor.

After all options have been selected, the actual calibration and profiling process can be started. The main window of DisplayCal is then hidden and does not open again until the measurements are completed. Instead, the display now shows a measuring field on which the inserted measuring device is placed. If "Interactive Display Adjustment" is activated, the user is first prompted to perform a manual hardware calibration of the display after starting the measurement process. Various options are displayed in a window that opens automatically, allowing the current settings to be brought closer to the target values entered. A prerequisite for this, however, is that the display used also allows the necessary settings to be changed on the hardware side. The OSD should allow control for brightness, RGB gain and color temperature, or other white point settings. During the continuous measurement of the displayed test field, the white point is first adjusted so that the displayed ΔE to the specified target white point is as small as possible, and then the brightness of the display is adjusted to the target. Ideally, this should only be done with the brightness adjustment of the backlight, and the contrast should be left at the factory default setting. Once the required adjustments have been made, the next step is to perform the profiling automatically based on the selected test chart.

After the process is completed, the created profile and all corresponding information are stored in the designated directory. A window displays the gamut coverage compared to the standard color gamuts sRGB, AdobeRGB, and DCI-P3. The created profile may also be optionally installed immediately, while detailed information up to a 3D representation of the gamut for the created profile can be called up. In addition, it is possible to perform various verification measurements in Tab 4 (Verification).

4.5.1.3 Summary

It must be stated here that the available application programs from the device manufacturers do not allow a qualitative comparison of the measurement results. The measurement geometries used are too disparate, and too little is known about the transformations used to create the profiles. DisplayCal, on the other hand, offers comprehensive options for specifically adapting the calibration and profiling process to individual requirements, opening up possibilities that the manufacturer applications do not offer (or only to a much lesser extent). These are necessary to ensure the highest possible quality of the profiles created in relation to the requirements set. Equally, the use of the same user software for all measuring devices—while taking importable device-related manufacturer information into account—allows the best possible comparison of the results obtained.

4.5.2 Definition of the reference display

To define a reference display for the second part of the examinations based on solid data, all four available displays are first calibrated and profiled with all four display measuring devices. The displays are connected to the graphics card via DisplayPort 1.4. The measuring devices are connected to the PC via USB 2.0 and are then immediately ready for use. Four profiles are created for each display and then checked using a defined test form. The data obtained is then analyzed; based on this analysis, a reference display is selected for further testing in step 2. The quality of the profiles to be created is based on the settings made in DisplayCAL.

To start the process, DisplayCAL is opened. Display and measuring devices are normally detected automatically, although it is still useful to have the software perform device detection. This should always be done when the measuring device is changed after a completed profiling. The user interface of the main window of the software application then provides the aforementioned four tabs for adjusting the necessary settings. In the following section, the settings selected for the measurements are presented and explained.

In Tab 1 (Display & Instrument), the available displays are shown in a drop-down list and can be selected by mouse click. The connected measuring device is automatically shown after device recognition has been performed. The plain name is used for this purpose. In the "Mode" drop-down list, correction data sets suitable for the connected display can now be selected. These are based on data imported from the device-related manufacturer software of the measuring device used and refer to different display technologies. Since these can differ from device to device depending on the manufacturer, the setting "LCD generic" is selected in the pursuit of the desired comparability. Thus, an identical standard correction data set from DisplayCAL is used for all measuring devices. The option for "White luminance drift compensation" is not activated because the displays have already reached the necessary preheating time at the beginning of the measurements. However, "Black balance drift compensation" is activated since the colorimeters used are not temperature stabilized. Different correction data sets are offered in the "Correction" drop-down list. After various tests, the correction data set "LCD PFS Fluorescent WLED Family" was selected, which is recommended for the selected displays and covers the spectral properties of the displays very well.

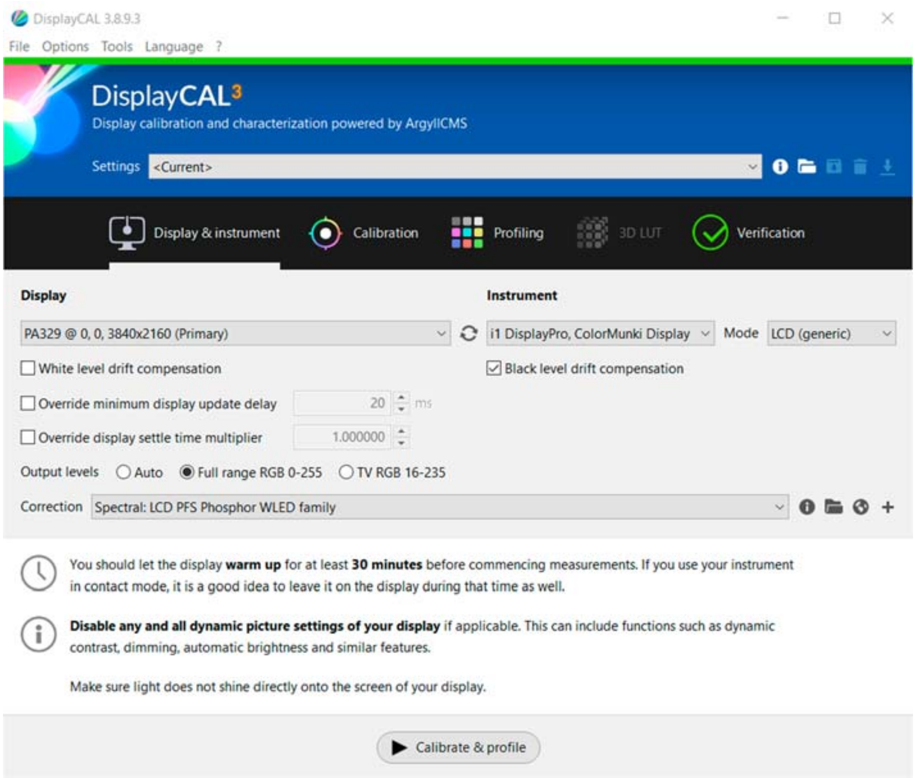


Figure 18. DisplayCal user interface—activated Tab 1 (Display & Instrument) and settings made for the measurements. [304]

The selected target settings are now made in Tab 2 (Calibration). For this purpose, the "Interactive settings" option is selected, which allows the input of individual desired target values. The CIE 1931 2° standard observer is used as the measurement geometry. Based on the basic settings of the AdobeRGB color space, the target values for the white point (6,500 K) and the white luminance (160 cd/m²) are then entered. For LCD displays, the black luminance depends on the white luminance setting. Since LCDs are not perfectly impervious to light, increasing the backlight always brightens the black areas as well. Generally, the black on the display should be as dark as possible; therefore, "as measured" (i.e., taking over the measured black value) is selected. The tone value curve (gamma) is a measure of the brightness distribution in the image. For AdobeRGB, the base value is 2.2. The black output offset remains at the default settings of 100%. This accounts for the fact that real displays, unlike target rendering curves, do not have zero black response. The black point correction is set to automatic, and no adjustment to the ambient brightness is made. This reflects an attempt to optimize the visual brightness of the grayscale under non-optimal ambient lighting conditions.

The "Calibration speed" slider is not used because it is of the size of the test shape yet to be selected.

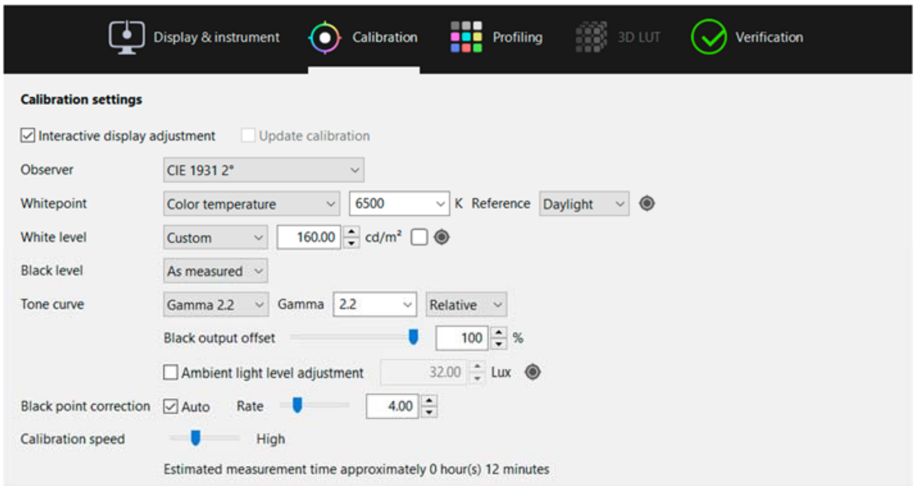


Figure 19. DisplayCal user interface—activated Tab 2 (Calibration) and settings made for the measurements.[304]

In Tab 3 (Profiling), the profile settings are selected. The profile type (matrix profiles or LUT profiles) determines the internal structure of the profile. By default, DisplayCAL uses "XYZ LUT + Matrix", a combination format that combines both profile types. The LUT profile is the basic profile type, while the matrix profile serves as fallback. Since depth compensation is mainly useful for matrix profiles, it is not activated here. The profile quality determines how detailed the correction curves of the profile become: "Large" (with 745 measuring fields) is selected as the test form to ensure high quality. In turn, the profile name describes the display and the measuring device, the target color gamut, and the version (e.g., Display1_MD1_Adobe_160_V1).

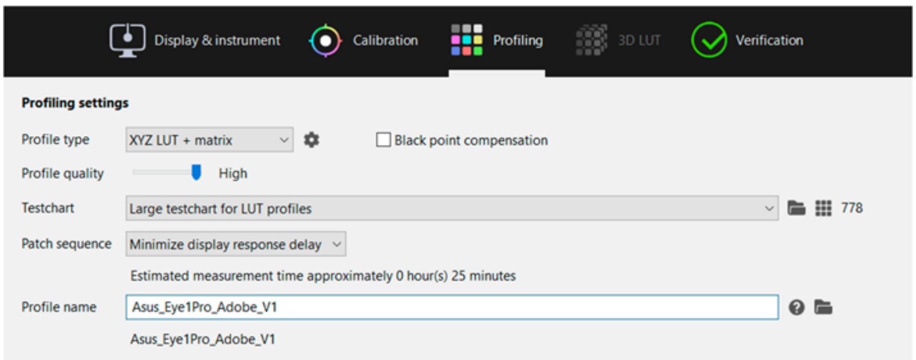


Figure 20. DisplayCal user interface—activated Tab 3 (Profiling) and settings made for the measurements.[304]

After these settings have been entered, the calibration and profiling process can be conducted. "Calibrate and profile" starts the measurements to be performed; the main interface window is closed and a measurement window appears on the display, onto which the colorimeter is placed. This is positioned in the center of the display area and can be resized. The positioning is maintained here since the performance of a display typically decreases toward the edges. Additionally, the measuring field is not enlarged to avoid irradiation.

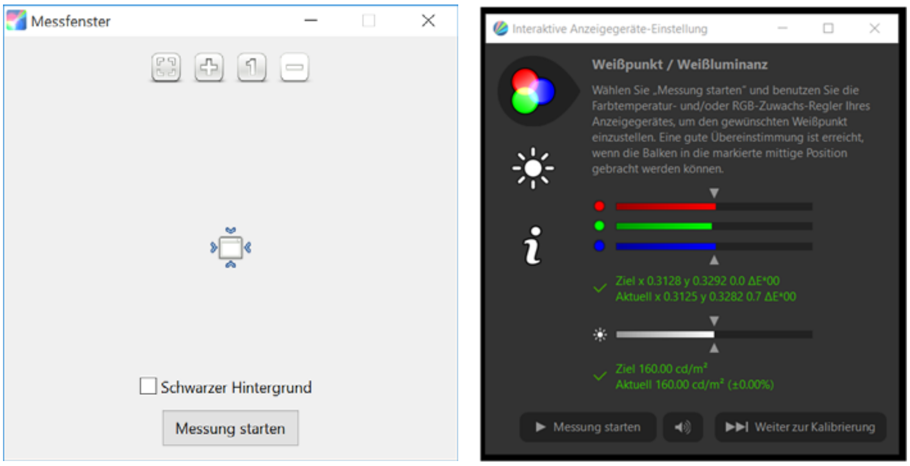


Figure 21. Measurement field for positioning the display calibration device (left) and active window for updating measurement value indication during hardware calibration.[304]

When the process is started, a short sequence of preparatory measurements begins. Five test patches are measured one after the other in the colors white (RGB = 256), black (RGB = 0), and the primary colors red (RGB = 256, 0, 0), green (RGB = 0, 256, 0), and blue (RGB = 0, 0, 256). Another display window then opens to show the result of the measurements in comparison to the entered target values for the white point and the white luminance. The white point is shown as a target and an actual value with the current color difference, ΔE. In addition, the values of the three primary color channels (red, green, and blue) are set in relation to the target value in the form of bars. The same applies to the value of the white luminance. The measurement remains active, and a measurement field of the color white (RGB = 256) is now displayed and continues to be measured at short intervals. The shown values are updated accordingly.

Calibration on the hardware side is now performed via the OSD. It should be noted here that the degree of control via the OSD varies greatly from display to display. By changing the values for brightness and those of the individual color channels in the RGB gain, the aim is to reflect the specified target values as accurately as possible. The results of these changes are updated in the shown window on the basis of the current measuring process. As soon as an accepted tolerance as defined via the software is reached, the displayed values are shown in green. At this point, the measurement is very sensitive and reacts to even the smallest changes in the settings. As a result, a 100% achievement of the target values is very difficult to realize, but a very good approximation within a small color distance ΔE is possible.

As soon as the best possible setting match is reached, the measurement can be stopped. Once all hardware settings (brightness, contrast, color gain) are documented, the profiling can be continued. The necessary measurements and the generation of the resulting profile are automated. The time required for the selected test format is around 30–90 min, depending on the measuring device used.

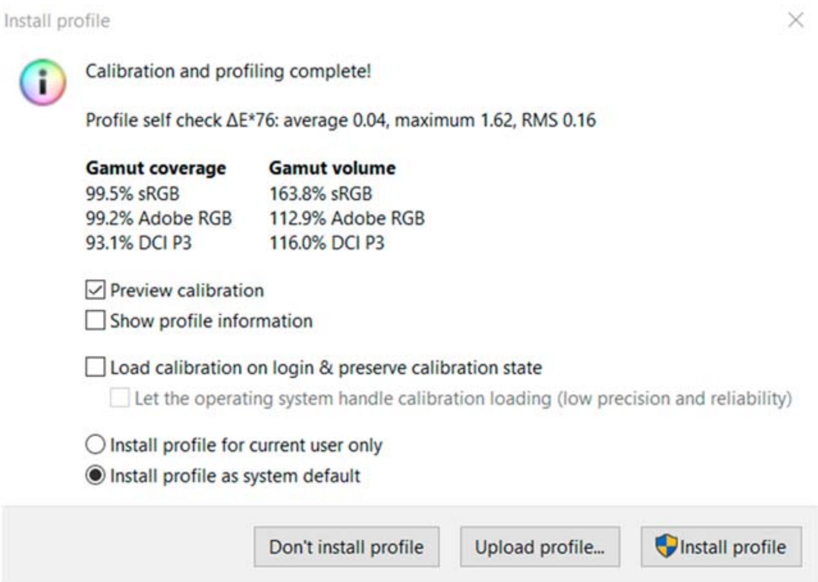


Figure 22. Display for completion of profiling process with specification of gamut coverage and gamut volume, as well as selection of further use of the created profile.[304]

After completion of the process, the results of the measurement process are shown in a new window in the form of values for color gamut coverage or color gamut volume in relation to the standard color gamuts sRGB, AdobeRGB, and DCI-P3. A brief check of the profile information and properties is performed. However, the profile itself is not installed or activated. All data is automatically saved and can be activated at any time.

4.5.2.1 Measurement results

This section presents the measurements conducted in the course of this study in a summarized, condensed form. The complete results are given in Annex 1.

To first define a reference display for conducting the performance benchmark of the available display calibration devices, the four test displays were calibrated and profiled with all four measurement devices (MD). The display with the best coverage of the standard color gamut AdobeRGB is selected as the reference display. The hardware-based calibration of the displays reset to the basic hardware settings, which was conducted first, led to the results shown in Table 11. This calibration was only performed via the settings for the brightness as well as the gain of the RGB color channels. These hardware settings resulted in the basic white point and display brightness values shown in Table 12, which were used for subsequent profiling of the displays.

	Display 1				Display 2				Display 3				Display 4			
	Lum	R	G	B	Lum	R	G	B	Lum	R	G	B	Lum	R	G	B
MD 1	61	61	58	57	62	98	87	86	45	193	190	197	47	47	46	38
MD 2	59	65	60	66	64	96	86	87	44	194	191	195	45	47	46	38
MD 3	58	65	60	67	69	97	87	91	47	194	184	205	49	49	42	43
MD 4	59	62	56	58	74	96	82	83	42	198	185	197	41	47	46	39

Table 11. Settings made for hardware calibration of the displays via OSD.

		White Point			Luminance	
		x	y	ΔE^*_{00}	Lum	Δ%
Display 1	MD 1	0.3124	0.3288	0.2	159.67	-0.21
	MD 2	0.3137	0.3298	0.5	160.66	0.41
	MD 3	0.3125	0.3288	0.2	159.29	-0.44
	MD 4	0.3118	0.3290	0.7	161.15	0.72
Display 2	MD 1	0.3125	0.3293	0.2	160.15	0.09
	MD 2	0.3124	0.3282	0.6	159.83	-0.11
	MD 3	0.3123	0.3292	0.4	159.96	-0.02
	MD 4	0.3128	0.3285	0.6	160.08	0.05
Display 3	MD 1	0.3124	0.3289	0.2	160.49	0.31
	MD 2	0.3130	0.3298	0.4	159.64	-0.23
	MD 3	0.3132	0.3294	0.2	160.49	0.31
	MD 4	0.3123	0.3287	0.3	159.50	-0.31
Display 4	MD 1	0.3134	0.3294	0.4	159.55	-0.28
	MD 2	0.3127	0.3282	0.8	160.25	0.16
	MD 3	0.3116	0.3280	0.7	159.72	-0.18
	MD 4	0.3124	0.3294	0.5	159.64	-0.23

Table 12. Resulting basic values for white point and display luminance.

The profiling process produces the following results in terms of the displays' representable gamuts based on the measured tristimulus values of the primary colors red, green, and blue. This serves as the basis for calculating the coverage of the standard color spaces sRGB, AdobeRGB (1998), and DCI-P3, as well as the comparison of the total volume of displayable colors.

		Red			Green			Blue		
		X	Y	Z	X	Y	Z	X	Y	Z
Display 1	MD 1	56.85	25.37	0.69	18.25	68.31	6.45	19.75	8.32	102.15
	MD 2	57.93	25.41	0.72	18.23	66.25	6.38	19.75	8.34	102.33
	MD 3	59.23	26.56	0.00	16.00	64.96	5.04	19.65	8.47	104.04
	MD 4	57.82	27.06	1.16	17.20	64.43	6.06	20.07	8.51	102.20
Display 2	MD 1	51.53	23.57	0.88	18.25	68.31	6,45	20,35	5,50	103.28
	MD 2	50.39	23.03	0.87	23.82	71.32	4.38	20.64	5.65	103.45
	MD 3	51.19	23.40	0.00	22.20	71.11	2.71	21.73	5.49	106.06
	MD 4	52.61	25.69	1.24	22.10	68.93	4.17	20.24	5.38	103.60
Display 3	MD 1	56.85	25.37	0.69	37.8	72.7	12.66	18.15	7.27	93.71
	MD 2	48.98	22.22	0.77	26.78	71.31	6.79	19.1	6.46	100.73
	MD 3	52.62	23.71	0.31	24.51	69.74	5.55	19.16	6.45	102.16
	MD 4	49.14	22.3	0.74	26.44	71.26	6.6	19.52	6.43	101.87
Display 4	MD 1	39.06	20.03	1.84	18.25	68.31	6.45	19.75	8.32	102.15
	MD 2	39.05	20.02	1.88	37.84	72.64	12.66	18.36	7.33	94.71
	MD 3	41.60	21.65	1.65	35.51	71.00	11.59	17.66	7.36	94.98
	MD 4	40.08	21.40	2.16	36.62	71.36	12.40	18.22	7.24	93.38

Table 13. Overview of the measured tristimulus values X, Y, Z of the primary colors R, G, B.

		Measurement Device 1		Measurement Device 2		Measurement Device 3		Measurement Device 4	
		Gamut		Gamut		Gamut		Gamut	
		Coverage	Volume	Coverage	Volume	Coverage	Volume	Coverage	Volume
Display 1	sRGB	99.5 %	164.2 %	99.5 %	164.2 %	99.2 %	179.5 %	99.3 %	160.9 %
	AdobeRGB	99.2 %	113.1 %	99.2 %	113.1 %	99.2 %	123.7 %	99.0 %	110.9 %
	DCI-P3	93.3 %	116.3 %	93.2 %	116.3 %	96.8 %	127.1 %	91.8 %	114.0 %
Display 2	sRGB	99.4 %	168.5 %	99.2 %	166.3 %	99.0 %	181.5 %	99.3 %	164.9 %
	AdobeRGB	92.2 %	116.1 %	90.7 %	114.6 %	92.3 %	125.1 %	93.2 %	113.6 %
	DCI-P3	96.5 %	119.4 %	96.3 %	117.8 %	98.2 %	128.6 %	95.2 %	116.8 %
Display 3	sRGB	99.9%	143.9%	99.9%	144.5%	99.9%	154.4%	99.8 %	144.3%
	AdobeRGB	87.8%	99.2%	88.1%	99.6%	91.6%	106.4%	87.7%	99.4%
	DCI-P3	92.4%	102.0%	92.5%	102.0%	95.7%	109.4%	92.3%	102.2%
Display 4	sRGB	95.1 %	95.2 %	95.0 %	95.3 %	97.0 %	100.4 %	93.3 %	93.4 %
	AdobeRGB	65.5 %	65.6%	65.5 %	65.6 %	69.1 %	69.1 %	64.3%	64.3 %
	DCI-P3	67.5 %	67.5 %	67.5 %	67.5 %	71.0 %	71.1 %	66.1 %	66.1 %

Table 14. Results of profiling the test displays in relation to coverage and volume of the standard color spaces sRGB, AdobeRGB and DCI-P3.

4.5.2.2 Definition of the reference display

The display with the largest coverage of the standard color space AdobeRGB is selected as the reference display for the performance benchmarking of the available display calibration devices. The presented measurement results speak a clear language. With a coverage of the AdobeRGB color space of 99.2%, Test Display 1 clearly shows the best outcome. This value was achieved in the measurements with three of the four selected display calibration devices.

Only the result with measuring device 4 deviates slightly, with a determined value of 99%. Such conformity cannot be seen with the other three test displays used.

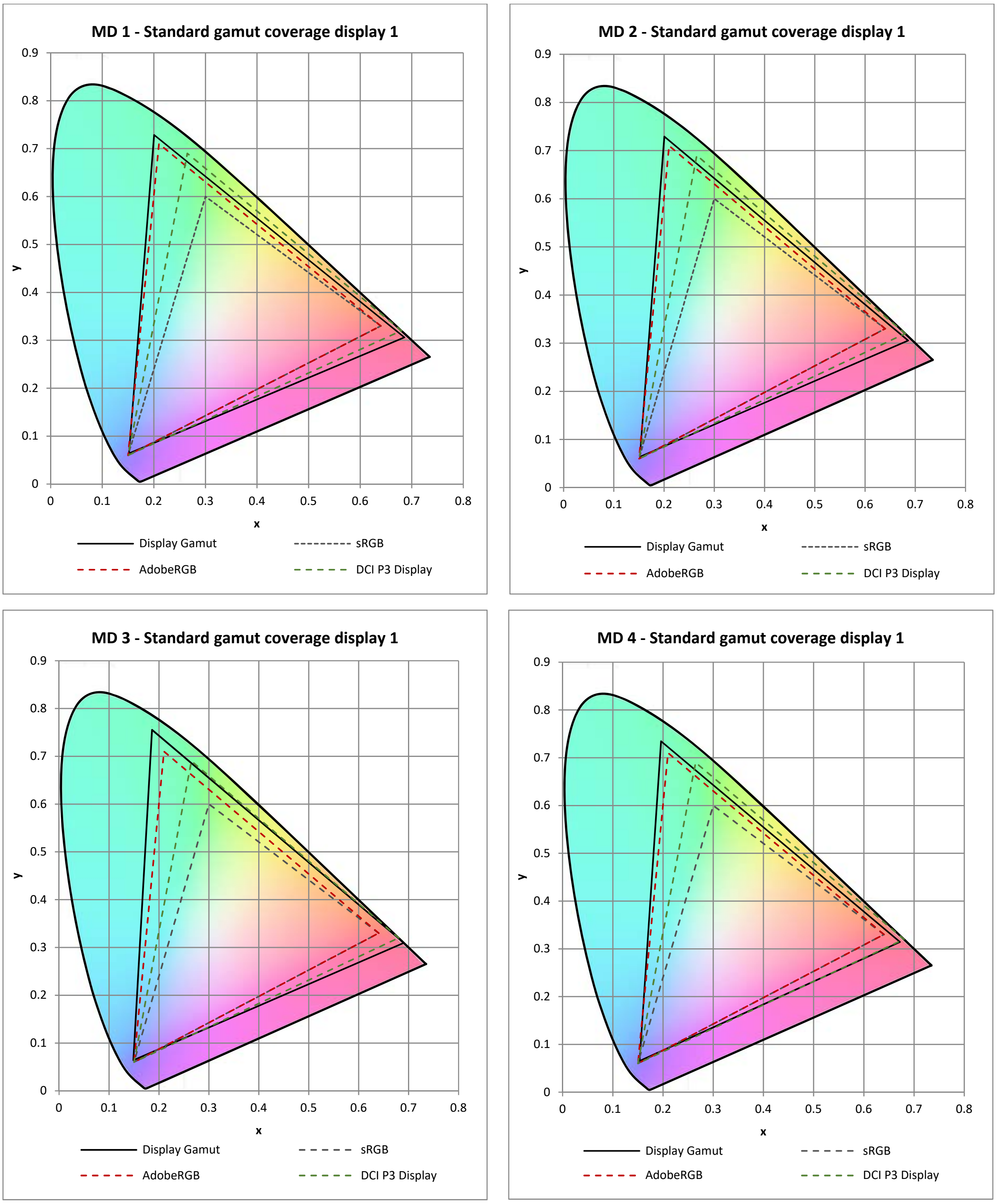


Figure 23. Diagram of the device-dependent color gamut determined with the four display calibration devices for test Display 1 in comparison with the standard color spaces sRGB, AdobeRGB, and DCI-P3.

4.5.3 Comparison of the performance of the display calibration devices used

For a valid comparison of the performance of the available display calibration devices, it is necessary to establish Display 1 as a reference point that is reproducible and repeatable. For this purpose, the display profiles already created with all four measuring instruments are used for the reference display. For the measurements to be performed, the color rendering properties of the reference display are thus defined by a display profile created with the display calibration device currently in use. The data required for the intended analysis is obtained by a defined test form.

	Device Values			Nominal Values				
Color	R	G	B	L*	a*	b*	x	y
1	128	0	0	30.73	64.64	48.49	0.6819	0.3069
2	255	0	0	58.82	104.87	93.98	0.6886	0.3069
3	255	128	128	68.38	77.12	37.49	0.5621	0.3274
4	0	128	0	55.46	-97.26	64.06	0.2206	0.7142
5	0	255	0	84.76	-137.79	91.88	0.2203	0.7178
6	128	255	128	88.01	-95.27	64.37	0.2789	0.5924
7	0	0	128	16.63	43.55	-74.76	0.1594	0.0736
8	0	0	255	31.70	66.67	-112.36	0.1581	0.0706
9	128	128	255	52.23	30.77	-78.08	0.2131	0.1640
10	0	128	128	52.42	-63.49	-6,60	0.1912	0.4103
11	0	255	255	88.57	-91.25	-18.75	0.1882	0.3848
12	170	255	255	92.32	-53.30	-12.88	0.2503	0.3734
13	128	0	128	29.70	63.13	-41.21	0.3619	0.1630
14	255	0	255	64.65	113.43	-56.57	0.4056	0.1803
15	255	170	255	78.06	68.31	-34.66	0.3833	0.2492
16	128	128	0	59.79	-11.50	73.79	0.4478	0.5171
17	255	255	0	96.92	-15.49	111.96	0.4514	0.5159
18	255	255	170	98.03	-10.96	54.52	0.4073	0.4520
19	170	85	85	50.38	59.69	28.73	0.5583	0.3280
20	85	170	85	69.25	-83.59	54.31	0.2692	0.6056
21	85	85	170	37.77	25.27	-63.60	0.2098	0.1595
22	85	170	170	66.79	-60.36	-9.17	0.2171	0.3926
23	170	85	170	49.37	68.10	-40.04	0.3768	0.2041
24	170	170	85	72.91	-14.02	66.66	0.4287	0.4972
25	255	0	170	61.82	109.31	-21.62	0.4951	0.2203
26	170	255	0	91.74	-54.11	103.44	0.3828	0.5758
27	0	170	255	67.78	-42.55	-52.16	0.1769	0.2672
28	0	255	170	86.51	-116.69	25.04	0.2016	0.5247
29	170	0	255	45.97	87.19	-88.38	0.2717	0.1207
30	255	170	0	81.67	29.87	101.25	0.5295	0.4471

Table 15. Overview of the test colors defined by digital device color values with the corresponding nominal spectral color values for the created profile "Display1_MD1_Adobe_160".

In Tab 4 (Review), DisplayCal offers various options to generate a measurement report with the help of defined test forms. "Settings" allows the selection of one of the provided profiles, while "Testchart or Reference" shows a dropdown list with a selection of different test forms available from DisplayCAL. Here, the selected test chart includes 52 test fields. The measurement process takes 3–8 min depending on the measuring device used. The white point, white luminance, black luminance, and the gray balance, as well as the color locations of 30 predefined color values, are checked. These are defined by digital values for the spectral color values R, G, and B and are used as the basis for the ensuing performance analysis. Through the respective created profile, nominal spectral target values are assigned to these digital values, which are then compared with the actually measured real spectral values.

To make a conclusion about the accuracy and repeatability of the measurements, the spectral values of the 30 colors included in the test form are recorded in 10 successive measurement runs. Based on these values, the color difference ΔE_{00} to the defined nominal values is then calculated. These data form the basis of the subsequent analysis of the performance of the displays used. The determined color difference ΔE_{00} of each individual color is taken as the base value. First, each measurement run is examined individually before the results of the individual colors are analyzed over the 10 measurement runs performed.

4.5.3.1 Measurement results and analysis

Here, too, the results are presented in a summarized form. The acquired values of all the display calibration devices used are shown and graphically presented in Annex 2. The analysis conducted on the available data is presented in Figure 25 as an example using display calibration device 1.

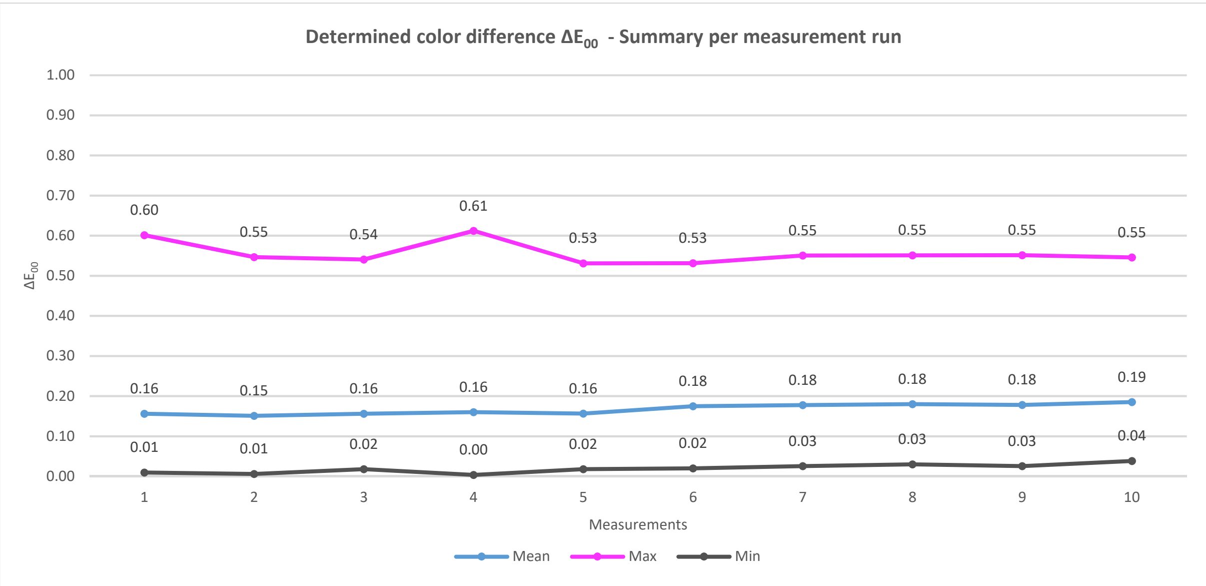


Figure 24. Graphical visualization of the mean values obtained from the 10 measurement runs conducted, as well as the respective maximum and minimum values.

For a valid comparison of the performance of the available display calibration devices, it is necessary to set Display 1 as a reference to a reproducible and repeatable state. For this purpose, the display profiles already created with all four measuring instruments are used for the reference display. For the measurements to be performed, the color rendering properties of the reference display are thus defined by a display profile created with the display calibration device currently in use. The data required for the intended analysis are obtained by a defined test form.

		ΔE_{00} Measured Values													
Color		MR1	MR2	MR3	MR4	MR5	MR6	MR7	MR8	MR9	MR10	Mean	Min	Max	SD
	1	0.02	0.03	0.02	0.03	0.02	0.05	0.05	0.05	0.06	0.06	0.04	0.02	0.06	0.0173
	2	0.01	0.01	0.02	0.00	0.02	0.03	0.05	0.06	0.06	0.07	0.03	0.00	0.07	0.0244
	3	0.06	0.04	0.05	0.06	0.06	0.04	0.03	0.03	0.05	0.04	0.05	0.03	0.06	0.0126
	4	0.05	0.04	0.03	0.05	0.03	0.08	0.10	0.14	0.14	0.14	0.08	0.03	0.14	0.0443
	5	0.03	0.02	0.02	0.02	0.02	0.05	0.08	0.08	0.09	0.13	0.05	0.02	0.13	0.0369
	6	0.03	0.01	0.03	0.05	0.03	0.08	0.07	0.07	0.10	0.08	0.05	0.01	0.10	0.0270
	7	0.01	0.09	0.08	0.07	0.07	0.02	0.08	0.14	0.12	0.12	0.08	0.01	0.14	0.0416
	8	0.05	0.08	0.08	0.08	0.08	0.05	0.18	0.05	0.08	0.08	0.08	0.05	0.18	0.0372
	9	0.06	0.06	0.08	0.06	0.08	0.09	0.12	0.15	0.06	0.07	0.08	0.06	0.15	0.0283
	10	0.06	0.07	0.06	0.05	0.04	0.11	0.12	0.08	0.08	0.17	0.08	0.04	0.17	0.0398
	11	0.09	0.04	0.03	0.10	0.08	0.08	0.06	0.07	0.06	0.08	0.07	0.03	0.10	0.0210
	12	0.09	0.13	0.09	0.11	0.12	0.14	0.14	0.20	0.20	0.21	0.14	0.09	0.21	0.0444
	13	0.03	0.03	0.03	0.03	0.03	0.06	0.05	0.04	0.04	0.05	0.04	0.03	0.06	0.0114
	14	0.03	0.02	0.03	0.01	0.02	0.05	0.05	0.03	0.05	0.05	0.03	0.01	0.05	0.0142
	15	0.03	0.05	0.06	0.04	0.05	0.09	0.05	0.07	0.04	0.07	0.06	0.03	0.09	0.0175
	16	0.03	0.05	0.07	0.10	0.06	0.04	0.03	0.07	0.05	0.05	0.06	0.03	0.10	0.0211
	17	0.05	0.01	0.03	0.02	0.03	0.08	0.05	0.04	0.03	0.05	0.04	0.01	0.08	0.0193
	18	0.07	0.08	0.08	0.11	0.07	0.18	0.12	0.08	0.10	0.13	0.10	0.07	0.18	0.0351
	19	0.52	0.49	0.52	0.52	0.53	0.46	0.48	0.48	0.49	0.48	0.50	0.46	0.53	0.0213
	20	0.47	0.45	0.47	0.45	0.45	0.47	0.50	0.48	0.50	0.50	0.48	0.45	0.50	0.0200
	21	0.34	0.37	0.37	0.34	0.36	0.41	0.34	0.35	0.35	0.35	0.36	0.34	0.41	0.0213
	22	0.38	0.37	0.38	0.41	0.41	0.41	0.38	0.32	0.36	0.36	0.38	0.32	0.41	0.0297
	23	0.42	0.43	0.43	0.42	0.42	0.43	0.45	0.47	0.41	0.41	0.43	0.41	0.47	0.0193
	24	0.53	0.51	0.51	0.52	0.52	0.53	0.55	0.53	0.55	0.55	0.53	0.51	0.55	0.0146
	25	0.09	0.09	0.09	0.08	0.08	0.14	0.12	0.12	0.11	0.15	0.11	0.08	0.15	0.0240
	26	0.13	0.11	0.13	0.10	0.13	0.10	0.16	0.19	0.19	0.16	0.14	0.10	0.19	0.0344
	27	0.60	0.55	0.54	0.61	0.53	0.48	0.55	0.55	0.52	0.52	0.55	0.48	0.61	0.0372
	28	0.07	0.03	0.02	0.02	0.05	0.09	0.07	0.08	0.10	0.10	0.06	0.02	0.10	0.0290
	29	0.06	0.06	0.06	0.05	0.05	0.12	0.03	0.03	0.03	0.04	0.05	0.03	0.12	0.0274
	30	0.24	0.20	0.25	0.30	0.25	0.28	0.30	0.33	0.32	0.32	0.28	0.20	0.33	0.0441

Mean	0.16	0.15	0.16	0.16	0.16	0.18	0.18	0.18	0.18	0.19
Min	0.01	0.01	0.02	0.00	0.02	0.02	0.03	0.03	0.03	0.04
Max	0.60	0.55	0.54	0.61	0.53	0.53	0.55	0.55	0.55	0.55
SD	0.1833	0.1771	0.1793	0.1842	0.1787	0.1689	0.1734	0.1698	0.1685	0.1641

Table 16. Summary of the color differences ΔE_{00} calculated from the spectral values acquired with display calibration device 1 for all test colors.

In the next step, the single colors are examined across the measurement runs. This allows a qualitative evaluation of the accuracy and repeatability of the measurement results obtained.

The values used for the analysis are shown in Table 17. In Annex 2, all measurement results for each single color are shown in the CIExy chromaticity diagram. To evaluate the accuracy of the measurements, the color differences ΔE_{00} determined in the 10 measurement runs are used for each single color and averaged. To evaluate their repeatability, the spectral values measured in the 10 measurement runs are first the mean value for each single color, and then the color differences of the single measurements are calculated based on this mean value. The mean, minimum, and maximum values obtained for each of the 30 single colors and the resulting standard deviations are included in the analysis.

	Device Values			Nominal Values					Accuracy (ΔE_{00} MR 1 – 10)				Repeatability (ΔE_{00} MR 1 – 10)			
Color	R	G	B	L*	a*	b*	x	y	Mean	Min	Max	SD	Mean	Min	Max	SD
1	128	0	0	30.73	64.64	48.49	0.6819	0.3069	0.04	0.02	0.06	0.0173	0.02	0.01	0.02	0.0048
2	255	0	0	58.82	104.87	93.98	0.6886	0.3069	0.03	0.00	0.07	0.0244	0.02	0.01	0.04	0.0113
3	255	128	128	68.38	77.12	37.49	0.5621	0.3274	0.05	0.03	0.06	0.0126	0.03	0.02	0.05	0.0100
4	0	128	0	55.46	-97.26	64.06	0.2206	0.7142	0.08	0.03	0.14	0.0443	0.05	0.05	0.09	0.0160
5	0	255	0	84.76	-137.79	91.88	0.2203	0.7178	0.05	0.02	0.13	0.0369	0.06	0.02	0.08	0.0177
6	128	255	128	88.01	-95.27	64.37	0.2789	0.5924	0.05	0.01	0.10	0.0270	0.04	0.02	0.08	0.0196
7	0	0	128	16.63	43.55	-74.76	0.1594	0.0736	0.08	0.01	0.14	0.0416	0.04	0.01	0.08	0.0304
8	0	0	255	31.70	66.67	-112.36	0.1581	0.0706	0.08	0.05	0.18	0.0372	0.03	0.00	0.10	0.0311
9	128	128	255	52.23	30.77	-78.08	0.2131	0.1640	0.08	0.06	0.15	0.0283	0.03	0.01	0.09	0.0283
10	0	128	128	52.42	-63.49	-6.60	0.1912	0.4103	0.08	0.04	0.17	0.0398	0.05	0.04	0.13	0.0255
11	0	255	255	88.57	-91.25	-18.75	0.1882	0.3848	0.07	0.03	0.10	0.0210	0.06	0.04	0.08	0.0127
12	170	255	255	92.32	-53.30	-12.88	0.2503	0.3734	0.14	0.09	0.21	0.0444	0.06	0.03	0.10	0.0213
13	128	0	128	29.70	63.13	-41.21	0.3619	0.1630	0.04	0.03	0.06	0.0114	0.04	0.02	0.05	0.0062
14	255	0	255	64.65	113.43	-56.57	0.4056	0.1803	0.03	0.01	0.05	0.0142	0.03	0.02	0.04	0.0085
15	255	170	255	78.06	68.31	-34.66	0.3833	0.2492	0.06	0.03	0.09	0.0175	0.03	0.01	0.05	0.0129
16	128	128	0	59.79	-11.50	73.79	0.4478	0.5171	0.06	0.03	0.10	0.0211	0.04	0.02	0.10	0.0252
17	255	255	0	96.92	-15.49	111.96	0.4514	0.5159	0.04	0.01	0.08	0.0193	0.04	0.01	0.05	0.0160
18	255	255	170	98.03	-10.96	54.52	0.4073	0.4520	0.10	0.07	0.18	0.0351	0.03	0.02	0.10	0.0226
19	170	85	85	50.38	59.69	28.73	0.5583	0.3280	0.50	0.46	0.53	0.0213	0.03	0.02	0.04	0.0076
20	85	170	85	69.25	-83.59	54.31	0.2692	0.6056	0.48	0.45	0.50	0.0200	0.03	0.03	0.08	0.0160
21	85	85	170	37.77	25.27	-63.60	0.2098	0.1595	0.36	0.34	0.41	0.0213	0.04	0.02	0.11	0.0286
22	85	170	170	66.79	-60.36	-9.17	0.2171	0.3926	0.38	0.32	0.41	0.0297	0.05	0.03	0.08	0.0148
23	170	85	170	49.37	68.10	-40.04	0.3768	0.2041	0.43	0.41	0.47	0.0193	0.04	0.01	0.05	0.0118
24	170	170	85	72.91	-14.02	66.66	0.4287	0.4972	0.53	0.51	0.55	0.0146	0.04	0.01	0.07	0.0178
25	255	0	170	61.82	109.31	-21.62	0.4951	0.2203	0.11	0.08	0.15	0.0240	0.04	0.03	0.07	0.0118
26	170	255	0	91.74	-54.11	103.44	0.3828	0.5758	0.14	0.10	0.19	0.0344	0.04	0.01	0.06	0.0177
27	0	170	255	67.78	-42.55	-52.16	0.1769	0.2672	0.55	0.48	0.61	0.0372	0.05	0.02	0.11	0.0352
28	0	255	170	86.51	-116.69	25.04	0.2016	0.5247	0.06	0.02	0.10	0.0290	0.05	0.03	0.07	0.0184
29	170	0	255	45.97	87.19	-88.38	0.2717	0.1207	0.05	0.03	0.12	0.0274	0.05	0.02	0.09	0.0211
30	255	170	0	81.67	29.87	101.25	0.5295	0.4471	0.28	0.20	0.33	0.0441	0.04	0.01	0.09	0.0211
								Mean	0.17	0.13	0.21	0.0272	0.04	0.02	0.08	0.0181

Table 17. Graphical visualization of mean values from the 10 measurement runs performed with display calibration device 1 as well as the respective maximum and minimum values for each individual color.

For the evaluation of the accuracy of the measured color values, the determined color difference ΔE_{00} from the nominal values defined by the profile used is examined more closely. Table 4 ("Interpretation and evaluation of color differences") already briefly shows how this can be interpreted as a basis for evaluation. A color difference $\Delta E_{00} < 0.2$ is considered to be a difference that is not visually perceptible, while $\Delta E_{00} = 0.2$ to $\Delta E_{00} < 1$ is evaluated as a very small color difference.

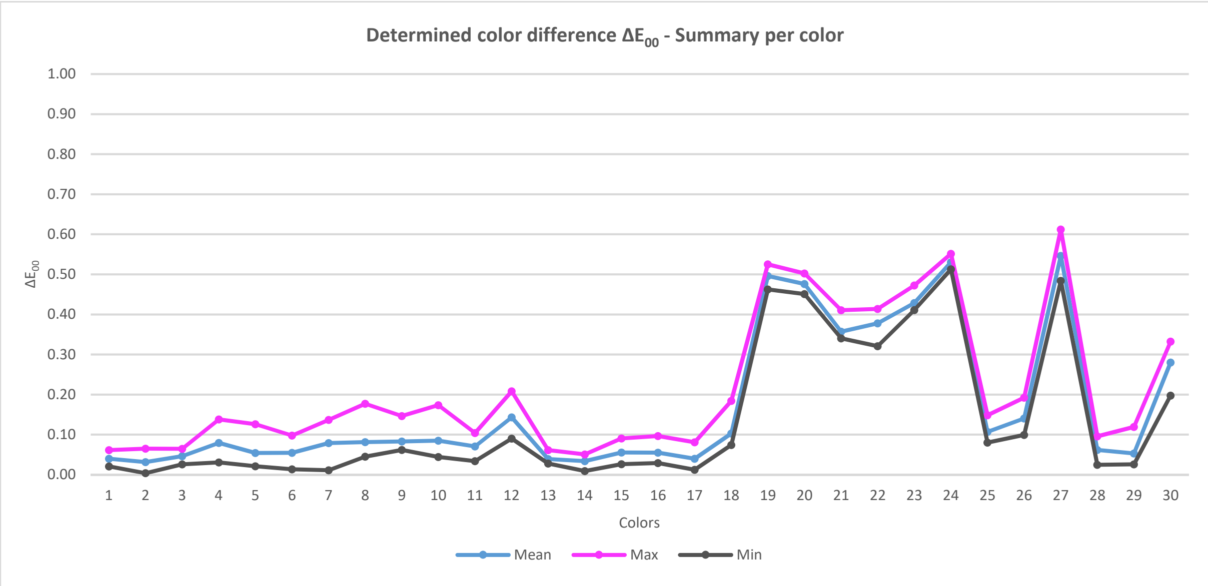


Figure 25. Graphical visualization of mean values from the 10 measurement runs performed with display calibration device 1 as well as the respective maximum and minimum values for each individual color.

Summarizing the results, the average color difference over all 30 single colors is $\Delta E_{00} = 0.17$, with a minimum of $\Delta E_{00} = 0.13$ and a maximum of $\Delta E_{00} = 0.21$. The average standard deviation is SD = 0.0272. In principle, this is a very good result, as such color differences are considered to be visually imperceptible. However, a look at Figure 26 shows significant differences depending on the single color measured. For Color 2, for example, a mean color difference $\Delta E_{00} = 0.03$ (Min $\Delta E_{00} = 0.00$ / Max $\Delta E_{00} = 0.07$) is found, whereas for Color 27, this rises to $\Delta E_{00} = 0.55$ (Min $\Delta E_{00} = 0.48$ / Max $\Delta E_{00} = 0.61$). If the limits described in Table 4 are taken into account, it can be seen that 22 colors (73%) exhibit an average color difference of $\Delta E_{00} < 0.2$. Thus, the average color differences of eight colors exceed this limit. The maximum average color difference $\Delta E_{00} = 0.55$; however, this is still clearly below the limit value of $\Delta E_{00} = 1$ that represents the transition from a very small to a small visually perceptible color difference.

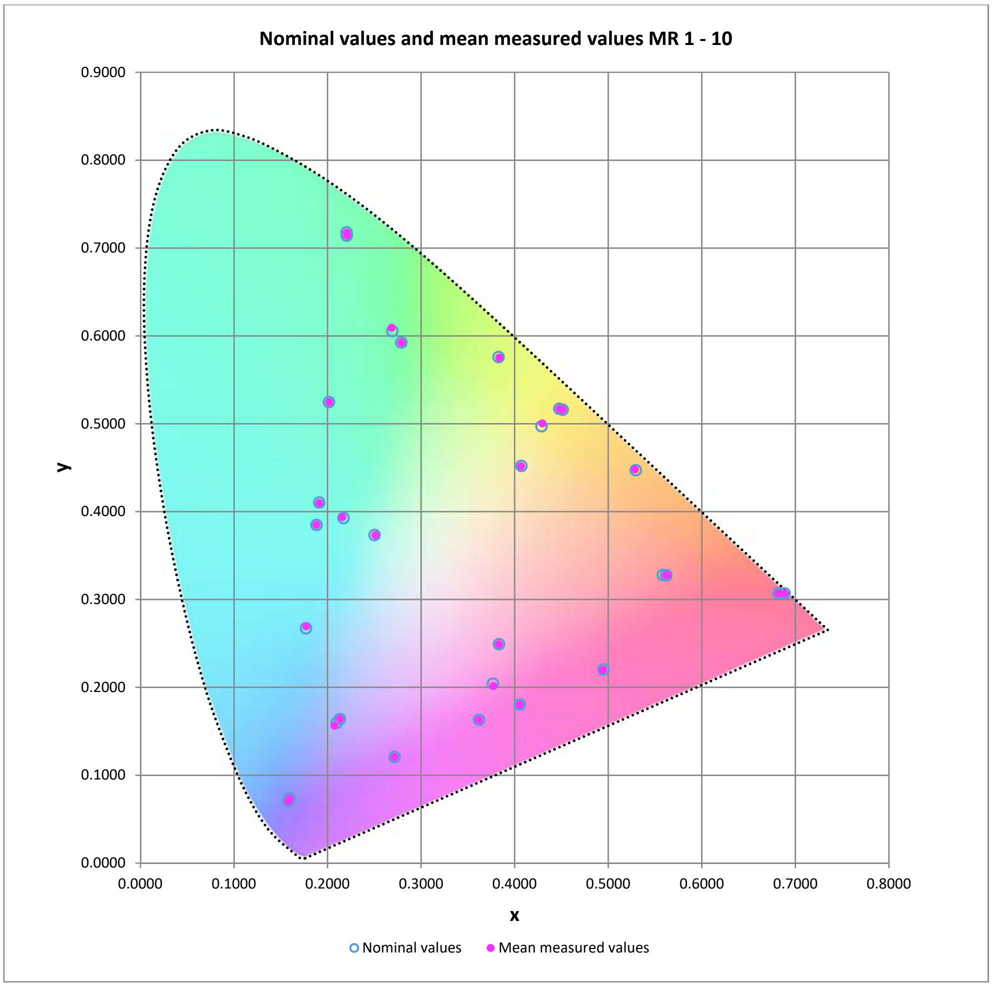


Figure 26. Visualization of the nominal and mean measured color values in the CIExy chromaticity diagram.

Further analysis of the results shows that the primary colors R, G, and B in the test form (colors 1, 2, 4, 5, 7, 8) are driven with the color values 255 and 128 for the corresponding color channel. This also applies to the secondary colors C, M, and Y (colors 10, 11, 13, 14, 16, 17). Here, the color channels of the primary colors responsible for the color impression (by additive color mixing) are driven with the values 255 and 128, respectively. In addition, nearby tertiary colors (colors 3, 6, 9, 12, 15, and 18) are measured here. For the primary color range, the channel of the respective primary color contains the maximum color values 255, and the other two color channels 128 each. For the secondary colors, the color channels of the primary colors responsible for the color impression receive the maximum color values 255, while the third color channel is driven with the color value 170. In the measurements conducted, very good results were obtained for all these colors. Color 12, with a color difference $\Delta E_{00} = 0.15$, already appears to be a discordant value; all other results are in a narrow range from $\Delta E_{00} = 0.03$ to $\Delta E_{00} = 0.10$. The smallest color differences were measured in the red/magenta color range.

Colors 19 to 25 are tertiary colors composed of the color values 85 and 170 in different combinations. Here, the measurement results show a different picture: the color differences of the six tertiary colors are clearly above a color difference of ΔE_{00} = 0.2, varying from ΔE_{00} = 0.36 (color 21) to ΔE_{00} = 0.53 (color 24). It can be seen that the color differences increase as the weighting of the color values shifts from blue to green to red. The final six secondary colors are composed of a color value of 255 and a color value of 170. The color differences range from ΔE_{00} = 0.05 (color 29) to the maximum value of the measurement series: ΔE_{00} = 0.55 (color 27). Colors 25 and 29 are composed of the red and blue color channels, and the measured color differences ΔE_{00} = 0.11 and ΔE_{00} = 0.05 are very small. Colors 26 and 30 are composed of the red and green color channels. In color 26, the green color channel with a color value of 255 is higher than the red color value of 170, and the measured color difference is ΔE_{00} = 0.14. In color 30, the color values are swapped, resulting in a significantly higher measured color difference of ΔE_{00} = 0.28. Considering the combination of the green and blue color channels in color 27, the maximum color difference of ΔE_{00} = 0.55 was measured with a dominating blue channel. In comparison, in color 28, the color values are swapped, making the green color channel dominant. The measured color difference is reduced to a value of ΔE_{00} = 0.06.
The repeatability of the measurement results is very good. As already explained, the spectral values measured in the 10 measurement runs are first averaged for each single color, and then the color differences of the single measurements are calculated to this mean value. For the mean over all 30 single colors, a color difference of ΔE_{00} = 0.04 is obtained with a minimum of ΔE_{00} = 0.02 and a maximum of ΔE_{00} = 0.08. The mean standard deviation is SD = 0.0181. Simply put, this is a very good result. The range of variation across all single colors is very small. Even in the colors that have larger color differences from the nominal values in the context of accuracy, very good repeatability can be seen, with no noticeable discordant values.

	ΔE_{00} MR 1 –10				ΔE_{00} Accuracy Single Colors				ΔE_{00} Repeatability Single Colors			
	Mean	Min	Max	SD	Mean	Min	Max	SD	Mean	Min	Max	SD
MD 1	0.17	0.02	0.56	0.1747	0.17	0.13	0.21	0.0272	0.04	0.02	0.08	0.0181
MD 2	0.20	0.02	0.59	0.1583	0.20	0.16	0.25	0.0275	0.04	0.02	0.08	0.0207
MD 3	0.25	0.02	1.56	0.3268	0.25	0.17	0.31	0.0444	0.05	0.01	0.12	0.0357
MD 4	0.37	0.09	0.73	0.1835	0.37	0.23	0.57	0.1043	0.15	0.05	0.32	0.0912

Table 18. Summary of obtained basic values for the performance evaluation of the available display calibration devices.

Using the procedure presented here, an analysis of the data was conducted for all display calibration devices used. This led to the decision to use display calibration device 1 as the measuring device of choice for the subsequent examinations. Looking at the acquired values, the measurements conducted with this measuring device show the best results for the defined criteria of accuracy and repeatability.

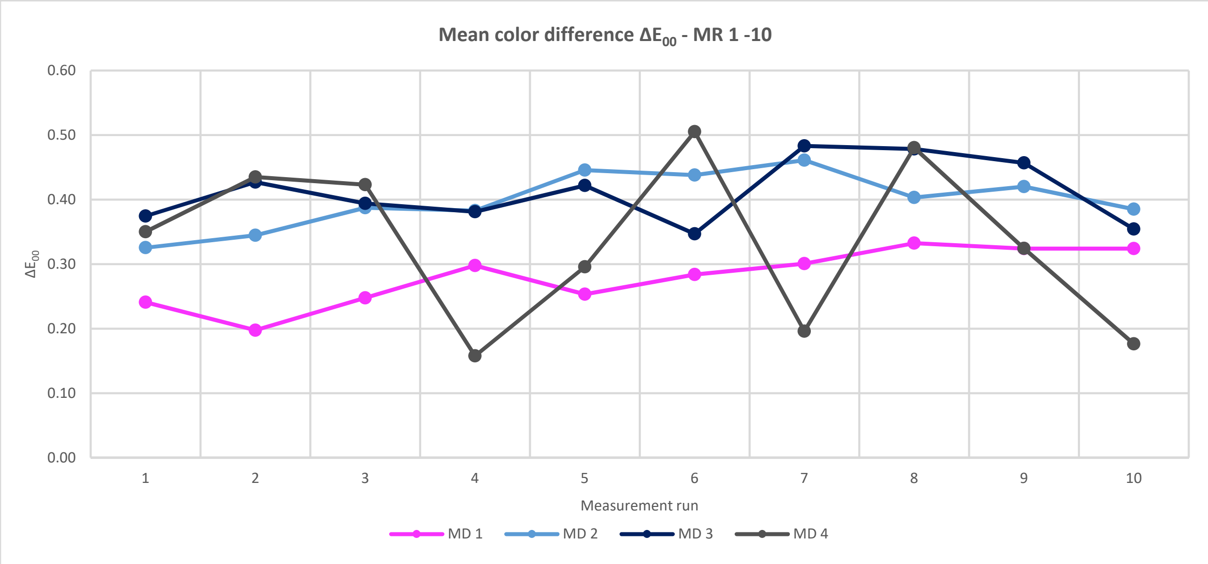


Figure 27. Visualization of the average color difference ΔE_{00} from 30 single colors per measuring run based on the measured values acquired with the available display calibration devices.

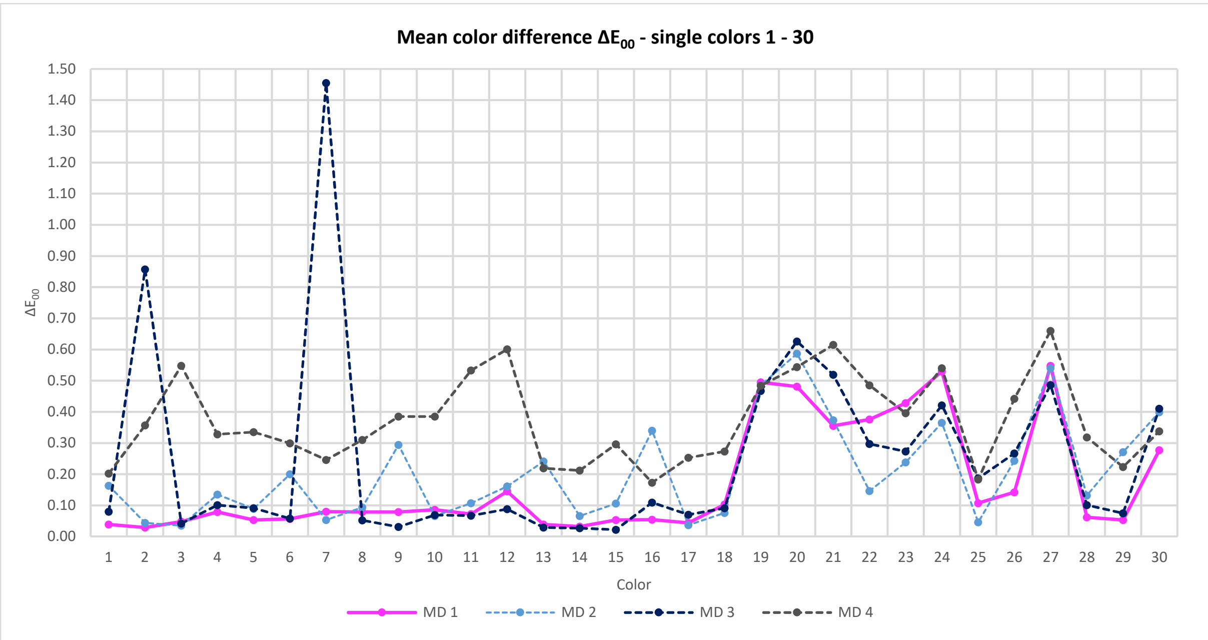


Figure 28. Visualization of the average color difference ΔE_{00} for all 30 single colors based on 10 measurements runs performed with the available display calibration devices.

Considering colors 1 to 18 first, the measurement results of display calibration device 1 show the best values for the accuracy criterion. All mean color differences are below the limit value ΔE_{00} = 0.2, so they are not visually perceptible. Similarly good results are obtained for this color range with display calibration device 3, but two discordant values are found for color 2 (ΔE_{00} = 0.86) and color 7; the color difference determined here ΔE_{00} = 1.46 is not acceptable. In addition, the range of variation for display calibration device 3 is somewhat larger, varying from a color difference of ΔE_{00} = 0.04 (color 2) to ΔE_{00} = 0.34 (color 16). For colors 19 to 30, almost identical trends are seen across all measuring devices. The measured color differences are mostly clearly above those of colors 1–18. Colors 19 and 27 are problematic for all measuring devices. The measurement results obtained here with display calibration device 1 show the lowest color differences, with the exception of colors 23, 24 and 27.
The evaluation of the repeatability also gives the best values for display calibration device 1. The mean over all 30 single colors is a color difference of ΔE_{00} = 0.04 with a standard deviation SD = 0.0181. The measurement results obtained with measuring device 2 indicate an identical color difference with a slightly higher standard deviation (SD = 0.0207). The results obtained with measuring device 3 are only minimally higher. Only measuring device 4 falls off significantly in the results obtained.

4.6 Performance benchmarking of the displays used

The aim of this investigation is to record various defined performance values of the four selected test displays, thereby allowing an analysis of their color representation performance. The results can subsequently be used in the color matching experiments outlined. All measurements are performed using display calibration device 1 and the DisplayCal software. This combination offers all the necessary options for the implementation.

4.6.1 Procedure and realization of the measurements

In preparation for the measurements, a change of the basic settings to maximum settings is first made on all displays via their OSD. This mainly applies to the brightness, contrast, and gain of the RGB color channels. In the first step, the maximum luminance and the corresponding power requirement are determined. With these values, a calculation of the luminance efficiency can be made. The black level or black luminance is also measured, along with the associated native white point. The maximum displayable color gamut of the displays, as well as the coverage of the standard color spaces sRGB, AdobeRGB, and DCI-P3, can then be determined.

To begin the measurement procedure, display calibration device 1 is placed in the center of the screen surface at the position specified by the DisplayCal software. Then, to measure the maximum luminosity, a white test field is displayed over the entire surface and measured. A voltage meter is interposed between the display and the power source to measure the current power consumption of the display. The luminance efficiency can then be calculated from the values obtained. The black luminance is then measured with a black test field before the data of the display primaries are recorded with a red, green, and blue test field.
This is followed by a measurement of the display uniformity and color homogeneity. For this purpose, a measurement report offered by DisplayCal is used. In Tab 4 (Verification), one of these will be selected. A 5 x 5 matrix (i.e., 25 measurement fields) is selected as the basic setting and measurement template. With the start of the measuring process, the selected 25 measuring fields are shown on the display and can be activated and measured individually. For this purpose, the measuring instrument is always positioned at the center of the individual measuring fields before the measuring process is started. Four measurements for four different brightness levels (100%, 75%, 50%, and 25%) are automatically taken for each field. The results obtained are then documented in a measurement report.

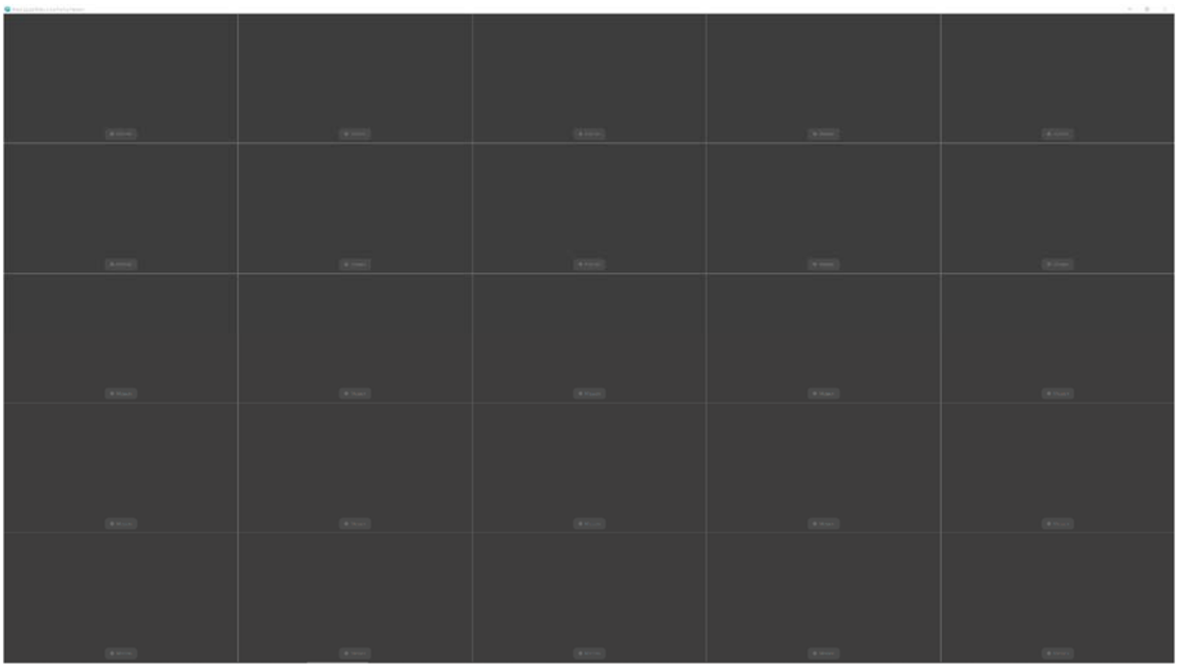


Figure 29. Visualization of the 5 x 5 measurement matrix provided in DisplayCal to capture display uniformity.

For the further measurements, it is necessary to set the displays to a defined state. Profiles created with display calibration device 1 are used for this purpose. As already mentioned, the basic rule here is that the standard color gamut used should be covered as closely as possible by the native technical color gamut of a display. The examinations already conducted show how different the native color gamuts of the displays are. Based on the results obtained, the decision was made to work with profiles on different base settings. For displays 1 and 2, the profiles already created with the selected measurement device on the AdobeRGB base settings are used, whereas the profiles for Displays 3 and 4 are newly created on the base settings of the sRGB standard due to the color gamut coverage achieved. For this purpose, the selected target settings must be adjusted in Tab 2 (Calibration). The target value for the white point remains identical throughout at 6,500 K. The value for the white luminance of the sRGB color space is 80 cd/m². For the adjustment of the TRC or gamma, the predefined sRGB setting in DisplayCAL is selected from the drop-down list. As mentioned above, this contains an exponential curve with a straight segment at the dark end. The newly created profiles are then checked immediately using the previously used test form. This measurement process is repeated three times, and the data required for the planned analysis are acquired.

Based on these profiles, the stability of the displays' performance over a longer period of use is then tested using the previously used test form. The aim here is to be able to draw a conclusion about the stability of color representation, given that changes over the duration of use cannot be ruled out. To evaluate the performance of the displays, the measured values for white point, color temperature, white luminance, black luminance, and contrast are documented. In addition, the spectral values for the 30 defined test colors are also measured. These measurements are performed in three time slots over a period of five days. Time slot 1 refers to a runtime of up to 120 min (including preheating time), time slot 2 to a runtime of at least 300 min, and time slot 3 to a runtime of at least 480 min. At the end of each day, the uniformity of the display is measured at the luminance specified by the profile used. This procedure makes it possible to collect a sufficient quantity of data to make a qualitative statement about the stability of the color representation of the displays concerned.

4.6.2 Measurement results and analysis

In this section, the results of the measurements are first presented as an example using the selected reference Display 1. The complete data of all the displays used are shown in Annex 3 and are then included in summarized form in the analysis.

Via the OSD of the displays, all settings influencing the color representation performance are set to maximum values. As already mentioned, the available settings vary from display to display. In essence, the focus should be on the settings for brightness, contrast, and the gain of the individual color channels R, G, and B. To record the desired performance data, the necessary measurements are conducted over three measurement runs.

	White Lum. (cd/m²)	Power (W)	Lum. Eff. (cd/W)	Black Lum. (cd/m²)	White point (CIExy)		Display Gamut					
							sRGB		AdobeRGB		DCI-P3	
					x	y	Cov. (%)	Vol. (%)	Cov. (%)	Vol. (%)	Cov. (%)	Vol. (%)
MR1	412.47	69.1	5.97	0.3502	0.3039	0.3371	99.5	163.8	99.2	112.9	93.1	116.0
MR2	413.02	69.2	5.97	0.3557	0.3045	0.3365	99.5	164.2	99.2	113.1	93.3	116.3
MR3	412.73	69.2	5.96	0.3546	0.3042	0.3363	99.5	164.2	99.2	113.1	93.3	116.3

Table 19. Summary of the values acquired in three measurement runs at maximum settings for reference Display 1.

On the basis of these examples, a comparative analysis of the displays can be conducted. For this purpose, the complete data for all displays used, as presented in Annex 3, are included here in compressed form.

In the first step of the analysis, the parameters white luminance, white point, and color temperature, as well as black luminance, are examined in more detail. The position of the white point is expressed by the correlated color temperature (CCT). This is a measure of the color illumination of a light source defined by its proximity to the blackbody location. It is expressed as a value (in Kelvin) rather than by chromaticity coordinates xy. CCT is used to specify an emitted spectrum of non-blackbody emitters, such as LEDs used in the BLU of displays.

	White Lum. (cd/m²)	Power (W)	Lum. Eff. (cd/W)	Black Lum. (cd/m²)	White point (CIE_xy)		Display Gamut					
							sRGB		AdobeRGB		DCI-P3	
					x	y	Cov. (%)	Vol. (%)	Cov. (%)	Vol. (%)	Cov. (%)	Vol. (%)
Display 1	413	69.2	5.97	0.3535	0.3048	0.3366	99.5	164.1	99.2	113.0	93.2	116.2
Display 2	329	33.6	9.80	0.2341	0.2869	0.3287	99.3	167.6	91.6	115.5	96.4	118.8
Display 3	469	37.0	12.69	0.4750	0.3150	0.3314	95.0	95.2	65.4	65.6	67.4	67.4
Display 4	293	44.8	6.55	0.1052	0.3015	0.3184	99.9	144.1	87.9	99.3	92.4	102.1

Table 20. Summary of the defined performance indicators averaged from three measurements for the four displays used.

Looking first at the measured maximum white luminance, the range between the used displays is quite large after all. Display 4 achieves the highest luminance at 469 cd/m². The other displays drop significantly here: display 3 has the lowest luminance at 239 cd/m². The measured black luminance is directly related to the maximum white luminance. Here, too, the highest value of 0.4750 cd/m² was determined for Display 4, while Display 3 provides the lowest value with 0.1052 cd/m². It should be noted that the black luminance also decreases significantly with a lower maximum white luminance. While this nonetheless corresponds to 0.1% at the maximum white luminance of 469 cd/m² (Display 4), the value is 0.9% at the measured 413 cd/m² (Display

2), only 0.7% at the measured 329 cd/m² (Display 2), and finally 0.04% for the measured 293 cd/m² (Display 3).

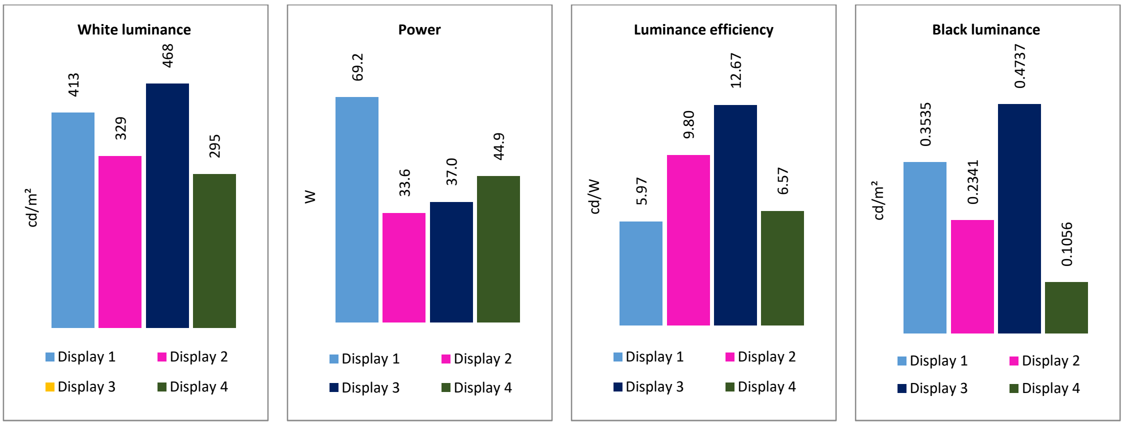


Figure 30. Visualization of the data for white luminance, power consumption, luminance efficiency, and black luminance of the selected test displays.

Power consumption also differs widely across the four displays. As expected, it is higher for the two displays with a screen diagonal of 32" than for those with 27". Therefore, the luminance efficiency is calculated here as a comparison value. This is defined as the ratio of the luminance at 100% white to the power consumption:

$$\text{Luminance efficiency} = \frac{Luminance\ in\ cd/m^2}{Power\ consumption\ in\ W} \qquad (3.01)$$

Both displays with a screen diagonal of 27" deliver the better results here. Display 4 has a very good luminance efficiency of 12.69 cd/W. Display 1, on the other hand, has a very high power consumption at 69.2 W, which results in a rather low luminance efficiency of 5.97 cd/W.

The measured native white points of the displays are shown in Figure 35. These deviate from the nominal white point of the standard color spaces sRGB and AdobeRGB (x = 0.3127, y = 0.3290) to varying degrees from display to display. Display 1 offers the largest native color gamut overall, closely followed by Display 2. This difference is mainly due to more representable colors in the color ranges from medium blue to blue-green (wavelength range from approximately 475–530 nm). The native color gamut of Display 2, on the other hand, offers more colors in the violet range (approximately 460 nm) and in the range from medium green to yellow-green (approximately 535–570 nm). The color gamut of Display 3 is already significantly smaller, while Display 4 offers by far the smallest native color gamut. This is also visible in the examined color gamut coverage of the standard color spaces sRGB, AdobeRGB, and DCI-P3.

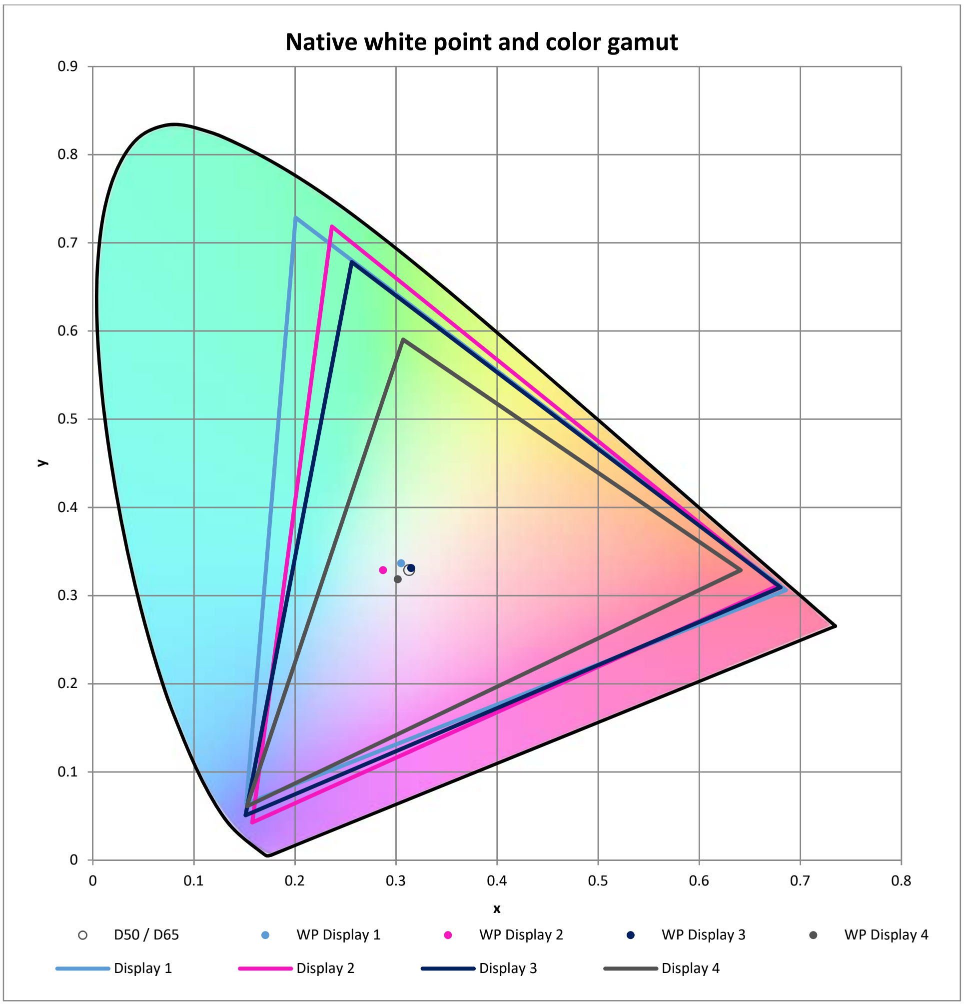
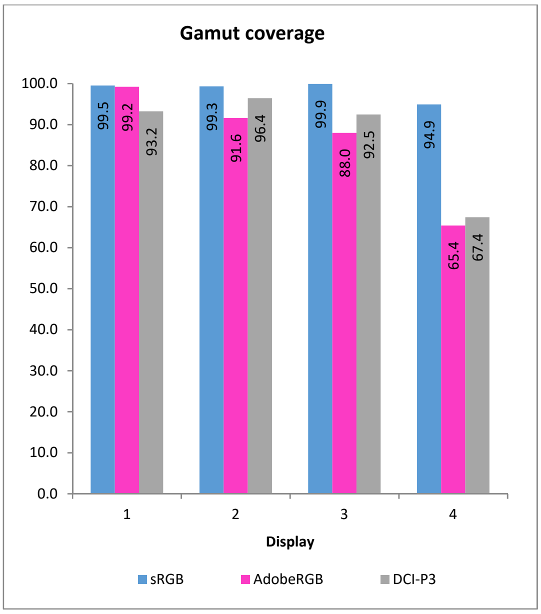


Figure 31. Visualization of the native white point and color gamuts of the displays used.



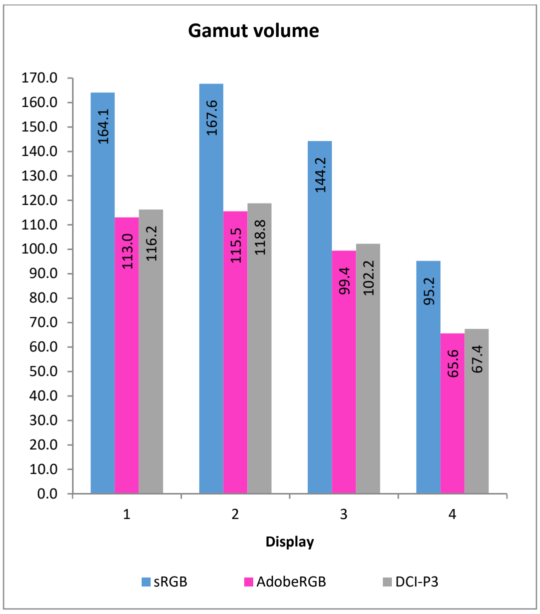


Figure 32. Visualization of the results in relation to coverage and volume of the standard color spaces sRGB, AdobeRGB, and DCI-P3.

Due to their native color gamut, the test displays offer significantly more colors than the standard color spaces sRGB, AdobeRGB, and DCI-P3 cover (volume). However, complete coverage is not achieved.

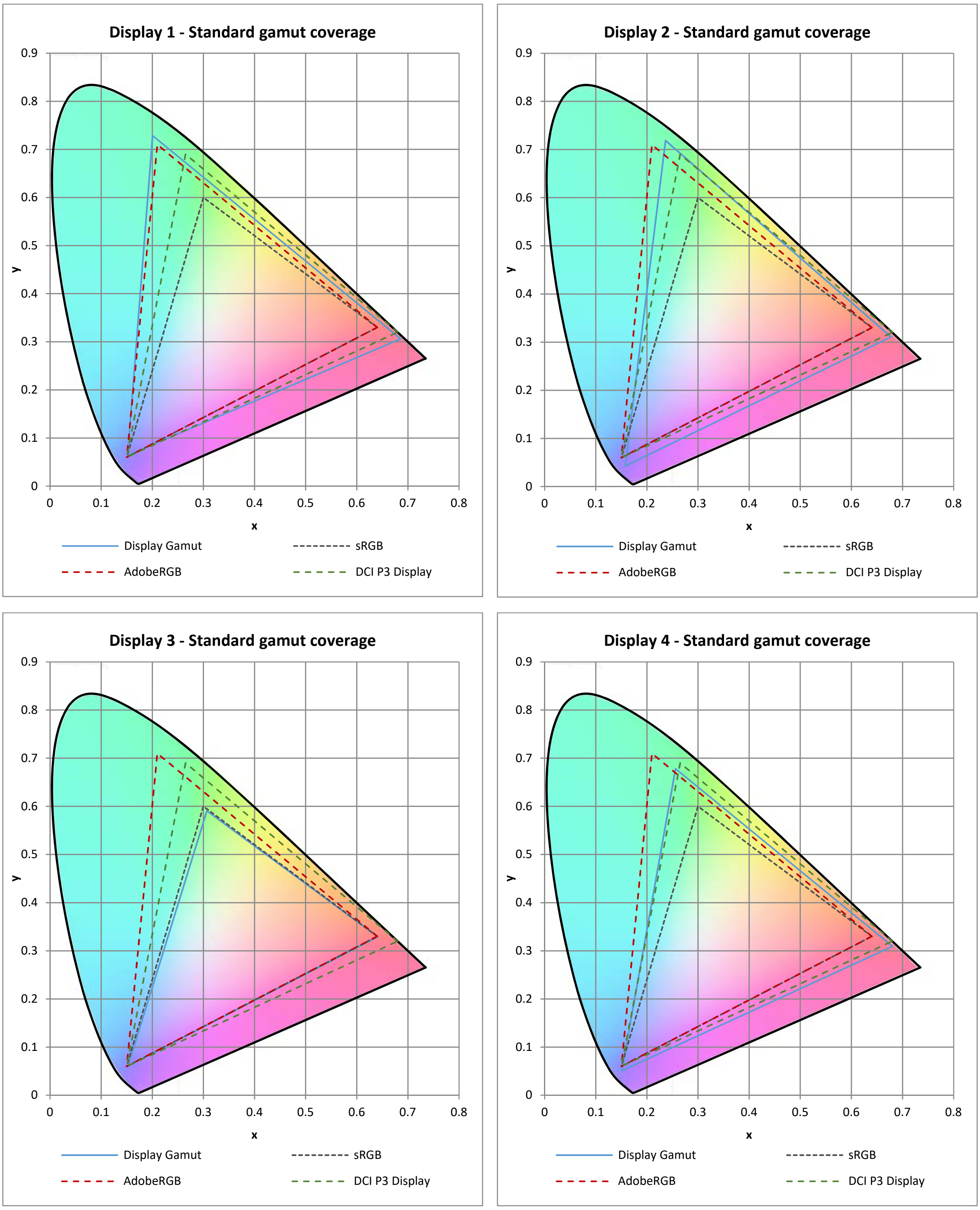


Figure 33. Visualization of the coverage of the standard color spaces for the displays used.

Display 1 achieves a very good coverage of the three selected standard color spaces. Coverage of 99.3% of the AdobeRGB color space and 99.5% of the sRGB color space is achieved, with the missing colors due to the primary color blue of the native color gamut. The 93.2% coverage of the DCI-P3 color space is also a good result. Here, Display 2 shows the best value with a coverage of 96.4%. This is due to the difference of the native color gamut, which covers more colors in the green to yellow-green range compared to Display 1 and thus better fulfills the requirements of the DCI-P3 color space. However, this has a slightly more negative effect on the coverage of the AdobeRGB color space, which is slightly lower at 91.6% as a result. In this case, the primary color green is shifted too far in the direction of the spectral colors, so that some of the colors in the blue-green range are not covered. Furthermore, the primary color blue is slightly shifted into the violet range, which then also explains the not quite complete coverage of 99.3% of the sRGB color space.

Display 3 delivers the top value for the sRGB color space with a color gamut coverage of 99.9%, but this unfortunately falls somewhat with only 87.9% coverage of the AdobeRGB color space. The DCI-P3 color space is well covered at 92.4%. Display 4 clearly falls behind in color gamut coverage compared to the other displays: while the sRGB color space is well covered at 95%, only 65.4% coverage of the AdobeRGB color space and 67.4% of the DCI-P3 color space are deemed insufficient.

The planned measurements for evaluating uniformity and color homogeneity of the displays are then performed using a measurement report offered by the DisplayCal application software, the results of which are presented in Table 21.

Selecting the appropriate measurement report activates 25 measurement fields evenly distributed over the display area in a 5 x 5 matrix. For each field, measurement values are acquired for white with 100%, 75%, 50%, and 25% luminance. This results in the mean luminance difference in % and likewise the mean chromaticity difference (ΔC^*_{00}) in relation to the values measured in each case in the central field of the matrix. It is assumed that the highest luminance is achieved in the center of the screen, and the values obtained here serve as the basis for calculating the deviation of the individual measurement fields. The measurements are performed three times, and the averaged values are used for analysis.

The achieved values for 100% luminance were used for analysis of the displays' respective uniformity. The luminance distribution of Display 1 is not satisfactory, with an average deviation of 11.91% and a maximum value of 25.19% in the upper-left field of the matrix. By contrast, the perception threshold for luminance differences is around 10%. The color homogeneity also only achieves a moderately satisfying result and falls off, especially in the lower area of the display. The mean chromaticity difference is ΔC^*_{00} = 1.69; the maximum is ΔC^*_{00} = 3.72 at the lower edge in the fourth field from the left.

	Lum. cd/m²	Delta %	ΔC^*_{00}	Lum. cd/m²	Delta %	ΔC^*_{00}	Lum. cd/m²	Delta %	ΔC^*_{00}	Lum. cd/m²	Delta %	ΔC^*_{00}	Lum. cd/m²	Delta %	ΔC^*_{00}
100%	310.73	-25.19	1.18	310.95	-25.14	0.67	333.22	-19.78	1.86	331.27	-20.25	0.49	338.85	-18.43	0.71
75%	310.74	-25.20	1.13	310.94	-25.15	0.59	333.21	-19.79	1.48	331.19	-20.27	0.42	338.75	-18.45	0.67
50%	183.59	-15.48	-0.67	186.17	-14.86	-1.46	199.29	-11.70	-1.96	197.28	-12.19	-0.25	198.73	-11.83	-0.98
25%	26.96	-2.66	-0.23	28.24	-2.35	-0.75	30.00	-1.93	-1.08	29.64	-2.01	-0.12	29.40	-2.07	-0.83
100%	317.59	-23.54	2.03	348.32	-16.15	0.37	373.88	-9.99	0.50	368.80	-11.21	0.40	345.63	-16.79	1.71
75%	317.60	-23.54	1.99	348.33	-16.15	0.33	373.87	-10.00	0.47	368.80	-11.22	0.36	345.64	-16.80	1.61
50%	187.76	-14.47	-0.22	208.12	-9.57	-0.71	222.98	-6.00	-0.73	218.72	-7.02	-0.07	202.12	-11.02	-1.22
25%	28.05	-2.40	0.02	31.75	-1.50	-0.36	33.94	-0.98	-0.40	32.87	-1.24	-0.04	29.93	-1.94	-0.98
100%	351.56	-15.36	1.72	378.10	-8.97	0.61	415.38			398.77	-4.00	1.48	379.65	-8.60	1.98
75%	351.54	-15.37	1.69	378.12	-8.98	0.56	415.40			398.78	-4.00	1.47	379.66	-8.60	1.94
50%	208.58	-9.46	-0.33	226.43	-5.16	-0.54	247.88			236.54	-2.73	0.38	222.28	-6.16	-0.87
25%	31.77	-1.50	0.04	35.15	-0.69	-0.05	38.01			36.07	-0.46	0.35	33.32	-1.13	-0.63
100%	362.69	-12.68	2.28	376.93	-9.25	1.87	396.38	-4.57	1.93	398.80	-3.99	3.32	396.70	-4.50	2.17
75%	362.71	-12.68	2.23	376.97	-9.25	1.84	396.37	-4.58	1.89	398.79	-4.00	3.27	396.71	-4.50	2.09
50%	215.43	-7.81	0.47	225.14	-5.48	0.11	236.11	-2.83	0.42	234.52	-3.22	1.58	230.82	-4.11	0.22
25%	33.06	-1.19	0.48	35.22	-0.67	0.29	36.20	-0.44	0.39	35.70	-0.56	1.05	34.31	-0.89	0.18
100%	369.62	-11.02	3.19	365.81	-11.94	3.21	384.96	-7.32	2.84	386.74	-6.90	3.72	403.01	-2.10	2.03
75%	369.66	-11.01	3.12	365.81	-11.94	3.17	384.92	-7.34	2.80	386.75	-6.90	3.69	403.01	-2.09	2.00
50%	218.94	-6.96	2.06	216.01	-7.67	1.74	224.74	-5.57	1.84	222.42	-6.13	2.08	229.69	-4.38	0.17
25%	33.69	-1.04	1.52	33.53	-1.08	1.30	33.66	-1.05	1.33	32.80	-1.25	1.54	32.94	-1.22	0.18

Table 21. Mean measured values for a 5 x 5 matrix to determine the display uniformity for Display 1.

Figure 34. Visualization of the measured luminance differences at 100% for Display 1.

Looking at the visual representation of the measured results in Figure 36, it can be seen for Display 1 that the luminance decreases very strongly in the upper area of the display. Here, it should be noted that the illumination of most displays decreases toward the edges of the screen surface. This is especially true for the entire left area of this display, which shows strong deviations. The largest deviations are found in the upper area, decreasing significantly toward the bottom.

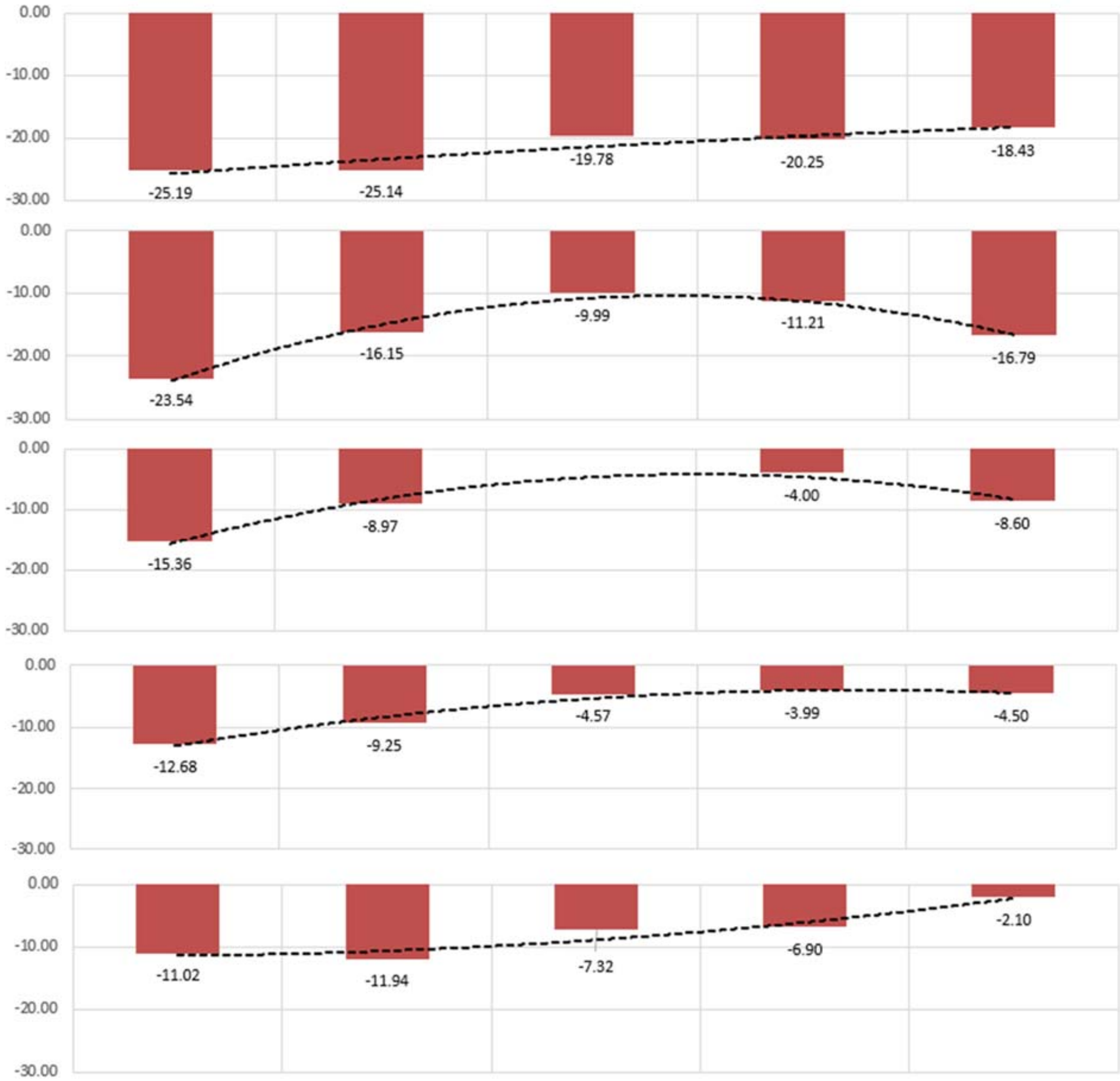


Figure 35. Graphical representation of the measured luminance differences at 100% for Display 1.

Looking at the results for the chromaticity difference ΔC^*_{00}, the overall picture changes: the largest deviations here are found in the lower area across the entire width of the display. The values also decrease upwards at the edges, with the left edge deviating more.

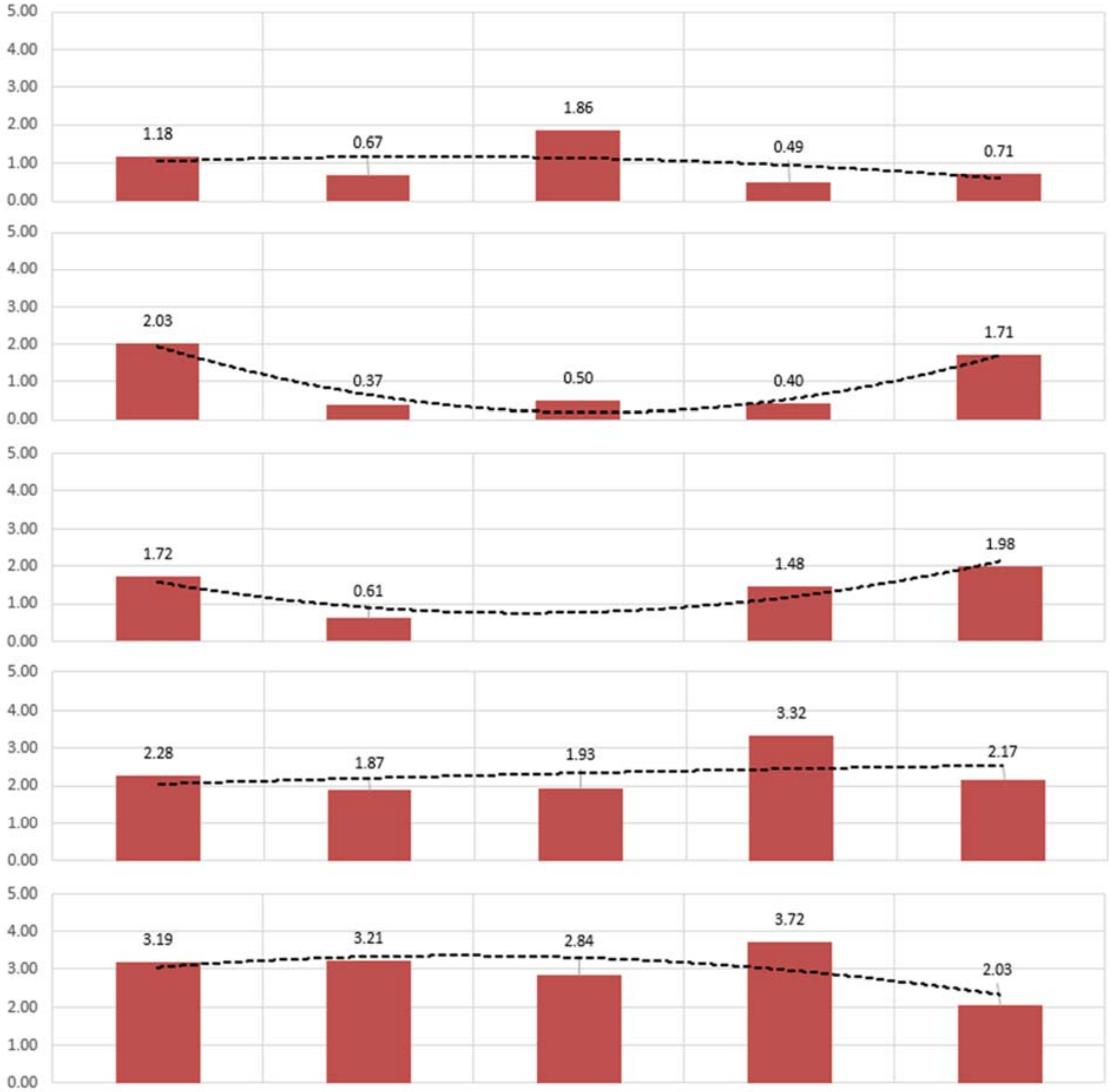


Figure 36. Graphical representation of the measured chromaticity differences ΔC^*_{00} at 100% for Display 1.

The values obtained for Display 2 are noticeably different. With a mean difference of 10.98%, the brightness distribution is almost identical to that of Display 1. The maximum value of 28.08% is slightly higher and can be found in the lower-left field. The mean chromaticity difference is $\Delta C^*_{00} = 1.63$, and the maximum difference $\Delta C^*_{00} = 3.79$ is in the upper-left field. The luminance of this display decreases very strongly, especially in the measurement fields at the lower edge of the screen. It also decreases significantly at the lateral edges, with the left edge being more affected. At the same time, the display also offers an area measuring 2 x 3 fields upwards from the center with excellent values (i.e., the display center extended upwards is relatively evenly illuminated). In contrast, large chromaticity difference values ΔC^*_{00} can be measured in all four corner fields and over the complete left edge. In the lower-left area of the display surface, a larger area of 2 x 3 fields deviates strongly.

	Lum. cd/m²	Delta %	ΔC^*_{00}	Lum. cd/m²	Delta %	ΔC^*_{00}	Lum. cd/m²	Delta %	ΔC^*_{00}	Lum. cd/m²	Delta %	ΔC^*_{00}	Lum. cd/m²	Delta %	ΔC^*_{00}
100%	289.08	-11.53	3.79	298.20	-8.74	0.70	304.46	-6.83	1.11	305.90	-6.39	2.04	313.45	-4.07	2.68
100%	282.59	-13.52	2.54	323.74	-0.93	0.69	333.39	2.03	0.77	332.27	1.68	1.58	305.27	-6.58	1.02
100%	272.13	-16.72	3.16	316.95	-3.00	1.02	**326.77**			322.78	-1.22	1.23	301.31	-7.79	0.61
100%	261.61	-19.94	1.97	289.86	-11.30	2.75	295.21	-9.66	2.67	291.14	-10.90	0.58	273.98	-16.16	0.51
100%	235.02	-28.08	2.87	249.89	-23.53	2.79	253.56	-22.38	1.70	250.65	-23.30	0.20	243.35	-25.53	1.87

Table 22. Mean measured values in the 5 x 5 matrix at luminance 100% for Display 2.

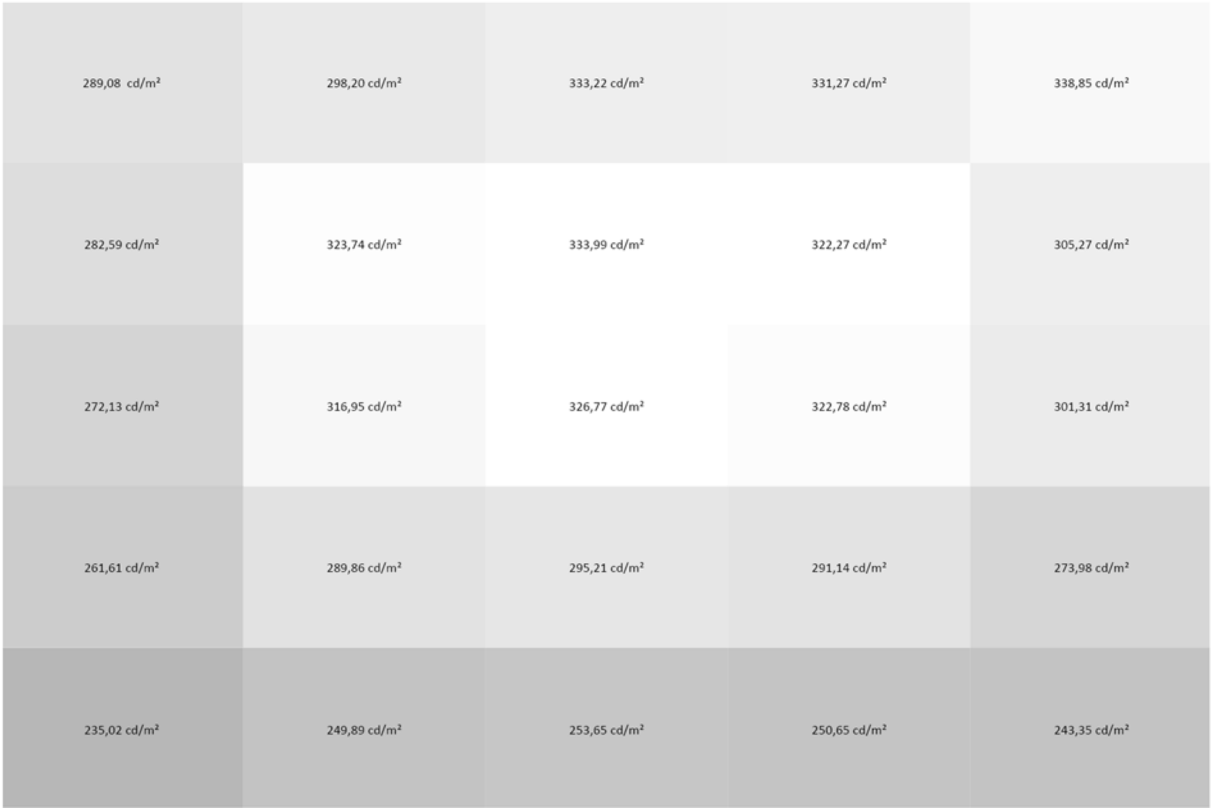


Figure 37. Visualization of the measured luminance differences at 100% for Display 2.

The measurements taken for Display 3 show the highest value out of all four displays, with a mean difference for the luminance distribution of 12.11%. The maximum value of 24.18% was measured at the lower-left edge of the screen. The largest deviations are also found at the edges of this display and, again, the left edge area in particular falls off. The upper and lower edges show similar deviations across the five measurement fields. Field 2 from the left at the upper as well as the lower edge are the areas with the largest measured differences.

The mean chromaticity difference for Display 3 is ΔC^*_{00} = 1.26. However, the highest differences of all displays (ΔC^*_{00} = 4.41 and ΔC^*_{00} = 4.04) were measured in two fields on the right edge in the center area of the screen. Whereas good results are offered by the middle area of the display, the deviations increase significantly toward the edges and the corners. The lower-left area is especially conspicuous, with slightly higher values compared to the upper edge.

	Lum. cd/m²	Delta %	ΔC*₀₀	Lum. cd/m²	Delta %	ΔC*₀₀	Lum. cd/m²	Delta %	ΔC*₀₀	Lum. cd/m²	Delta %	ΔC*₀₀	Lum. cd/m²	Delta %	ΔC*₀₀
100%	231.84	-20.94	1.55	227.69	-22.35	1.04	255.84	-12.75	1.09	239.78	-18.22	1.07	268.16	-8.55	1.34
100%	243.93	-16.82	1.16	272.40	-7.10	1.18	274.29	-6.46	0.38	269.83	-7.98	0.53	262.46	-10.50	1.41
100%	261.03	-10.99	1.14	272.88	-6.95	0.74	**293.26**			270.18	-7.86	0.53	263.53	-10.13	4.41
100%	244.67	-16.57	0.94	269.23	-8.19	0.75	273.26	-6.82	0.31	269.05	-8.25	0.62	263.80	-10.03	4.06
100%	237.64	-18.96	1.70	222.34	-24.18	1.95	254.79	-13.11	1.86	236.78	-19.25	0.98	264.35	-9.85	0.67

Table 23. Mean measured values in the 5 x 5 matrix at luminance 100% for Display 3.

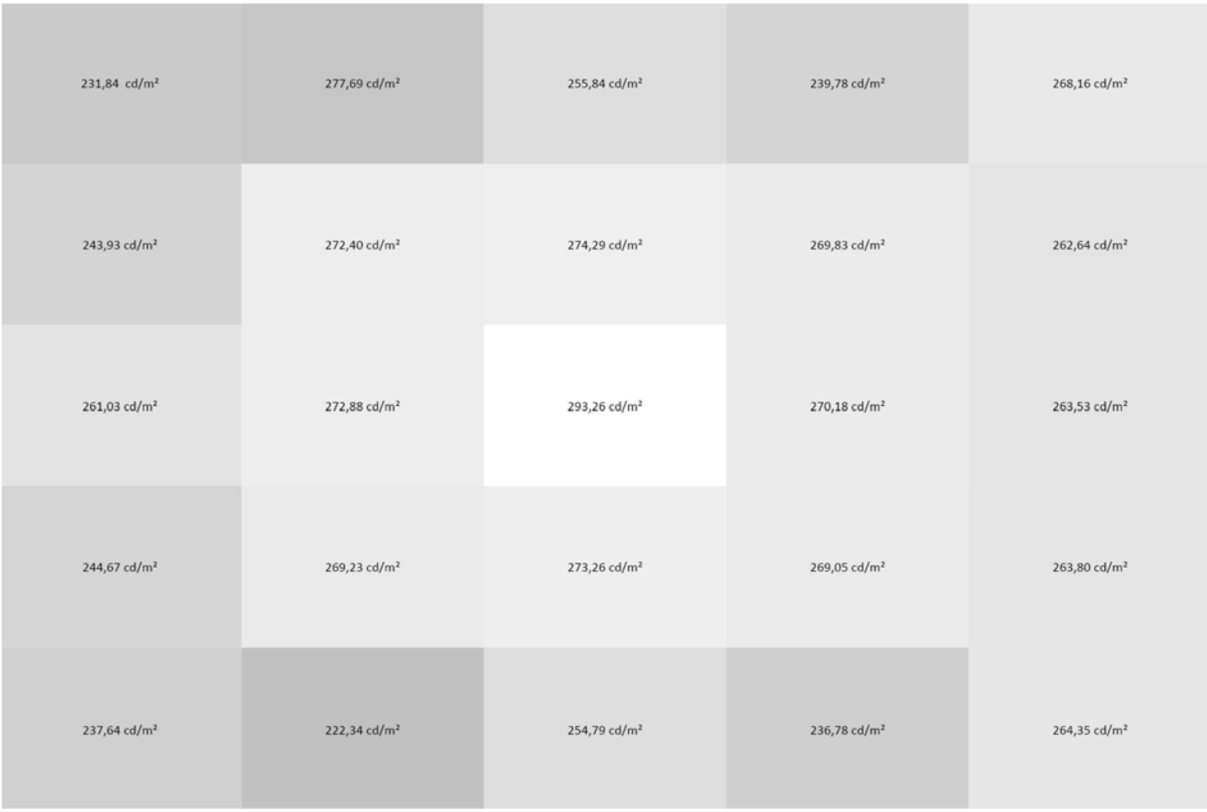


Figure 38. Visualization of the measured luminance differences at 100% for Display 3.

Finally, the uniformity and color homogeneity of Display 4 is examined. The measurements resulted in a mean difference of 8.20% for the luminance distribution. The maximum value was also measured in the lower-left field of the matrix for and is a significantly lower value of 19.47% compared to the other displays. The luminance decreases relatively evenly toward all edges in the overall view. The lower edge as well as the left edge of the screen show slightly larger differences and are therefore slightly darker.

The mean chromaticity difference is also lower at a value of ΔC^*_{00} = 1.40, while the maximum measured deviation is ΔC^*_{00} = 2.84. Here, too, the edges are mainly affected. However, the left and bottom edges show particularly strong deviations here: the eight largest measured deviations are found in the nine affected measuring fields.

	Lum. cd/m²	Delta %	ΔC^*_{00}	Lum. cd/m²	Delta %	ΔC^*_{00}	Lum. cd/m²	Delta %	ΔC^*_{00}	Lum. cd/m²	Delta %	ΔC^*_{00}	Lum. cd/m²	Delta %	ΔC^*_{00}
100%	411.08	-11.88	2.09	427.83	-8.29	0.81	428.44	-8.16	1.12	429.47	-7.94	1.37	404.67	-13.25	1.25
100%	409.98	-12.12	2.51	434.08	-6.95	0.69	436.66	-6.40	0.96	441.61	-5.34	1.18	415.82	-10.86	1.38
100%	432.71	-7.24	2.51	454.90	-2.49	0.69	466.50			470.13	0.78	0.25	445.96	-4.41	1.12
100%	413.39	-11.39	2.77	438.50	-6.00	0.88	444.24	-4.77	0.77	448.71	-3.81	1.00	439.03	-5.89	1.30
100%	375.66	-19.47	1.71	400.72	-14.10	1.10	411.54	-11.78	2.34	397.37	-14.82	2.84	427.05	-8.46	2.42

Table 24. Mean measured values in the 5 x 5 matrix at luminance 100% for Display 4.

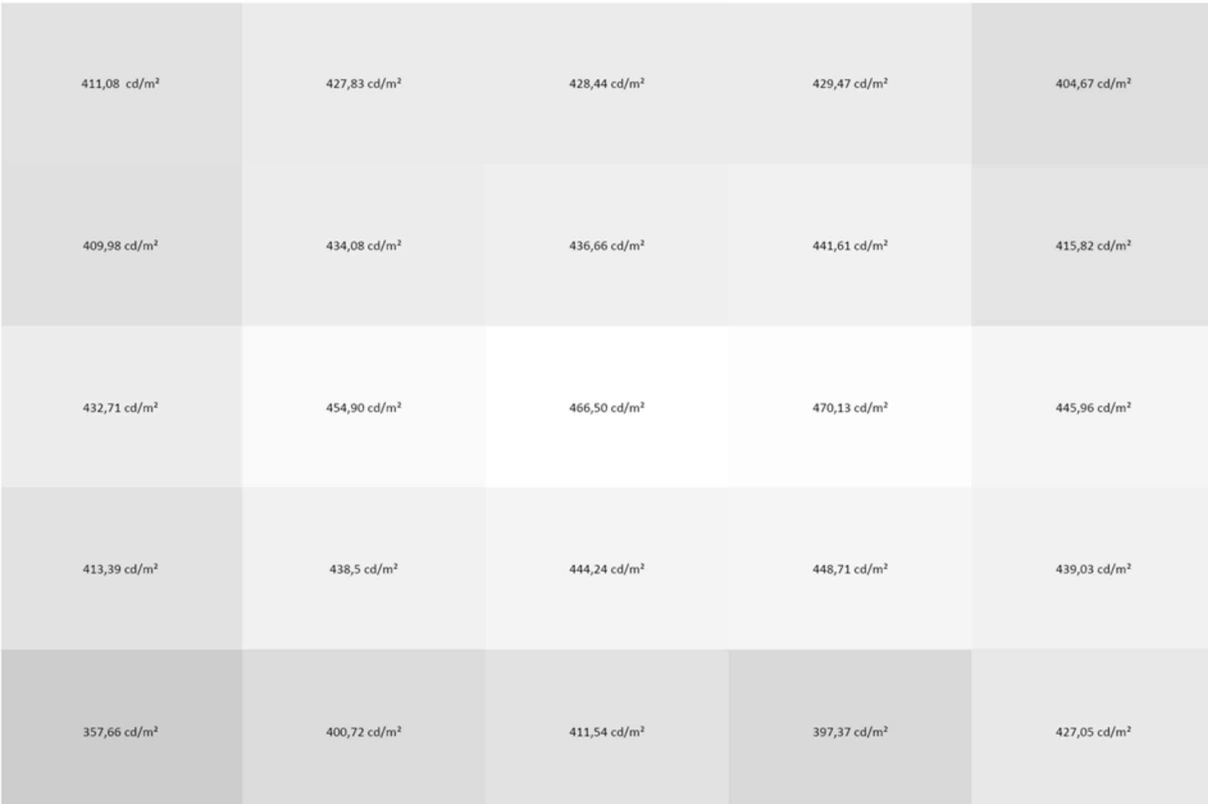


Figure 39. Visualization of the measured luminance differences at 100% for Display 4.

For the measurements to verify the stability of the color representation of the displays used, it is necessary to set them to a defined reproducible state. For Displays 1 and 2, the hardware settings already acquired for calibration and the profiles created on this basis are used, while Displays 3 and 4 are reprofiled on the basis of the native device color gamuts recorded in the previously performed measurements based on the sRGB color space. The previous nomenclature is also retained (e.g., Display3_sRGB_80_V1).

		White Lum. (cd/m²)	Black Lum. (cd/m²)	CCT (K)	White point				
					X	Y	Z	x	y
Day 1	Slot 1	159.50	0.2337	6452	95.16	100.00	107.91	0.3140	0,3300
		159.50	0.2339	6432	95.15	100.00	107.24	0.3139	0,3299
	Slot 2	159.60	0.2340	6436	95.10	100.00	107.95	0.3138	0,3300
		159.70	0.2341	6441	95.10	100.00	108.18	0.3137	0,3299
	Slot 3	159.60	0.2345	6441	95.07	100.00	107.60	0.3135	0,3298
		159.70	0.2343	6441	95.10	100.00	108.02	0.3136	0,3299
Day 2	Slot 1	159.60	0.2337	6452	95.07	100.00	108.04	0.3136	0,3298
		159.70	0.2342	6446	95.07	100.00	108.14	0.3137	0,3297
	Slot 2	159.60	0.2342	6451	95.09	100.00	108.13	0.3136	0,3298
		159.90	0.2337	6439	95.09	100.00	107.97	0.3138	0,3300
	Slot 3	160.20	0.2350	6480	95.03	100.00	108.51	0.3131	0,3294
		160.30	0.2356	6494	95.00	100.00	108.67	0.3128	0,3293
Day 3	Slot 1	160.00	0.2336	6379	95.19	100.00	108.13	0.3150	0,3309
		159.50	0.2342	6379	95.16	100.00	107.15	0.3148	0,3308
	Slot 2	159.60	0.2347	6388	95.11	100.00	107.19	0.3146	0,3308
		159.70	0.2350	6406	95.11	100.00	107.47	0.3143	0,3305
	Slot 3	159.40	0.2330	6399	95.15	100.00	107.43	0.3145	0,3305
		159.30	0.2334	6449	95.04	100.00	108.04	0.3136	0,3299
Day 4	Slot 1	159.30	0.2337	6400	95.11	100.00	107.38	0.3144	0,3306
		159.50	0.2341	6423	95.13	100.00	107.79	0.3140	0,3301
	Slot 2	159.70	0.2343	6441	95.10	100.00	108.02	0.3137	0,3299
		160.20	0.2349	6436	95.09	100.00	107.92	0.3138	0,3300
	Slot 3	160.50	0.2354	6483	95.04	100.00	108.58	0.3130	0,3294
		160.50	0.2355	6483	95.04	100.00	108.58	0.3130	0,3294
Day 5	Slot 1	159.90	0.2350	6468	95.05	100.00	108.35	0.3133	0,3296
		160.00	0.2351	6477	94.99	100.00	108.39	0.3131	0,3296
	Slot 2	160.10	0.2352	6481	94.99	100.00	108.46	0.3130	0,3295
		159.70	0.2349	6411	95.07	100.00	107.49	0.3142	0,3305
	Slot 3	159.90	0.2350	6419	95.08	100.00	107.64	0.3143	0,3303
		160.00	0.2353	6433	95.05	100.00	107.80	0.3138	0,3302

Mean	159,8	0.2344	6439	95.08	100.00	107.94	0.3138	0.3300
Min	159,3	0.2330	6379	94.99	100.00	107.15	0.3128	0.3293
Max	160,5	0.2356	6494	95.19	100.00	108.67	0.3150	0.3309
SD	0,3197	0.0007	31	0.0494	0.0000	0.4260	0.0006	0.0004

Table 25. Measured values for reference Display 1 acquired in the defined time slots as the basis of the stability analysis of the color representation performance.

During the defined period of five days, control measurements are taken in the three specified time slots with the previously used test form. Time slot 1 refers to a runtime of up to 120 min (including preheating), time slot 2 to a runtime of at least 300 min, and time slot 3 to a runtime of at least 480 min. In each of these time slots, two control measurements are made using display calibration device 1. The data gathered in this way is then used to evaluate the stability of the display performance over the increasing utilization periods of the displays. With each measurement performed, the values for white point, color temperature, white luminance, and black luminance are acquired, as examined in more detail in Part 1 of the analysis. In addition, the spectral values of 30 defined test colors are measured, which are then analyzed in Part 2.

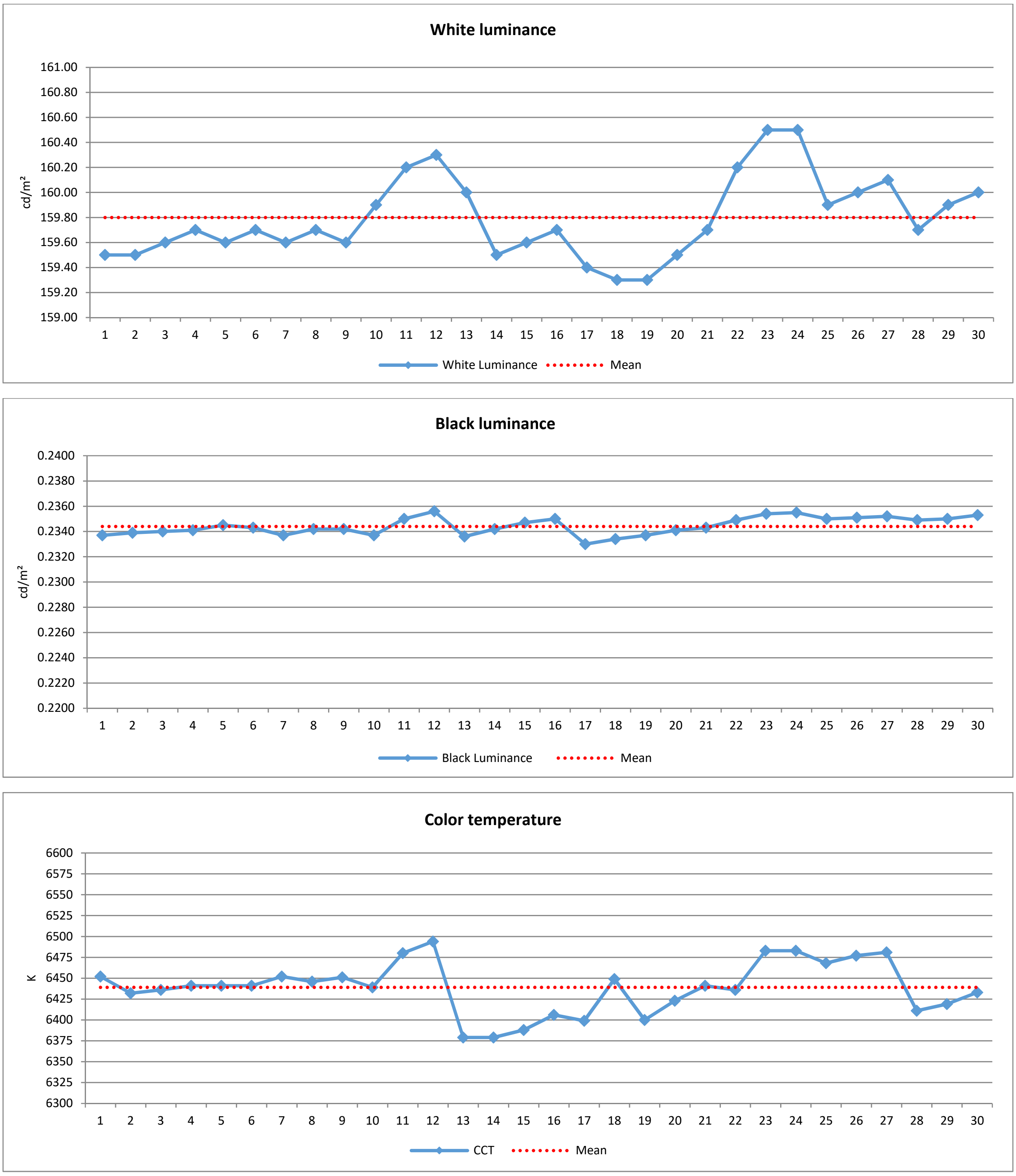


Figure 40. Measured values from 30 measurements in the defined test period of five days for Display 1.

Table 25 summarizes the values for white luminance, black luminance, color temperature, and white point achieved in the scheduled measurement cycle for Display 1. Considering all 30 measurements, a mean value of 159.8 cd/m² is obtained for the white luminance, with a minimum value of 159.3 cd/m² and a maximum of 160.5 cd/m². The fluctuation range is therefore 1.2 cd/m², while the standard deviation is SD = 0.3197. These are stable values. The white luminance deviates by a value of 0.7%, which means that these luminance deviations are not visually perceptible to humans. The black luminance has a mean value of 0.2344 cd/m² and varies by 0.0026 cd/m² with a maximum value of 0.2356 cd/m² and a minimum of 0.2330 cd/m². The standard deviation here is SD = 0.0007. For the CCT, which is a benchmark for measuring the white point, the averaged value of 6,430 K was acquired. The minimum of the measurements is 6,379 K and the maximum is 6,491 K, which means a delta of 115 K.

Leaving the overall view and first analyzing each of the five days of the test period separately, the picture shown in Figure 42 emerges. Here, the mean values of the six measurements performed per day are taken into account.

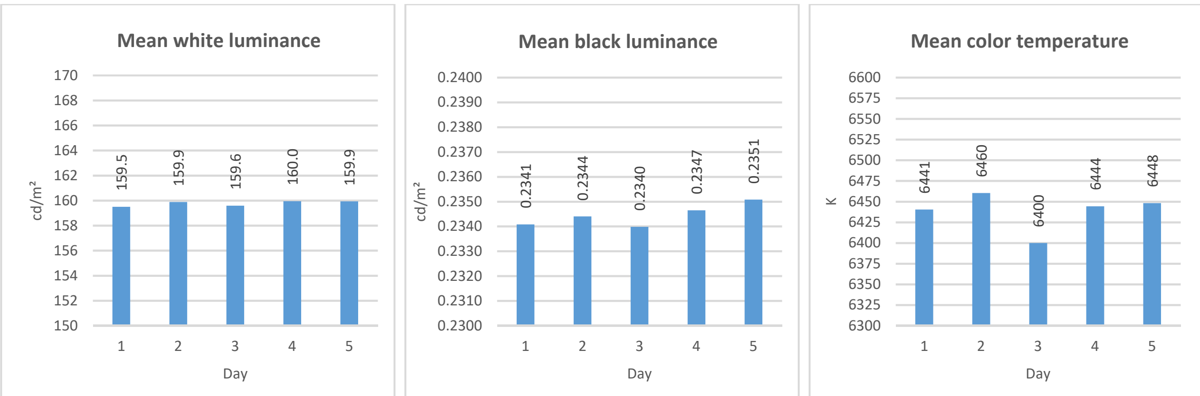


Figure 41. Mean measured values per single day of the test period (Display 1).

The average values of the white luminance vary over the five days from 159.5 cd/m² to 159.9 cd/m² (delta = 0.4 cd/m²). The mean values of the black luminance have their minimum at 0.2340 cd/m² and their maximum at 0.2351 cd/m² (delta = 0.0011). The minimum mean value for the color temperature is 6,400 K, while the maximum is 6,460 K; the values vary by 60 K. The most stable results are shown by the measurements on day 1: the delta of the white luminance is 0.2 cd/m², the delta of the black luminance is 0.0008 cd/m², and the delta of the color temperature is 20 K. By contrast, the measurements on day 4 show the greatest variation. Here, the delta of the white luminance is 1.2 cd/m²; for the black luminance, it is 0.0018 cd/m², and for the color temperature 80 K.

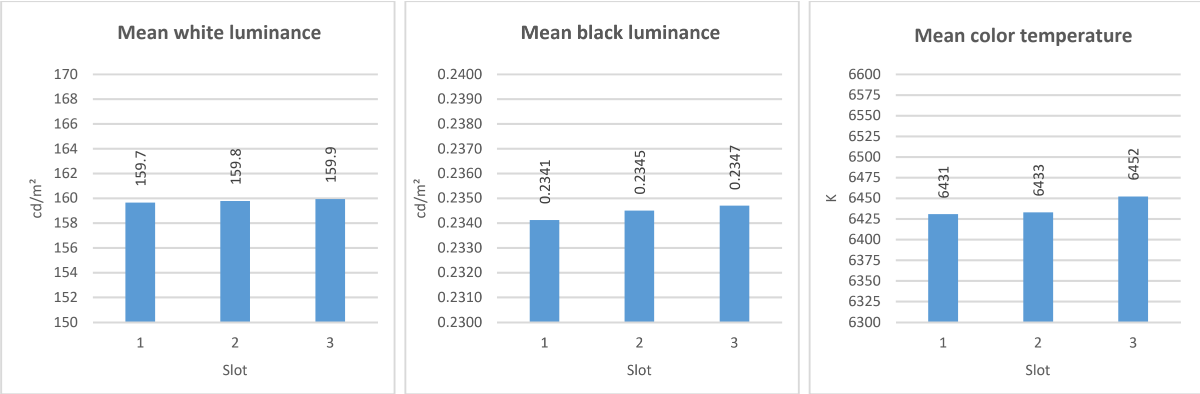


Figure 42. Mean measured values per time slot in the test period (Display 1).

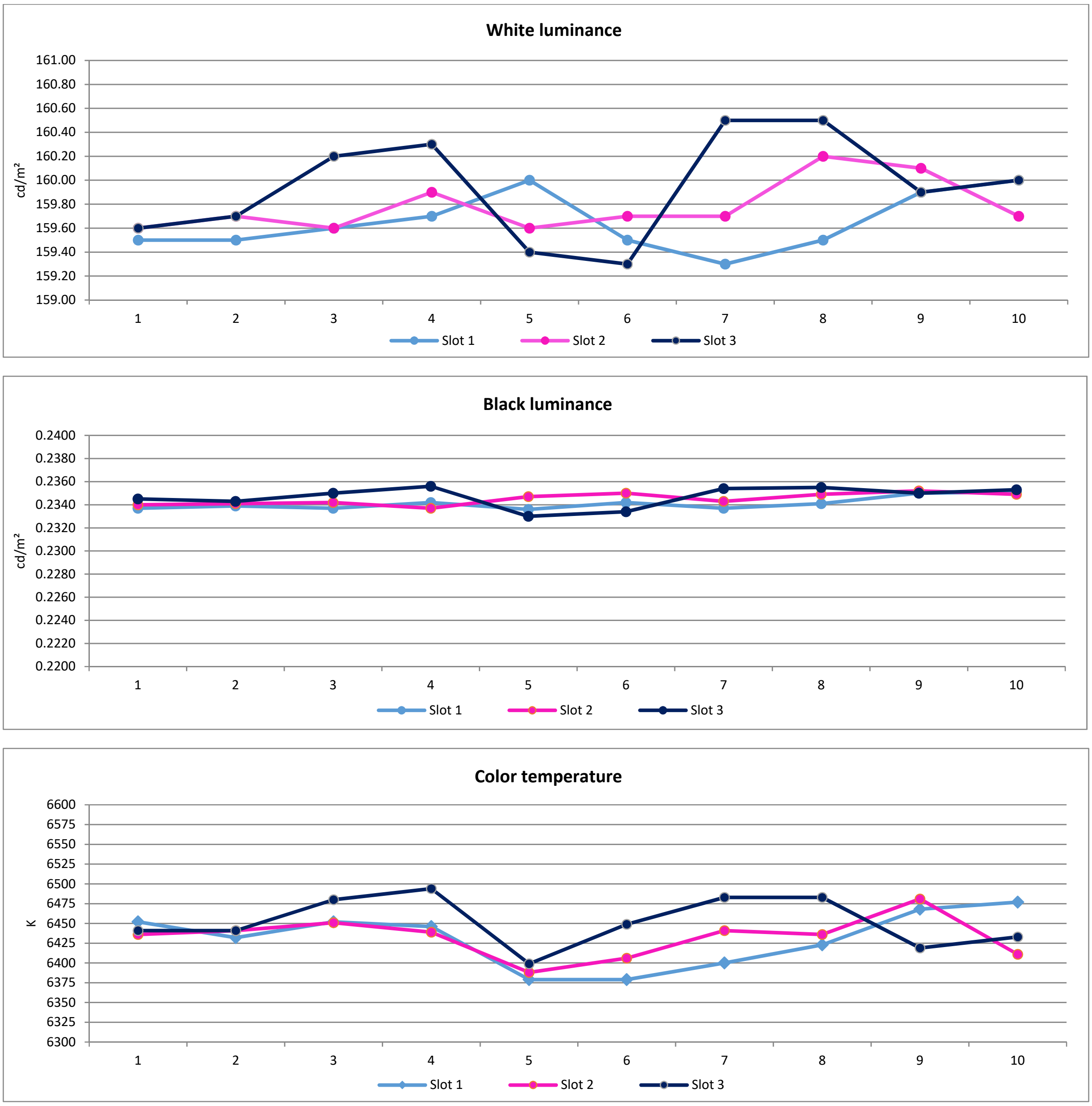


Figure 43. Measured values achieved per time slot for Display 1 (10 measurements in the test period of five days).

A look at the mean values for the single time slots 1 to 3 shows that they differ only slightly for white luminance, black luminance, and color temperature. As a tendency, a slight increase of the averaged values with increasing usage time can be observed. A more detailed look at the results in the individual time slots reveals a somewhat similar yet still unsettled picture for all parameters. The white luminance in time slot 1 is mostly slightly below the values measured in time slot 2. In time slot 3, on the other hand, we see strong variations that form both the maximum and minimum measured values. This consideration can be directly applied to the determined values for black luminance. The color temperature values are at almost the same level in time slots 1 and 2. Only on day 3 does the difference increase, which can be explained by a decrease of the measured values in time slot 1. The highest values are found in time slot 3. Only once on day 5 does the measured value fall below the values of the other two time slots.

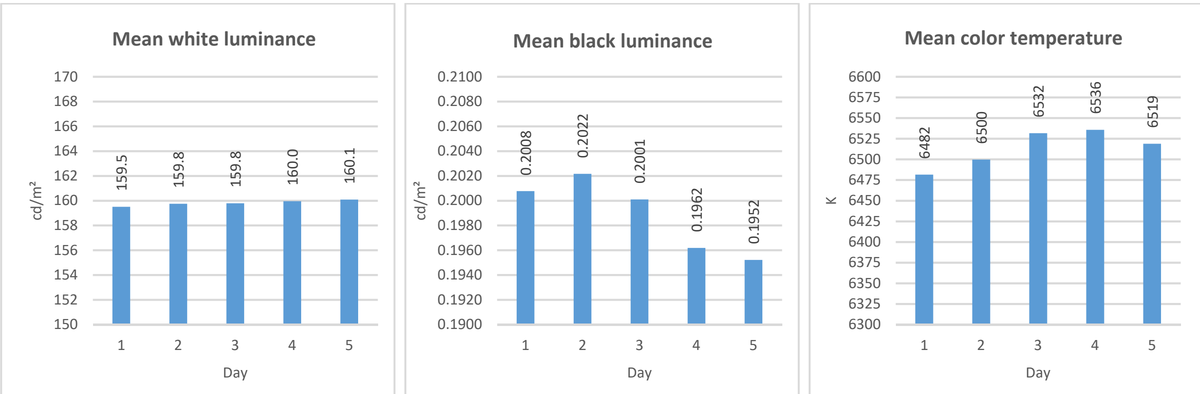


Figure 44. Mean measured values per single day of the test period (Display 2).

The analysis of the measured values for Display 2 also leads to good results. In the overall view, the mean white luminance is 159.9 cd/m². The measured values vary by 0.8 cd/m² between the maximum 160.3 cd/m² and the minimum 159.5 cd/m². The black luminance has a mean value of 0.1989 cd/m². The mean color temperature is 6,513 K, varying by 96 K over the 30 measurements performed.

An examination of the values for the respective test days shows a steady slight increase from day to day for the mean white luminance up to a maximum of 160.1 cd/m² on day 5. The black luminance, on the other hand, decreases after a peak of 0.2022 cd/m² on day 2 and is still 0.1952 cd/m² on day 5. The mean color temperature increases from 6,482 K on day 1 to the mean maximum of 6,536 K on day 4, before dropping slightly to 6,519 K on day 5. The smallest deviations for all 10 measurements in a single day are seen for all three parameters on day 1: the white luminance varies by only 0.3 cd/m², the black luminance by 0.0024 cd/m², and the color temperature by 23 K.

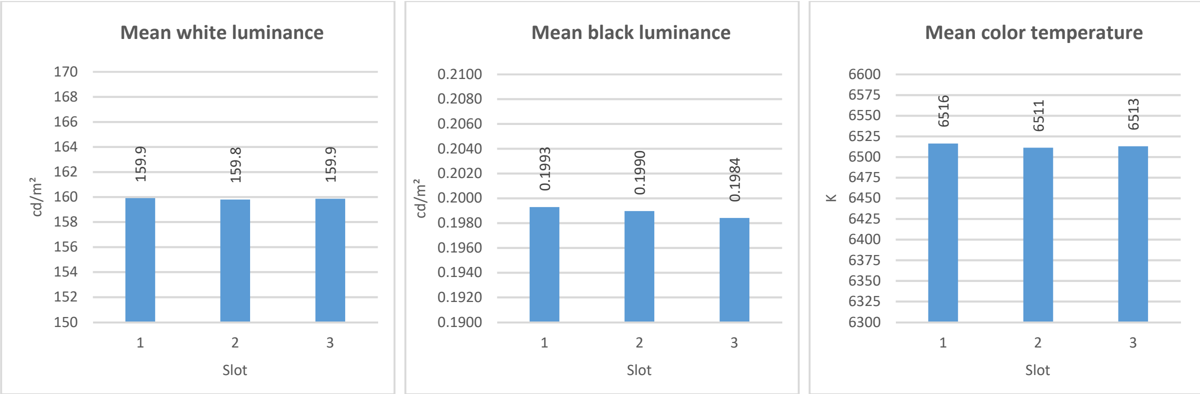


Figure 45. Mean measured values per time slot in the test period (Display 2).

Figure 46. Measured values achieved per time slot for Display 2 (10 measurements in the test period of five days).

Analysis of the data at the time slot level leads to the following results. The mean values of the white luminance show only minor differences. The minimum in time slot 2 is 159.8 cd/m², while the maximum in time slot 1 is 159.9 cd/m². Starting at time slot 1, the values for black luminance decrease from the maximum 0.1993 cd/m² to the minimum 0.1984 cd/m² in time slot 3. The averaged color temperature values show the same tendency as the white luminance. The maximum value of 6,516 K was measured in time slot 1 and the minimum of 6,511 K in time slot 2.

Comparing the values measured in the single time slots over the test period, it cannot be determined that one time slot dominates the others. The results are close to each other and vary only slightly. For the white luminance, the largest delta of 0.6 cd/m² is found in the last measurement on day 5. On day 3, the values in slot 2 drop slightly compared to slot 1 and slot 3 to a minimum of 159.5 cd/m². The largest variation in black luminance is seen in the first measurements on day 4: its value decreases by 0.0036 cd/m² from time slot 1 (0.2001 cd/m²) to time slot 3 (0.1963 cd/m²). The color temperature also has its largest delta on day 4, decreasing by 88 K (from 6,562 K to 6,474 K).

In contrast to displays 1 and 2, displays 3 and 4 are calibrated and profiled based on the sRGB standard color gamut. As a result, the reference value of the luminance here is 80 cd/m² rather than 160 cd/m².

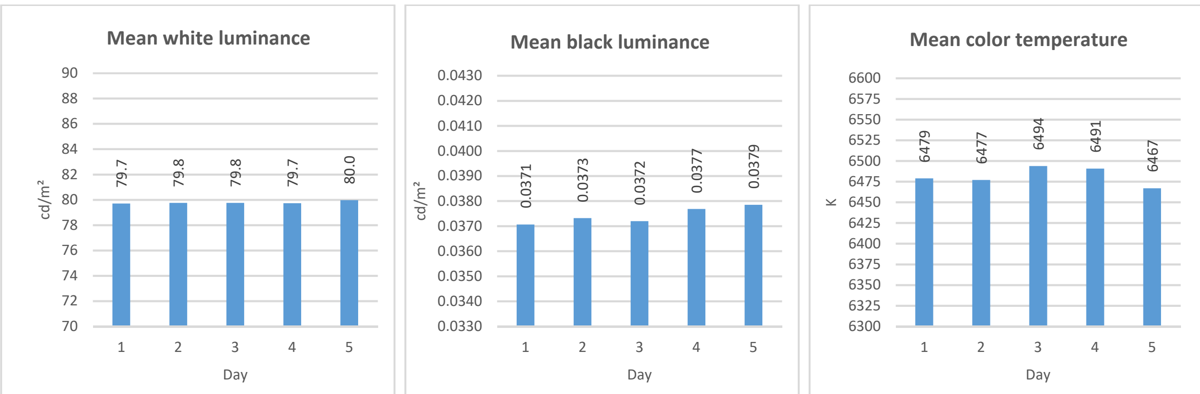


Figure 47. Mean measured values per single day of the test period (Display 3).

For Display 3, the mean value of the white luminance over all 30 measurements is 79.8 cd/m². The measured minimum is 79.5 cd/m²; the maximum is 80.1 cd/m². Thus, the results vary by 0.6 cd/m². The mean black luminance is 0.0374 cd/m². The values here vary between 0.0369 cd/m² and 0.0379 cd/m². The mean color temperature is 6,481 K, with a fluctuation range of 56 K between the maximum 6,510 K and the minimum 6,454 K, which is significantly lower than in the other tested displays.

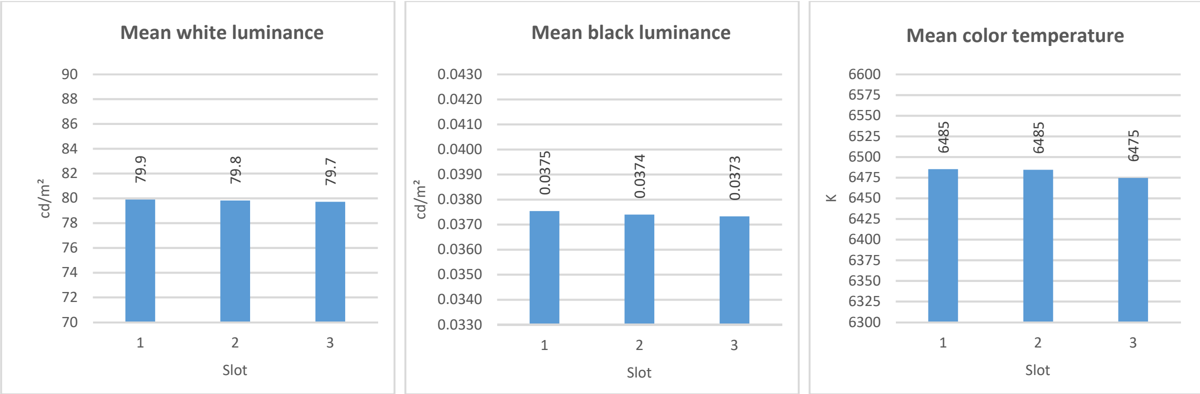


Figure 48. Mean measured values per time slot in the test period (Display 3).

Figure 49. Measured values achieved per time slot for Display 3 (10 measurements in the test period of five days).

Summarizing the measurements at the level of the single test days, the mean white luminance is 79.85 cd/m². The minimum of 79.73 cd/m² results from the measurements on day 4 and almost coincides with those of days 2 and 3. The maximum value is 79.97 cd/m² on day 5. The mean black luminance is 0.0374 cd/m². If this is still very constant over days 1 to 3, it increases over day 4 to the maximum of 0.0379 cd/m² on day 5. The mean color temperature varies by 27 K over the five days (i.e., in a very narrow range). The maximum of 6,454 K results from the measurements on day 3. In short, the results of the six measurements per day are very stable. Examining the data with a focus on the three single time slots, the expected results are obtained. The values from time slots 1 and 2 are very close to each other, while the values from time slot 3 are slightly lower, with the exception of measurement 8 from day 4. The maximum mean white luminance is 79.89 cd/m² in time slot 1, but the minimum of 79.72 cd/m² in time slot 3 deviates only slightly. Here, the measured values for the white luminance also vary the most (by 0.5 cd/m²). These conclusions can also be applied to the black luminance., where the mean maximum is 0.0375 cd/m² and the minimum is 0.0373 cd/m² in time slot 3. Here, too, the data obtained in time slot 3 are at a lower level, except for measurement 8 from day 4. The mean color temperature varies from the maximum 6,485 K in time slots 1 and 2 to the minimum 6,475 K. Days 1 and 2 still show the largest deviations between the results of the single time slots: the delta for day 2 is still 51 K before decreasing to 16 K on the following days.

The overall analysis of Display 4 provides very even values with little discordance. The mean white luminance for the 30 measurements is 81.2 cd/m² with a standard deviation of 0.1779. The measured maximum is 81.6 cd/m² and the minimum is 80.8 cd/m². Thus, the values vary within a range of 0.8 cd/m². The mean black luminance is 0.1204 cd/m² with a standard deviation of 0.0004. For the color temperature, the mean value is 6,401 K, varying by 114 K between the maximum of 6,471 K and the minimum of 6,357 K.

In the summary of the values for the individual test days, the mean value for the white luminance is 81.2 cd/m². However, this is only exceeded on day 2; the 81.5 cd/m² determined here is a small but noticeable peak since the mean values for the other four days are very close to each other and almost identical. The mean black luminance is 0.1204 cd/m². Again, a small peak is seen on day 2 at a maximum of 0.1210 cd/m². The difference to the minimum of day 1 is 0.0010 cd/m². The mean color temperature is 6,401 K. The maximum of 6,422 K on day 4 and the minimum of 6,380 K on day 2 represent a fluctuation range of 42 K. The measurements on day 3 are particularly stable: the white luminance here is a constant 81.2 cd/m², the black luminance varies by only 0.0002 cd/m², and the color temperature also only differs by 8 K. The strongest fluctuations of all three parameters can be seen on day 5.

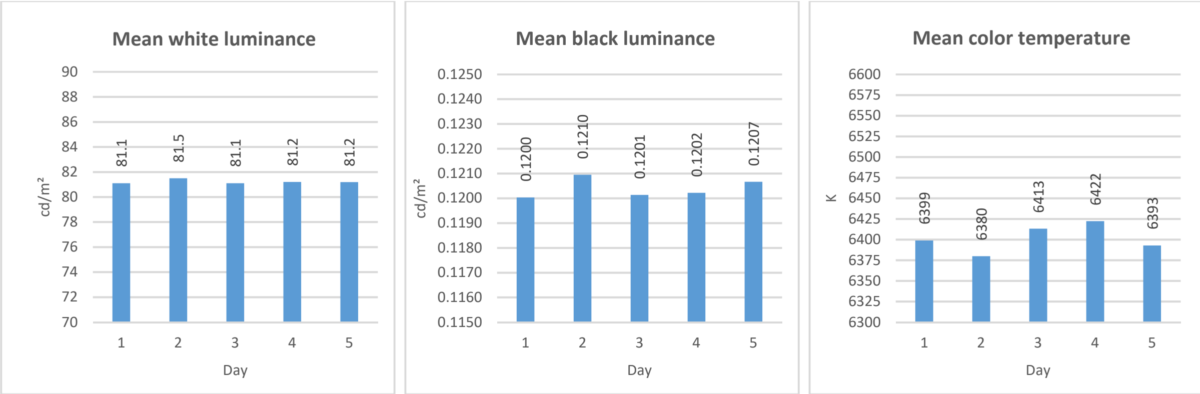


Figure 50. Mean measured values per single day of the test period (Display 4).

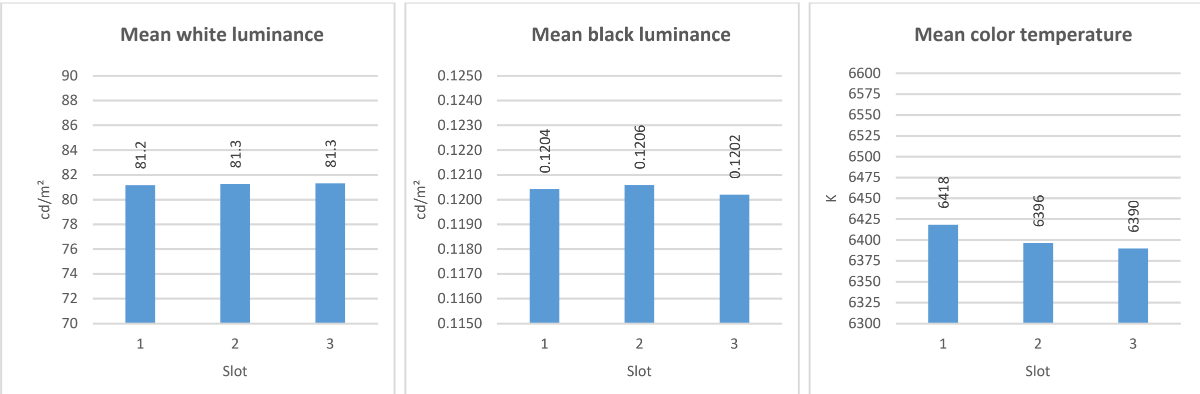


Figure 51. Mean measured values per time slot in the test period (Display 4).

At the time slot level, the respective mean white luminance shows a minimum of 81.25 cd/m² in time slot 1 and a maximum of 81.3 cd/m² in time slot 3. The mean black luminance varies from 0.1202 cd/m² to 0.1206 cd/m². The color temperature has a mean maximum of 6,415 K in time slot 1 and decreases to the minimum of 6,390 K in time slot 3. The largest deviations of the three characteristic values are found in the 10 measurements for time slot 1. The white luminance varies from 80.8 cd/m² to 81.5 cd/m²; these values are also the minimum and maximum for all 30 measurements. The maximum color temperature of 6,471 K was also measured in time slot 1.

Looking at the results for the white luminance more closely, it can be noted that the measured values in time slots 2 and 3 only differ slightly. However, two peaks are observed on day 3 and day 5, where the measured values then drop sharply, resulting in a correspondingly larger difference compared to the other time slots. By contrast, the values for the black luminance are very stable. Here, the results from day 2 show the largest deviation between the individual time slots. For the color temperature, the statement about the white luminance applies; the peaks are likewise found on day 3 and day 5. Here, however, the values increase significantly and are up to 83 K higher than in time slots 1 and 2.

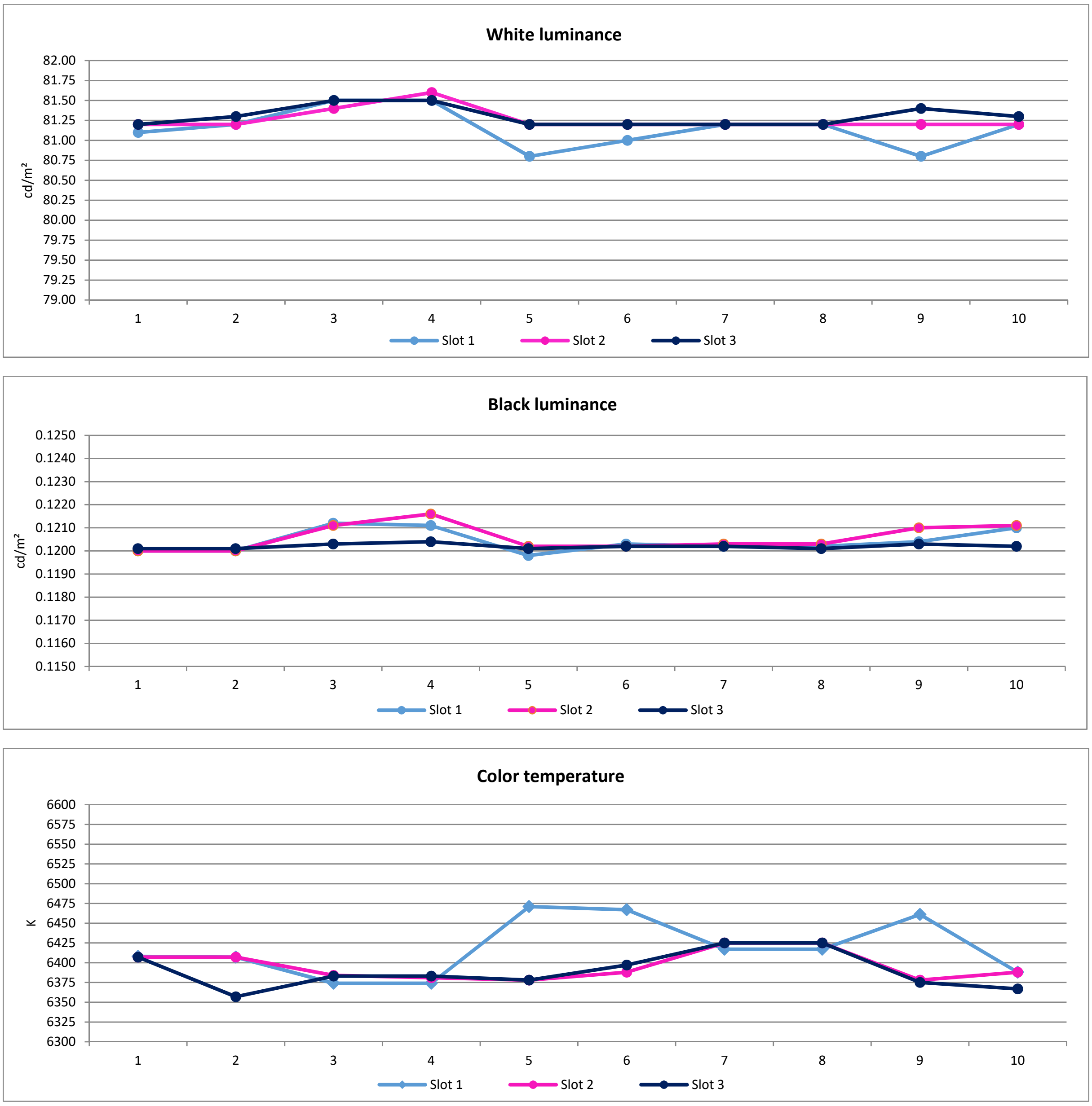


Figure 52. Measured values achieved per time slot for Display 4 (10 measurements in the test period of five days).

In Part 2 of the analysis, a larger database is provided to evaluate the stability of the color representation of the four displays. For each day of the test period, the values of all 30 included test colors are also evaluated based on two randomly selected measurements. For this purpose, the color difference ΔE_{00} between the nominal color values as defined by the display profile applied and the actually measured color values is used.

The values shown in Table 26 for Display 1 confirm the impression of stable color representation already gained in Part 1 of the analysis. Summarizing the 30 test colors of each measurement run, a mean color difference of ΔE_{00} = 0.18 is obtained for the entire test period. The minimum ΔE_{00} = 0.15 shows the results of the second measurement on Day 1, while the maximum ΔE_{00} = 0.23 comes from the second measurement on Day 4.

	Nominal Values			Day 1		Day 2		Day 3		Day 4		Day 5	
Color	L*	a*	b*	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}
1	30.73	64.64	48.49	0.02	0.03	0.03	0.05	0.01	0.01	0.13	0.13	0.16	0.15
2	58.82	104.87	93.98	0.01	0.01	0.00	0.02	0.08	0.05	0.02	0.07	0.04	0.03
3	68.38	77.12	37.49	0.06	0.05	0.06	0.04	0.09	0.06	0.10	0.12	0.15	0.12
4	55.46	-97.26	64.06	0.05	0.04	0.05	0.08	0.07	0.03	0.17	0.25	0.09	0.11
5	84.76	-137.79	91.88	0.03	0.02	0.02	0.05	0.11	0.04	0.05	0.08	0.03	0.02
6	88.01	-95.27	64.37	0.03	0.02	0.05	0.08	0.09	0.04	0.13	0.13	0.12	0.11
7	16.63	43.55	-74.76	0.01	0.09	0.07	0.02	0.11	0.05	0.05	0.10	0.06	0.02
8	31.70	66.67	-112.36	0.04	0.08	0.08	0.05	0.14	0.08	0.05	0.05	0.05	0.02
9	52.23	30.77	-78.08	0.06	0.06	0.06	0.08	0.24	0.08	0.26	0.19	0.17	0.19
10	52.42	-63.49	-6.60	0.06	0.07	0.05	0.12	0.08	0.08	0.10	0.18	0.07	0.16
11	88.57	-91.25	-18.75	0.09	0.05	0.11	0.08	0.13	0.11	0.07	0.06	0.07	0.05
12	92.32	-53.30	-12.88	0.10	0.13	0.11	0.15	0.04	0.10	0.20	0.23	0.17	0.14
13	29.70	63.13	-41.21	0.03	0.03	0.03	0.06	0.04	0.02	0.21	0.15	0.18	0.17
14	64.65	113.43	-56.57	0.03	0.02	0.01	0.05	0.10	0.05	0.04	0.05	0.06	0.05
15	78.06	68.31	-34.66	0.02	0.05	0.04	0.09	0.03	0.04	0.08	0.05	0.04	0.03
16	59.79	-11.50	73.79	0.03	0.05	0.10	0.04	0.09	0.06	0.13	0.16	0.09	0.12
17	96.92	-15.49	111.96	0.06	0.02	0.02	0.08	0.02	0.02	0.05	0.04	0.03	0.04
18	98.03	-10.96	54.52	0.08	0.08	0.11	0.18	0.08	0.07	0.13	0.11	0.05	0.09
19	50.38	59.69	28.73	0.51	0.49	0.52	0.46	0.52	0.51	0.60	0.61	0.61	0.60
20	69.25	-83.59	54.31	0.47	0.46	0.46	0.48	0.45	0.44	0.53	0.56	0.51	0.48
21	37.77	25.27	-63.60	0.34	0.36	0.34	0.41	0.34	0.36	0.51	0.49	0.50	0.51
22	66.79	-60.36	-9.17	0.38	0.36	0.42	0.41	0.44	0.37	0.36	0.38	0.36	0.34
23	49.37	68.10	-40.04	0.42	0.43	0.42	0.42	0.39	0.39	0.47	0.52	0.46	0.48
24	72.91	-14.02	66.66	0.53	0.51	0.52	0.53	0.49	0.51	0.52	0.56	0.53	0.53
25	61.82	109.31	-21.62	0.09	0.09	0.08	0.14	0.12	0.08	0.15	0.12	0.10	0.09
26	91.74	-54.11	103.44	0.14	0.11	0.10	0.10	0.08	0.12	0.18	0.18	0.14	0.18
27	67.78	-42.55	-52.16	0.60	0.55	0.61	0.48	0.60	0.64	0.59	0.62	0.63	0.60
28	86.51	-116.69	25.04	0.06	0.03	0.02	0.09	0.11	0.04	0.20	0.16	0.16	0.13
29	45.97	87.19	-88.38	0.06	0.06	0.05	0.12	0.13	0.04	0.12	0.10	0.16	0.14
30	81.67	29.87	101.25	0.24	0.20	0.29	0.28	0.17	0.21	0.34	0.36	0.21	0.24
			Mean	0.16	0.15	0.16	0.17	0.18	0.16	0.22	0.23	0.20	0.20
			Min	0.01	0.01	0.00	0.02	0.01	0.01	0.02	0.04	0.03	0.02
			Max	0.60	0.55	0.61	0.53	0.60	0.64	0.60	0.62	0.63	0.60
			SD	0.1806	0.1727	0.1821	0.1641	0.1659	0.1771	0.1789	0.1854	0.1846	0.1825

Table 26. Calculated color differences ΔE_{00} from the nominal color values of the 30 test colors from 10 randomly selected measurement runs for Display 1.

An examination of the 10 values acquired for each single color also confirms this conclusion. The mean value of the measured color differences over all 30 test colors is ΔE_{00} = 0.13, and the mean standard deviation is SD = 0.0411. The maximum measured color difference is found for color 4, with a delta of 0.22 over the 10 measured values (SD = 0.0648). The maximum is ΔE_{00} = 0.25, while the minimum is ΔE_{00} = 0.03. It should be noted that the measured color differences of the two examined measurements on day 4 deviate significantly from the results for the other test days. This also applies to other colors, which is also reflected in the mean color difference ΔE_{00} of all single colors for day 4. For both samples, the highest value was determined here compared to the other test days. This also corresponds with the analysis of white luminance and color temperature. Both characteristic values show the greatest deviation in the measurement cycle on this day when considering the three measurement windows.

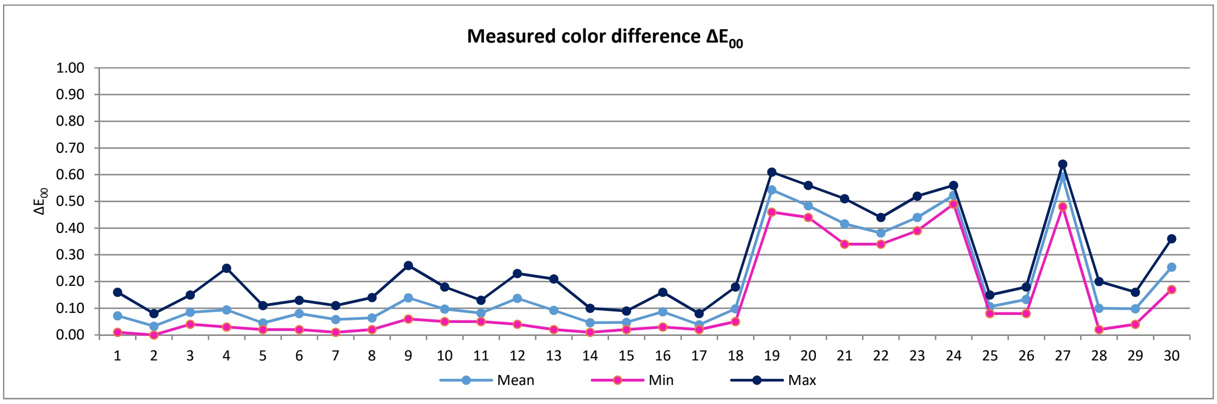


Figure 53. Summarized visualization of the color differences (ΔE_{00}) measured for the 30 test colors for Display 1.

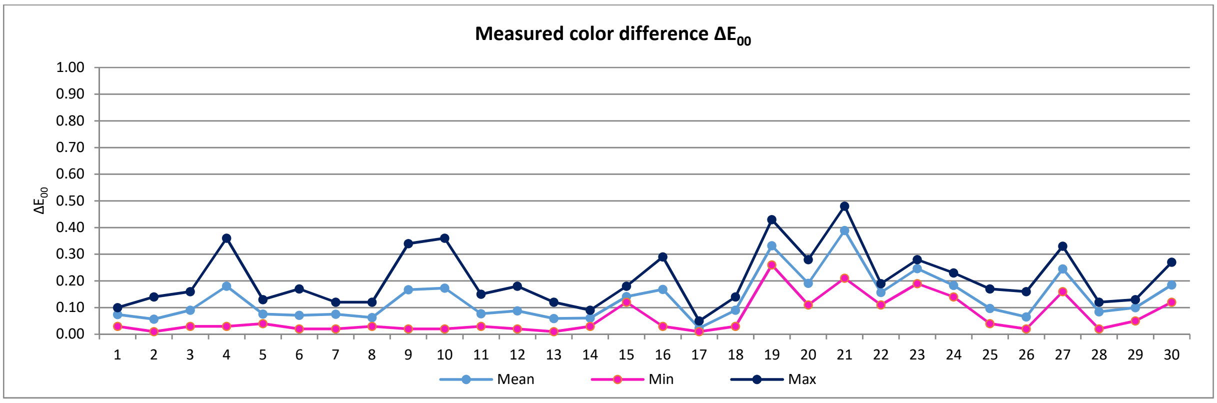


Figure 54. Summarized visualization of the color differences (ΔE_{00}) measured for the 30 test colors for Display 2.

For Display 2, the mean value of the measured color differences of the 10 evaluated measurement runs across all single colors is $\Delta E_{00} = 0.13$. The mean minimum of $\Delta E_{00} = 0.10$ results from sample 1 on day 1, and the maximum of $\Delta E_{00} = 0.18$ from sample 1 on day 4. The analysis of the 10 values for each single color also yields a mean $\Delta E_{00} = 0.13$. The measured values deviate most strongly within color 10, with a delta of 0.34. Larger differences are also

found for colors 4 and 16. These are due to the results of the second sample on day 2, all the samples on day 3, and sample 1 on day 4 for all three colors.
For Display 3, examination of the color differences determined here also shows slightly varying results. The mean color difference is ΔE_{00} = 0.18, and the mean standard deviation is SD = 0.1144. Considering all single colors, it can be seen that slightly larger color differences above the limit value ΔE_{00} = 0.2 are measured, especially for color 19. Larger differences between the single measurements can also be observed here. For color 30, the measured color difference varies most between measurement run 2 (ΔE_{00} = 0.21) and measurement run 10 (ΔE_{00} = 0.41). Similar differences can still be found in colors 20 and 26. However, the results obtained are essentially stable within the single color measurement.

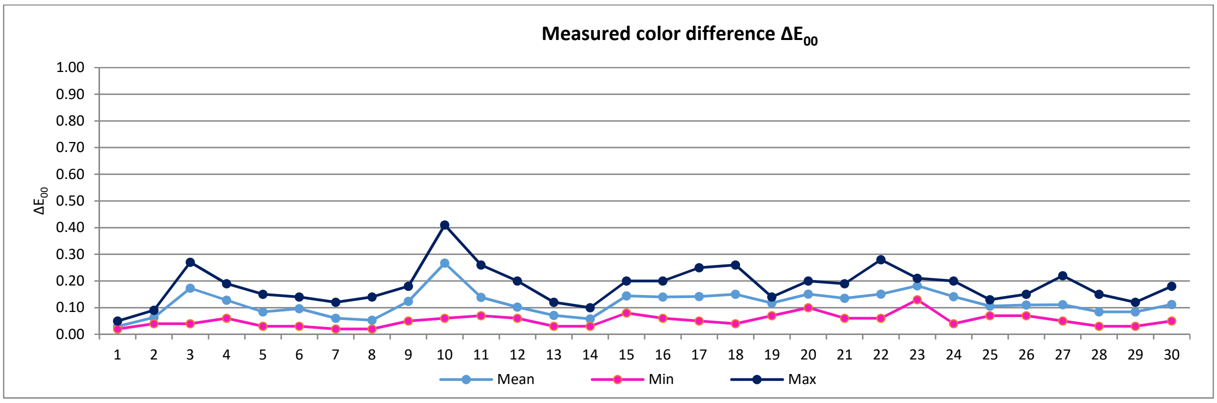


Figure 55. Summarized visualization of the color differences (ΔE_{00}) measured for the 30 test colors for Display 3.

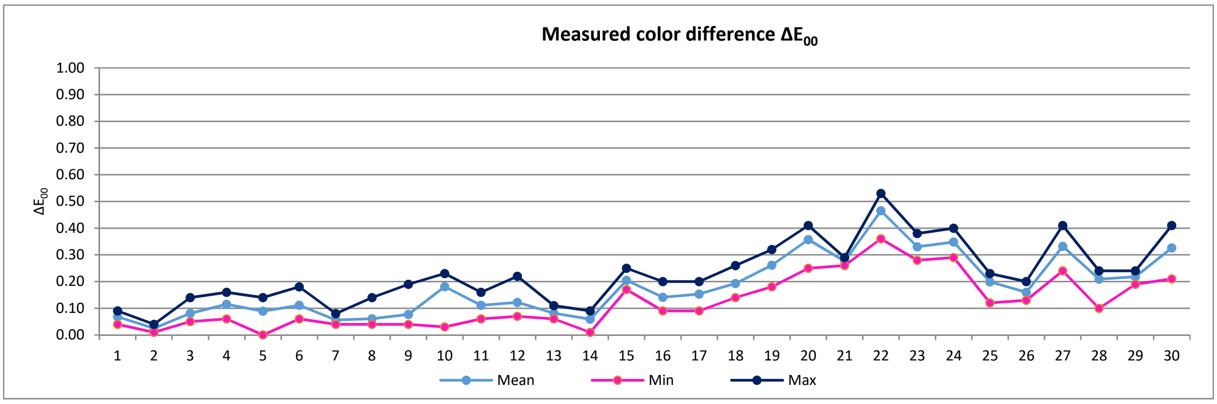


Figure 56. Summarized visualization of the color differences (ΔE_{00}) measured for the 30 test colors for Display 4.

Finally, the color difference measurements are also evaluated for Display 4. The mean color difference for the individual measurement runs is ΔE_{00} = 0.12. The averaged standard deviation

is SD = 0.0595. The minimum of ΔE_{00} = 0.07 results from measurement run 1 on day 1, while the maximum of ΔE_{00} = 0.15 comes from measurement run 9 on day 5.
The mean color difference of the 10 measured values for each single color here is also ΔE_{00} = 0.12. The mean standard deviation is SD = 0.0463. The largest difference between the color differences determined can be seen in color 10, with a delta of 0.35. The color differences measured for color 10 already increase slightly in measurement runs 1 to 3, and then make a clear jump to ΔE_{00} = 0.32 in measurement run 4 before varying at this clearly increased level in the subsequent measurements. Noticeable differences between the results of the single measurement runs can also be found for colors 3, 17, 18, and 22.

4.7 Color matching experiments

The quality of the color representation of a display has a significant influence on the individual color perception of an observer. In the context of this study, color matching experiments are used to investigate the correlation between individual visual color perception and the real reproduced colorimetric values of the displays. The aim is to obtain as many data sets as possible, on the basis of which an analysis of the individual color perception of the test participants is possible, and the influence of the respective displays can be properly assessed.

4.7.1 Procedure and approach

The participants are given the main task of matching a target color shown on a display in a defined size within an inserted mask and using the three primary colors red, green, and blue (RGB) until the visual match is as exact as possible. All test displays are set to a reproducible state for the experiments. For this purpose, the profiles created in the context of the previous examinations are used, while a check to verify the calibration is performed daily.
All displays are only tested after preheating of 60 min and are then approved for the experiments, which take place under defined measurement conditions in a darkened room. The participants are given sufficient time to adapt to the ambient light conditions (chromatic adaptation). This time is used to hold an introductory conversation with the participants, during which the procedure and details of the tests are presented. Possible risks are discussed, and the handling and use of the data obtained is explained. As a guideline, the document "Information form and consent" from the University of Strasbourg is used, which must be signed by the participants and the person carrying out the data collection (see Annex 4).
For the experiments, an application was programmed in the development environment "unity" to guide the participants through two defined part-experiments (hereafter referred to as Task 1

and Task 2). These are based on the identical basic task specified at the beginning of this chapter. The selected target colors are based on the colors of the ColorChecker Classic target. In Task 1, the test patches are presented to the participants one by one in a defined size and order. In Task 2, the complete chart (i.e., all 24 color patches) is presented and the processing sequence is freely selectable. As a basis for further evaluations, the digital numerical values R, G, and B of the visual color match are saved for each color in both tests. Likewise, the time required for each single color is saved in both experiments, and the total time for each is calculated accordingly. In Task 2, the processing sequence of the single colors in which the visual color matchings are carried out is also saved. Finally, all color patches are measured using a colorimeter, and the spectral values are captured.

In addition, participants are given a questionnaire requesting various personal details (see Annex 4) that are used to create a sociological profile of each participant, which can then be directly linked to the individual results obtained and included in the detailed analysis of the data. In principle, all data are collected anonymously and can only be linked to each other via an assigned ID.

Due to the COVID-19 pandemic, the execution of the planned experiments was only possible to a limited extent and after approval by the administration of Offenburg University. Based on a developed hygiene and safety concept (see Annex 4), the necessary approval was granted in early September 2020. Unfortunately, the time window was very limited due to the renewed deterioration of the crisis and the lockdown in Germany, which meant that the desired number of participants could no longer be achieved.

4.7.2 Technical implementation of the experimental tasks

The planned experiments were performed with the technical setup already presented. For this purpose, each display was set to a reproducible state with the pre-created profiles corresponding to their native technical color gamut.

To ensure an equal viewing position for all participants, a chin rest was used. This was necessary since even a relatively small change in viewing direction can lead to a change in the observer's color perception due to the viewing angle characteristics, which differ from display to display. As the displays differ in size and mechanical design, basic specifications for positioning at the workstation had to be developed first. Since only Display 1 is height-adjustable, this was used as a reference. In combination with the available desk surface, the adjustable chin rest, and a height-adjustable sitting position, a height of 40 cm above the work surface was defined for positioning the center of the display surface. To be able to align each display accordingly, pedestals adapted to the necessary height were produced for each of them. The chin rest was also adjusted so that the observer would look horizontally at the center of the screen. Seat height could be variably adjusted to provide the most comfortable sitting position possible. The distance between display and participant was set at 60 cm, which ensured an area of approximately 10 cm around the center of the screen was within a viewing angle of around 10° (i.e., the assumed area of sharpest vision).

The runtime and development environment "unity" from the company Unity Technologies (San Francisco, USA) was used to program the color masks for the experiments. The scripting in "unity" is based on Mono and offers C# as a possible scripting language. No special software is needed to run the application. It is an executable file (colorcomparator.exe) for the Windows operating system. The position and size of the test patches could be adapted to the screen diagonal and the selected resolution of the test displays for the specified viewing distance and viewing angle via the input of exact pixel values. The color values for the screen background, the color patches, and their integrated color masks were defined by a number triplet for the primary colors red, green, and blue (RGB). The control of the application and the adjustment of the color values were performed using fixed keys on the keyboard and with the help of a computer mouse with a selection wheel.

The colors of the test patches were selected on the basis of the x-rite ColorChecker, a color calibration target mainly applied in the media industry. Among other things, it is used to assess the color representation accuracy of displays and to perform simple calibrations. It was first introduced in 1976 in the *Journal of Applied Photographic Engineering* and has since become the industry standard.

The ColorChecker classic target used as the basis for the digital realization is a target in the form of a cardboard-framed card with basic dimensions of 27.9 x 21.0 cm and containing an array of 4 x 6 2 inch squares of various colors. These colors have been scientifically determined and systematically arranged. Looking at the first row, squares 1 and 2 represent skin tones, square 3 represents "blue sky", and square 4 represents "foliage green". Colors 5 and 6 of the first row, as well as all colors of the second row, have been formulated to emulate colors found in nature. Row 3 shows the primary colors of additive and subtractive color mixing. The six color patches in the bottom row form a uniform gray scale. All the colors used were described with colorimetric measurements using the CIE 1931 2° standard observer and illuminant C as well as the Munsell color system. From measured reflectance spectra, CIE L*a*b* coordinates for illuminants D65 and D50 and coordinates in the various technical color gamuts can be derived.[275, 306, 276, 307]

Figure 57. The ColorChecker classic target with 24 colors.[275, 307]

8 bit ColorChecker 2005		xyY (CIE D50)			L*a*b* (CIE D50)			Adobe (1998)			sRGB		
No.	Color name	x	y	Y	L*	a*	b*	R'	G'	B'	R'	G'	B'
0	illuminant	0.3457	0.3585	100	100	0	0	255	255	255	255	255	255
1	dark skin	0.4316	0.3777	10.08	37.99	13.56	14.06	107	82	70	116	81	67
2	light skin	0.4197	0.3744	34.95	65.71	18.13	17.81	184	146	129	199	147	129
3	blue sky	0.2760	0.3016	18.36	49.93	-4.88	-21.93	101	122	153	91	122	156
4	foliage	0.3703	0.4499	13.25	43.14	-13.10	21.91	95	107	69	90	108	64
5	blue flower	0.2999	0.2856	23.04	55.11	8.84	-25.40	128	127	173	130	128	176
6	bluish green	0.2848	0.3911	41.78	70.72	-33.40	-0.20	129	188	171	92	190	172
7	orange	0.5295	0.4055	31.18	62.66	36.07	57.10	201	123	56	224	124	47
8	purplish blue	0.2305	0.2106	11.26	40.02	10.41	-45.96	77	92	166	68	91	170
9	moderate red	0.5012	0.3273	19.38	51.12	48.24	16.25	174	83	97	198	82	97
10	purple	0.3319	0.2482	6.37	30.33	22.98	-21.59	86	61	104	94	58	106
11	yellow green	0.3984	0.5008	44.46	72.53	-23.71	57.26	167	188	75	159	189	63
12	orange yellow	0.4957	0.4427	43.57	71.94	19.36	67.86	213	160	55	230	162	39
13	blue	0.2018	0.1692	5.75	28.78	14.18	-50.30	49	65	143	35	63	147
14	green	0.3253	0.5032	23.18	55.26	-38.34	31.37	99	148	80	67	149	74
15	red	0.5686	0.3303	12.57	42.10	53.38	28.19	155	52	59	180	49	57
16	yellow	0.4697	0.4734	59.81	81.73	4.04	79.82	227	197	52	238	198	20
17	magenta	0.4159	0.2688	20.09	51.94	49.99	-14.57	169	85	147	193	84	151
18	cyan	0.2131	0.3023	19.30	51.04	-28.63	-28.64	61	135	167	0	136	170
19	white 9.5 (.05 D)	0.3469	0.3608	91.31	96.54	-0.43	1.19	245	245	242	245	245	243
20	neutral 8 (.23 D)	0.3440	0.3584	58.94	81.26	-0.64	-0.34	200	201	201	200	202	202
21	neutral 6.5 (.44 D)	0.3432	0.3581	36.32	66.77	-0.73	-0.50	160	161	162	161	163	163
22	neutral 5 (.70 D)	0.3446	0.3579	19.15	50.87	-0.15	-0.27	120	120	121	121	121	122
23	neutral 3.5 (1.05 D)	0.3401	0.3548	8.83	35.66	-0.42	-1.23	84	85	86	82	84	86
24	black 2 (1.5 D)	0.3406	0.3537	3.11	20.46	-0.08	-0.97	52	53	54	49	49	51

Table 27. R'G'B' coordinates of the ColorChecker in 8-bit format: the L*a*b* and sRGB data are from GretagMacbeth; the other values are derived from the L*a*b* data by BabelColor.[275, 276, 307]

The definition of the colors for the test fields is only possible within the programming via the number triplet RGB. From the manufacturer's side, L*a*b* values are always given to describe the colors of the ColorChecker chart, along with converted RGB values for the sRGB standard color gamut. For the programming of the test patches, values were provided by BabelColor, which published the results of an extensive study of the color values of the ColorChecker chart in 2006. This document contains extensive data conversion RGB coordinates in 8-bit and 16-bit formats for all color patches in the four common RGB color spaces (AdobeRGB, Apple RGB, ProPhoto, and sRGB), as defined in terms of primary colors, illuminants, and gamma response. The results of the conversion performed based on the data provided by the manufacturer are shown in Table 27. These RGB values were derived from the L*a*b* D50 data provided by GretagMacbeth, first made available in October 2005. The conversion to the illuminants of the RGB color spaces was performed using Bradford color adaptation matrices. Multiple parameter gamma functions were used instead of a single value function when such a function is defined for a given space.[66, 293, 265]

For the implementation of the programming, it should be noted that the profiling of displays 1 and 2 is based on the AdobeRGB standard color space, while that of displays 3 and 4 is based on the sRGB color space. Accordingly, two applications adapted to these color spaces are also required since they are based on different digital color values. As explained above, the tasks to be performed are divided into Task 1 and Task 2 and differ in structure. The basic task of matching a target color displayed in a color patch within a color mask until visual matching is achieved remains identical; both parts are integrated in the programmed application "colorcomparator.exe". The selection is made by mouse click [↗] on the start screen. The default for participants was to start with Task 1 first. Task 2 followed after a break of 10–15 min.

A keyboard and a mouse with a selection wheel were used to operate and perform the experiment. To select the primary color to be changed, the number keys [1] for red (R), [2] for green (G), and [3] for blue (B) are used, each marked according to their color. If one of the primary colors is to be changed, the participant must hold down the corresponding selection key. This conveys a conscious feeling of having made a selection. To change the selected primary colors, the mouse wheel is now used while the selection key is held down. If the wheel is turned forwards (away from the participant), the colors become brighter; if it is turned backwards (toward the participant), the colors become darker. Changing the primary color by one detent stop corresponds to changing the digital values of the selected primary color by one digital unit. Thus, all three primary colors can now be used to make a visual adjustment of the color in the mask to the target color. If the observer feels that he or she has not achieved the desired result, it is possible to reset the mask and start again by pressing the [DEL] key.

Once the visual matching is complete, the right arrow key [→] is used to switch to the next target color. At the same time, the adjusted digital RGB values are saved. If desired, it is possible to return to a test patch that has already been edited by pressing the left arrow key [←]. The color values that have already been saved are displayed, thus enabling any readjustments to be made. Switching to the next color again saves the current settings and, in this case, overwrites the values already saved. Once all colors have been processed and the run is complete, the application can be terminated by pressing the [ESC] key.

In Task 1, the participant is initially shown only single colors for processing. Here, it is considered that the visually perceived color appearance of a color element (stimulus) depends on different external influences. The color field shown has a size of 10 x 10 cm. In the center is a round mask with a diameter of 5 cm. This is to be visually matched to the target color by changing the color values of the primary colors R, G, and B. A full black background provides a stable adaptation of the observer. Initially, a neutral gray background was tested, but this resulted in irritating fading at the edges of the superimposed color field. Once processing is complete, the participant can move onto the next color field. The order in which the colors are presented is predefined in line with the order of the color numbers of the ColorChecker test chart.[19, 60, 308, 309]

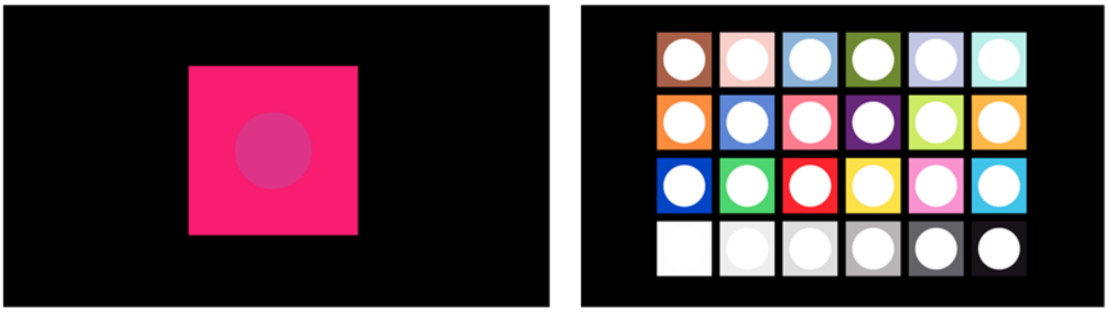


Figure 58. Screen view of the two-part experiment (Task 1 and Task 2)—single colors with integrated mask on the left, complete target with 24 colors on the right.

In Task 2, the complete ColorChecker target is shown on the display in the form of color fields with a total size of 29 x 19 cm (24 color patches, each with a size of 4 x 4 cm). Each color patch is provided with a round mask with a diameter of 2.2 cm. The task is again to match the target color until visual matching is achieved. However, the processing sequence is not specified here; rather, it can be freely selected. The mask to be edited is activated by clicking the left mouse button [↗], which is then made visible. When selecting a new color patch, the current digital values of the input are saved; subsequent changes are also possible here. The data obtained are then automatically exported to an MS Excel file preformatted for later evaluation; they are also provided with a generated ID for anonymization. The digital color values for the single color channels red (R), green (G), and blue (B) are saved, along with the time required for each single color and the total duration of the two-part experiment.

4.7.3 Evaluation of the experimental setup

Before the official start of the planned research, an evaluation of the experiments was first conducted with three test participants. Various aspects of the organization, the planned procedure, and the programmed application were tested.

The testing begins with a preliminary discussion with the respective participant. This takes place in the laboratory under the defined measurement conditions; the objective here is for the visual system of the participant to adjust to the given light conditions (chromatic adaptation). The basis or guideline for the preliminary discussion is the elaborated document "Information sheet and consent" (see Annex 4). Here, the overall project is briefly introduced and its aims explained. This is followed by an introduction to the specific tasks and how to manage the application. The time required for this sub-step is around 15 min. This is needed to prepare the participants, all of whom have no prior knowledge of the project, for the tasks ahead. This was confirmed by all participants.

The actual task to be performed is defined clearly and understandably for the participant, along with its representation on the test display used. A round mask is clearly visible in the color fields presented. This shows the area that is to be targeted for matching the specified target color. Using the mouse and keyboard to perform the task was found to be easy to understand and intuitive. Holding down the button to select a color channel likewise accomplished the desired purpose, creating a conscious feeling in the user that a selection has been made and thus conveying a certain sense of safety. The possibility of completely resetting the edited mask to the original base was positively evaluated. Returning to color fields that had already been edited was perceived as a good feature, although it was hardly used by the participants thereafter. Overall, the usability of the application was rated very positively.

The evaluation of Task 1 already led to some fundamental structural changes based on feedback from the first participant. The original plan had been to process all 24 colors of the ColorChecker chart. However, the time required for this task was excessive (over 90 min) and thus deemed impractical. It also became apparent that the task set was quite demanding and exhausting for the participant. It was observed that with increasing time, the necessary concentration became more difficult and decreased strongly as a result. In addition, a real sense of fatigue was felt. As a first response, the number of test colors was reduced to 18, but this did not lead to a desired result. In discussion, the decision was then made to halve the initial number of test colors and to work with only 12 selected colors.

Another point of discussion was the white starting color in the mask. Depending on the target color to be remixed, this required a greater or lesser expenditure of time. After various attempts, the decision was made to work with a neutral gray with identical color values for red, green, and blue as the start color. An adjustment was then made to the respective target color via its color value share in the green color channel. This color value was used and reduced by 15. The values for the red and blue color channels were then adjusted accordingly. This change does not affect the accuracy of the color matching but significantly reduces the time required for completion.

After these changes, the time required to complete Task 1 was reduced to approximately 20 min. While this time may naturally vary from participant to participant, it also leads to a desired reduction in participant stress. The task remains demanding and challenging, but a drop in concentration or even signs of fatigue were no longer observed. Test participants agreed that a 15-minute break was necessary before starting Task 2. This time is used to work on the questionnaire to produce a sociological profile of the participant (see Annex 4). The questions included were discussed and considered in the context of the intended goals of the research. No changes were made here.

Task 2 provided a somewhat surprising result: the time required coincided with that of Task 1 in its new reduced structure. This is despite the fact that all 24 colors have to be processed here. Based on the results of the evaluation of Task 1, all masks were also given a neutral gray adapted to the target color. All participants made the same statement that the task was or felt easier due to the smaller test fields. In general, the functionality in Task 2 was also judged to be easy to understand. The additional task of selecting the color field to be processed by mouse click was conclusive, and the fact that the selected color patch is briefly marked by a white frame was perceived as positive and helpful. Ultimately, it should be noted here that the participants generally proceed through Task 2 in a very structured manner. Almost without exception, they started in row 1 and then worked on the fields from left to right, row by row.

This evaluation phase proved to be very helpful; indeed, it was necessary to be able to implement a practicable realization of the planned experiments. In addition, some interesting aspects and questions arose, for example, on the influence of the size of the test fields, which will be included in the overall evaluation of the results derived from all participants.

4.7.4 Procedure of the experiments

On the basis of the evaluation conducted and the resulting changes, basic structural planning was made for the conducting of the experiments. From an organizational point of view, the time required was the greatest challenge. On the one hand, it was necessary to make the best possible use of the limited time available while complying with all hygiene and safety regulations. On the other hand, test participants had to be recruited who were willing to spend the time required and also to be available over the course of several days.

The initial setup of the studies allowed each participant to perform the presented experiments several times repeatedly using each of the four displays. However, based on the evaluation phase and the limited time available, it was decided to plan for only one repetition. To keep the workload low, participation in the experiments was only possible once per day. In addition, when allocating the time slots, attention was paid to ensuring that, where possible, a "rest day" could always be scheduled to avoid any routine arising in the performance of the experiments and thus to avoid possible systematic errors.

The hygiene and safety concept allowed two participants to perform the experiments simultaneously due to the room setup and the experimental design. The individual workstations are separated by a visual screen and thus cannot be seen from one to the other. Unwanted interference can thus be ruled out. The display used always depends on participant choice; here, either display 1 or display 3 (both with a screen diagonal of 32") were always selected for the first task.

Various aspects were considered around time scheduling. The time required to perform the experiments is 60–70 min, depending on the participant. To have sufficient time for the final measurement of the spectral values, but also for the implementation of the various hygiene procedures such as disinfection and ventilation, time slots of 90 min were planned. The preheating for the displays was also taken into account, as well as the planned implementation of control measurements of the color representation quality. The organization or schedule for one day can be seen in Figure 60. Preheating is necessary because the displays need time for the color representation to stabilize. All displays achieved more than acceptable results here. Nevertheless, it is useful to check the displays on a daily basis to avoid potential systematic errors. The check is again performed based on the test form provided by DisplayCal with the selected display calibration device 1.

The time slot for the experiments was set at 90 min. This provides six slots per day, divided into two blocks. Up to 12 participants could take part in the experiments per day. The presentation of the project and the tasks to be performed are only given when the participants attend for the first time; the same applies to the questionnaire to be completed. This makes any further participation feel more relaxed in terms of the time required.

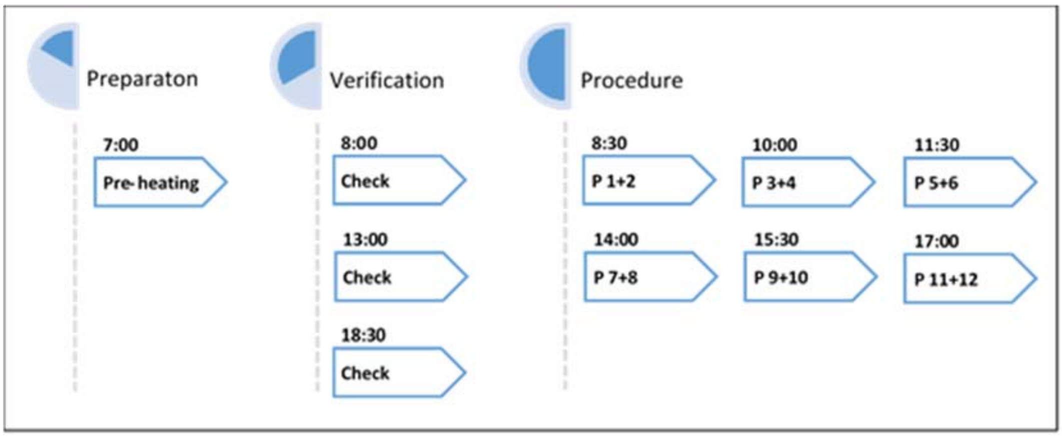


Figure 59. Overview of scheduling of a single examination day, including planned time slots.

4.7.5 User-related analysis of the acquired data

All data acquired are saved anonymously. An assigned ID is then used to ensure that all information is linked. A simple sociological profile is created for each participant with the help of the completed questionnaire, which is then included in the data analysis.

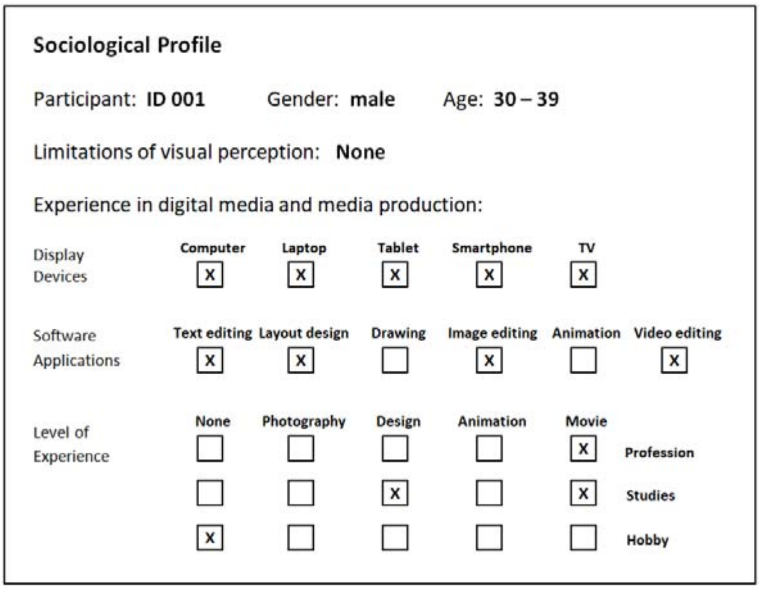


Figure 60. Summary of the sociological profile questionnaire using the example of user ID 01.

For each participant, all results are first saved for each participation (separately for Task 1 and Task 2) and then assigned to the displays used. For the final evaluation, all data sets for a participant are then combined using the assigned ID. The separation into Tasks 1 and 2, as well as the assignment to the display, is initially retained.

Data acquisition takes place in two steps. In step 1, the defined values of the experiment are automatically saved by the programmed application "colorcoparator.exe". The matching of the target colors is thus implemented via the digital color values for red, green, and blue. The settings made by the user are saved and then exported to a preformatted MS Excel file prepared for the following analysis. For each test patch, the digital target values and the user-related actual values are saved. The delta is determined for the graphical processing. Both the start and end times of the tasks are saved, as well as the specific processing time for each single color mask.

In step 2, the color values obtained are then also measured spectrally using display calibration device 1 and DisplayCal and then saved in a measurement report. This data is then also exported automatically to a prepared MS Excel file.

	Device Values			Nominal Values					Measured Values MR 1				
Color	R	G	B	L*	a*	b*	x	y	L*	a*	b*	x	y
1	107	82	70	38.60	15.61	16.13	0.4431	0.3790	38.43	16.26	16.08	0.4452	0.3776
2	184	146	129	65.98	24.83	27.80	0.4530	0.3832	65.59	25.74	28.27	0.4562	0.3828
3	101	122	153	50.00	-9.41	-26.94	0.2540	0.2914	49.68	-9.26	-27.12	0.2534	0.2904
4	95	107	69	45.66	-18.34	27.35	0.3677	0.4726	45.23	-17.98	27.02	0.3680	0.4717
5	128	127	173	53.52	10.91	-35.25	0.2780	0.2590	53.27	10.79	-35.51	0.2769	0.2581
6	129	188	171	73.91	-51.41	5.89	0.2662	0.4231	73.78	-52.23	5.91	0.2647	0.4241
8	77	92	166	39.00	15.09	-58.77	0.2048	0.1765	38.63	15.61	-59.57	0.2030	0.1737
11	167	188	75	79.15	-32.55	80.97	0.4046	0.5378	79.09	-32.04	81.75	0.4062	0.5378
12	213	160	55	75.61	29.82	89.29	0.5291	0.4411	75.60	30.01	89.02	0.5292	0.4406
16	227	197	52	87.45	6.29	102.03	0.4857	0.4830	87.75	7.96	102.39	0.4885	0.4805
17	169	85	147	49.28	66.21	-21.89	0.4304	0.2368	49.31	67.07	-21.32	0.4339	0.2371
18	61	135	167	53.96	-36.06	-32.32	0.1970	0.2995	53.51	-35.39	-33.17	0.1957	0.2960

Table 28. Spectral values measured for all stored color patches following task completion.

The analysis and evaluation of the results is performed as standard using a reference system with a fixed observer (CIE L*a*b* 1976). The data obtained provide insight into the relationship between individual visual color perception and real reproduced colorimetric values. By assigning the obtained results to the displays used, a qualitative statement on the influence of the display technology used on the observer's color perception can be made. All associated data and plots can be found in Annex 4.[19]

The aim of the evaluation is to determine the accuracy or deviation of the visual matching compared to the specified target values. Intra-variability (i.e., the ability of an observer to repeatedly perform the identical task) is also considered here. Possible deviations of the results in the performed repetitions are captured and analyzed. In the next step, the inter-variability of the results for all participants is considered, the focus of which is the expected variance among the participants. Subsequently, visual perception with respect to the defined colors is evaluated with the help of the obtained data to examine whether certain colors are easier or more difficult to match and whether possible preferred color areas (i.e., areas that are assessed preferentially) can be derived. The final question here is whether it is possible to classify the participants, as well as the colors to be processed, into meaningful categories.
The analysis is based on the determined nominal color values and the measured spectral values. The specified target colors are measured several times, and mean values are formed for each color. This is to compensate for any minor variations in the color representation of the display that may occur. The measurement of the color matching achieved by the user is performed once directly after the experimental run, and the color difference ΔE_{00} is calculated and used to evaluate the results. This is determined using the CIEDE2000 formula, a further development of the CIE 1994 color difference formula, as explained in Chapter 2.6.3.2. Its introduction as international standard ISO/CIE 11664-6.3, which specifies the calculation of color differences using this formula, took place in 2014. The basis for the interpretation and evaluation of the results is the following rating scale, revised for this analysis, which is based on the original interpretation of the CIE from 1976 (see Table 4) and the rating scale proposed in DIN standard 53218. The further development of the color distance formulae, as well as interpretations currently used in the media industry, are taken into account.

ΔE_{00}	Interpretation	Rating
0–0.2	Visually imperceptible	0
0.2–0.5	Almost unnoticeable	1
0.5–1	Noticeable to the trained eye	2
1–2	Small color difference	3
2–4	Perceived color difference	4
4–5	Significant color difference	5
5–	Rating as another color	6

Table 29. Basic rating scale for interpreting and evaluating the color differences determined.

4.7.6 Results, analysis, and evaluation

The analysis of the collected data is first performed on a user-specific basis for each deployed display and separately for Task 1 and Task 2. All data are then compiled into an overall analysis across all used displays. The complete data are shown in Annex 4.

4.7.6.1 Representation of the target colors on the displays used

As described above, the target colors specified for the examinations are based on the color fields defined in the x-Rite ColorChecker target. Digital RGB device values provided by BabelColor are used for the implementation in the programmed application. Since each display has a device-dependent color gamut of representable colors according to its technical characteristics, these values are represented by each display with deviating spectral values. To ensure a defined repeatable color representation for each display, a display profile was created for each, in which the color gamut of the respective device is described with a standardized data set. For further consideration, it is important to note that displays 1 and 3 were profiled on the basis of the AdobeRGB standard color space, according to the results of the performance benchmarking, while the sRGB standard color space was used for displays 2 and 4. This is followed by an analysis and evaluation of the representation of the target colors by the respective display.

4.7.6.2 Display 1

The spectral representation of the defined target colors for the color matching experiments performed with Display 1 is based on the profile "Display1_MD1_Adobe_160_V1". Table 30 shows the data basis for the implementation and evaluation of the tasks performed. It contains the digital RGB device values, the profile-related nominal spectral values derived, and the averaged measured spectral values.

The two control measurements deliver stable values for the chromatic colors (colors 1–18). However, in the neutral color range (colors 19–24), greater deviation of the measured spectral values from the nominal specifications can be observed. For all 24 colors, the average color difference is $\Delta E_{00} = 0.56$. The minimum $\Delta E_{00} = 0.19$ occurs for color 12, while the maximum of $\Delta E_{00} = 1.58$ occurs for color 24. The mean rating is 1.5. If only the chromatic colors are considered, the mean color difference is reduced to $\Delta E_{00} = 0.43$ and the maximum to $\Delta E_{00} = 0.89$ (color 16). By comparison, the color difference of the achromatic colors is $\Delta E_{00} = 0.95$ and is thus still above the maximum of the chromatic colors. For the chromatic colors, the rating is 1.2; for the achromatic colors, the rating of 2.3 is significantly worse.

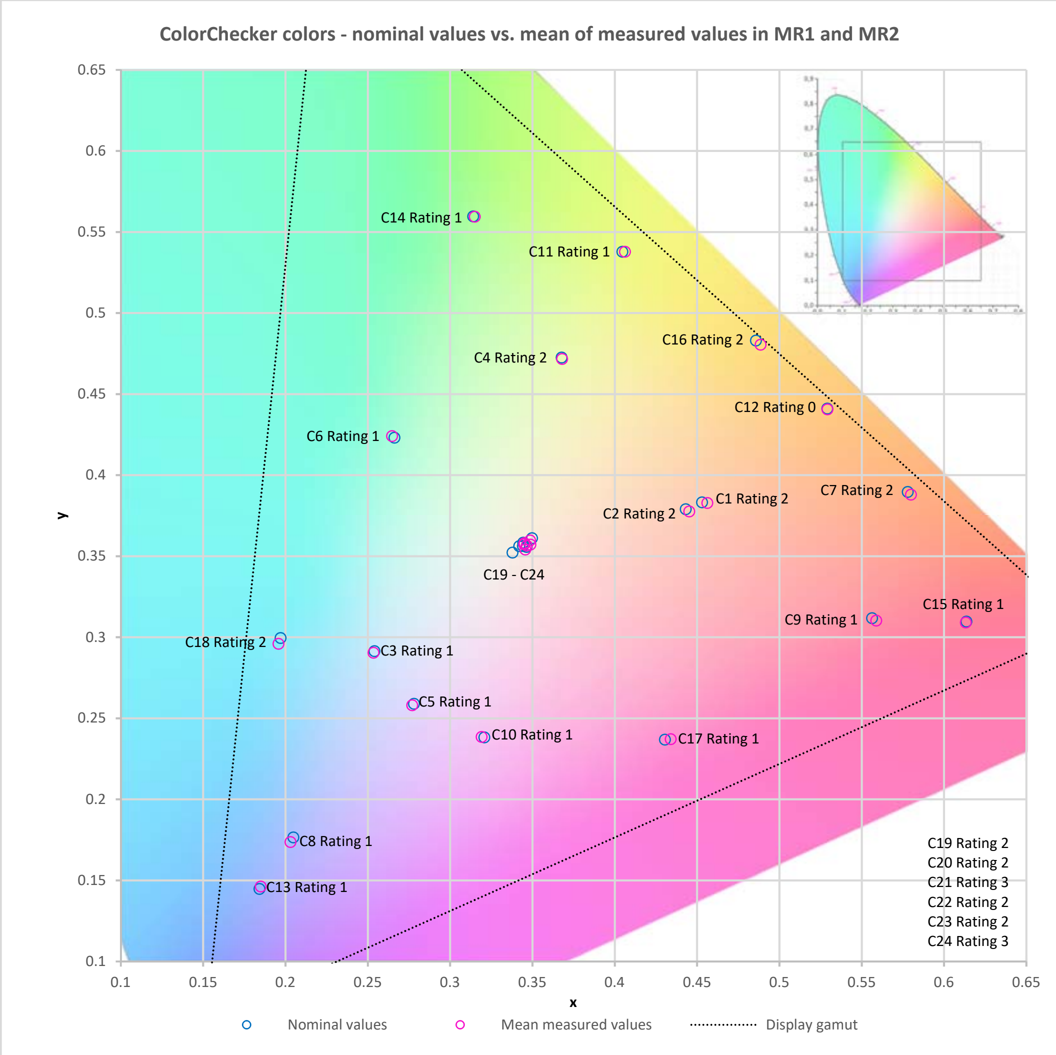


Figure 61. Presentation of color coordinates for nominal color values and averaged measured spectral values for Display 1 in the CIExy chromaticity diagram.

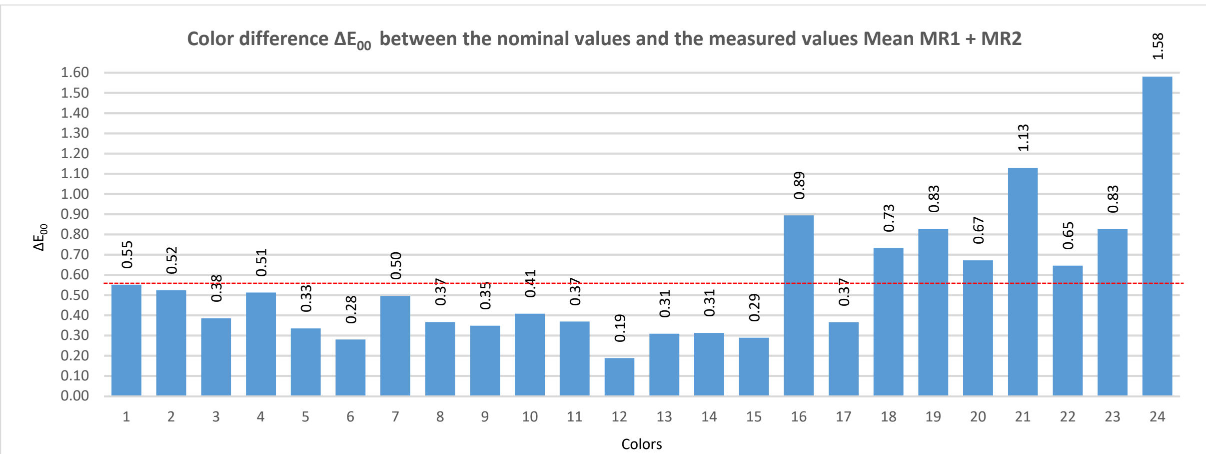


Figure 62. Visualization of the determined color difference ΔE_{00} between nominal values and measured spectral values of the two control measurements for Display 1.

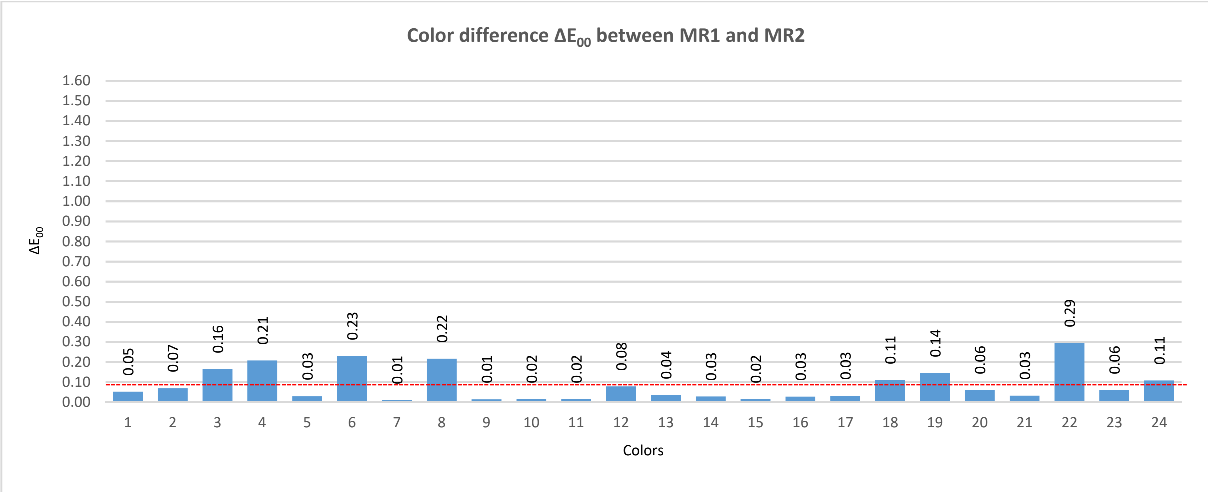


Figure 63. Visualization of the determined color difference ΔE_{00} between measured spectral values of the two control measurements MR1 and MR2 for Display 1.

	Device Values			Nominal Values					Mean Measured Values MR1 + MR2						
Color	R	G	B	L*	a*	b*	x	y	L*	a*	b*	x	y	ΔE_{00}	Rating
1	107	82	70	38.60	15.61	16.13	0.4431	0.3790	38.43	16.30	16.08	0.4452	0.3776	0.55	2
2	184	146	129	65.98	24.83	27.80	0.4530	0.3832	65.59	25.69	28.28	0.4562	0.3828	0.52	2
3	101	122	153	50.00	-9.41	-26.94	0.2540	0.2914	49.67	-9.15	-27.11	0.2534	0.2904	0.38	1
4	95	107	69	45.66	-18.34	27.35	0.3677	0.4726	45.22	-17.80	27.00	0.3680	0.4717	0.51	2
5	128	127	173	53.52	10.91	-35.25	0.2780	0.2590	53.28	10.77	-35.50	0.2769	0.2581	0.33	1
6	129	188	171	73.91	-51.41	5.89	0.2662	0.4231	73.76	-52.14	5.70	0.2647	0.4241	0.28	1
7	201	123	56	65.00	53.87	74.70	0.5779	0.3897	64.72	54.74	74.52	0.5799	0.3880	0.50	1
8	77	92	166	39.00	15.09	-58.77	0.2048	0.1765	38.62	15.46	-59.59	0.2030	0.1737	0.37	1
9	174	83	97	50.92	65.66	23.03	0.5563	0.3118	50.67	66.52	23.04	0.5588	0.3103	0.35	1
10	86	61	104	29.05	22.89	-24.02	0.3208	0.2382	28.75	22.26	-23.93	0.3191	0.2385	0.41	1
11	167	188	75	79.15	-32.55	80.97	0.4046	0.5378	79.09	-32.02	81.74	0.4062	0.5378	0.37	1
12	213	160	55	75.61	29.82	89.29	0.5291	0.4411	75.60	30.09	89.02	0.5292	0.4406	0.19	0
13	49	65	143	28.32	18.51	-59.45	0.1842	0.1447	28.02	17.93	-58.45	0.1849	0.1462	0.31	1
14	99	148	80	61.66	-55.26	46.94	0.3140	0.5596	61.35	-54.75	46.89	0.3149	0.5594	0.31	1
15	155	52	59	42.65	68.58	33.40	0.6136	0.3097	42.90	69.01	33.24	0.6132	0.3091	0.29	1
16	227	197	52	87.45	6.29	102.03	0.4857	0.4830	87.75	7.99	102.38	0.4885	0.4805	0.89	2
17	169	85	147	49.28	66.21	-21.89	0.4304	0.2368	49.32	67.05	-21.28	0.4339	0.2371	0.37	1
18	61	135	167	53.96	-36.06	-32.32	0.1970	0.2995	53.49	-35.33	-33.26	0.1957	0.2960	0.73	2
19	245	245	242	97.24	0.69	1.92	0.3497	0.3611	97.14	0.83	1.09	0.3485	0.3597	0.83	2
20	200	201	201	81.12	-0.49	-0.30	0.3444	0.3584	81.05	-0.04	-0.30	0.3451	0.3581	0.67	2
21	160	161	162	66.41	0.21	-0.89	0.3442	0.3563	66.35	0.92	-0.45	0.3465	0.3566	1.13	3
22	120	120	121	50.50	0.96	-0.57	0.3464	0.3557	50.46	1.10	0.07	0.3487	0.3572	0.65	2
23	84	85	86	35.92	-0.32	-0.82	0.3419	0.3562	36.01	0.10	-0.27	0.3450	0.3574	0.83	2
24	52	53	54	20.95	-0.26	-1.39	0.3379	0.3522	21.09	0.67	-0.63	0.3456	0.3541	1.58	3

Table 30. Base values of target colors for Display 1 profiled based on the AdobeRGB color space as well as averaged spectral values.

In both control measurements, the results show a stable color representation for the display. The values from MR1 and MR2 show an average color difference of $\Delta E_{00} = 0.09$. The minimum value (colors 7 and 9) is ΔE00 = 0.01, and the maximum (color 18) is ΔE00 = 0.24. With a mean rating of 0.2, the color differences are not visually perceptible.

Considering the measurement results of the chromatic colors first, it becomes apparent that the color matches achieved show, with a few exceptions, a lower value L* for the luminance compared to the nominal value. An increase can only be observed in colors 15, 16, and 17. Furthermore, the values show that almost all colors are represented in a more reddish tone. The exceptions are the colors 5, 10, and 13, which are in the spectral range of purplish blue to purplish pink. The colors 13, 14, and 15, which are closest to the display primaries R, G, and B, confirm this finding. Colors 14 and 15 are more reddish, but also somewhat more bluish, while color 13 is represented less red and blue. It is also noticeable that the unsaturated colors 1, 2, 3, 5, and 6 (close to the white point) are in part clearly more saturated. For the others, no clear tendency is recognizable here. The achromatic colors show similar results. The measured values clearly go in a more reddish direction, while the blue color value decreases with the exception of color 19. In colors 23 and 24, this leads to an increase in luminance, while in the brighter achromatic colors (colors 19–22), luminance decreases.

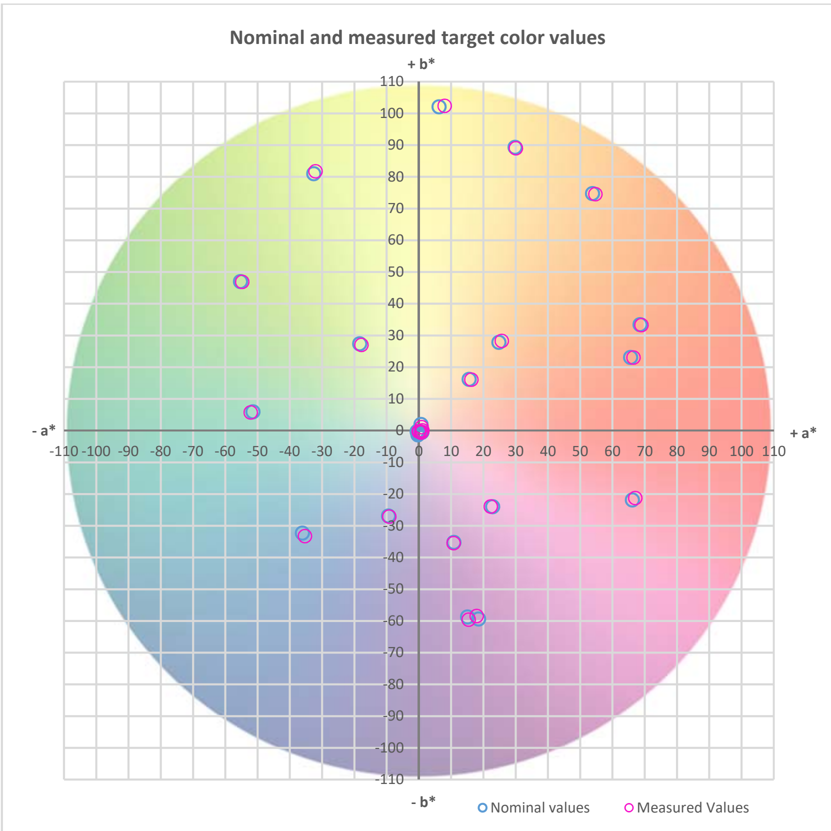


Figure 64. Plot of color locations of the nominal color values and the averaged measured spectral values for Display 1 in the a*b* plane (CIE Lab 1976).

4.7.6.3 Display 2

The profile "Display2_MD1_Adobe_160_V2" used for Display 2 is also based on the AdobeRGB standard color space. The assigned spectral color values are shown in Table 31 below.

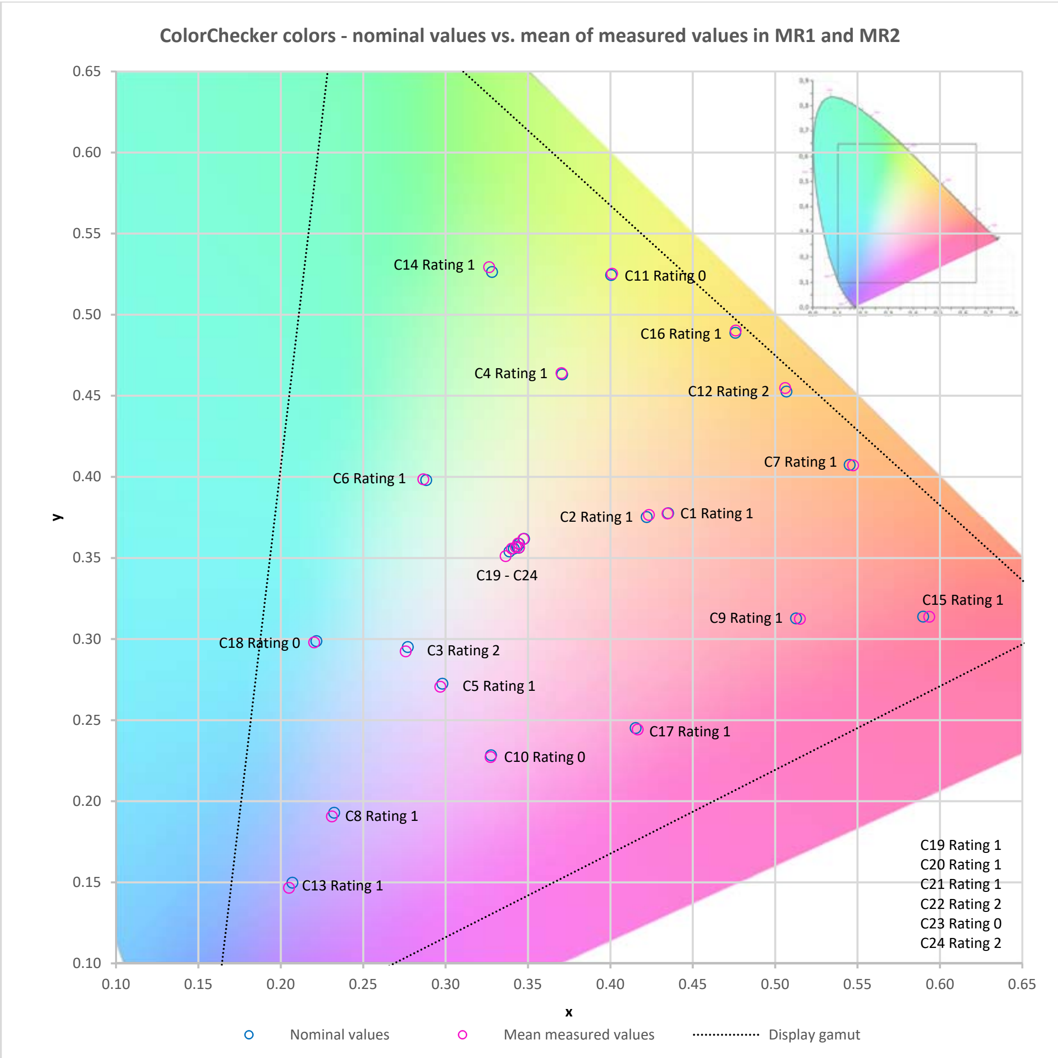


Figure 65. Presentation of color coordinates of the nominal color values and the averaged measured spectral values for Display 2 in the CIExy chromaticity diagram.

The measured spectral values from the two measurements provide excellent results. The average determined color difference of the measured values to the nominal values is ΔE_{00} = 0.34. The minimum ΔE_{00} = 0.16 is observed for color 18, and the maximum ΔE_{00} = 0.64 for color 12. Only four colors demonstrate a color difference above the limit value ΔE_{00} = 0.5 and are thus visually perceptible to experienced observers. All other color differences are not visually perceptible or almost unnoticeable. Furthermore, it can be seen that the color differences in the achromatic colors are slightly higher when viewed as a group compared to the chromatic colors. Four colors have a color difference that is above the average value for all colors. The values result in a rating of 1.0 for the display.

The results of the two control measurements differ only slightly. At the mean level, the determined color difference between MR1 and MR2 is $\Delta E_{00} = 0.08$, with a minimum in color 10 of $\Delta E_{00} = 0.01$ and a maximum of $\Delta E_{00} = 0.23$ in color 3. Here, too, the tendency is confirmed that the variations are somewhat higher in the achromatic colors. However, it should be noted that the differences are not visually perceptible. This results in a rating of 0.1.

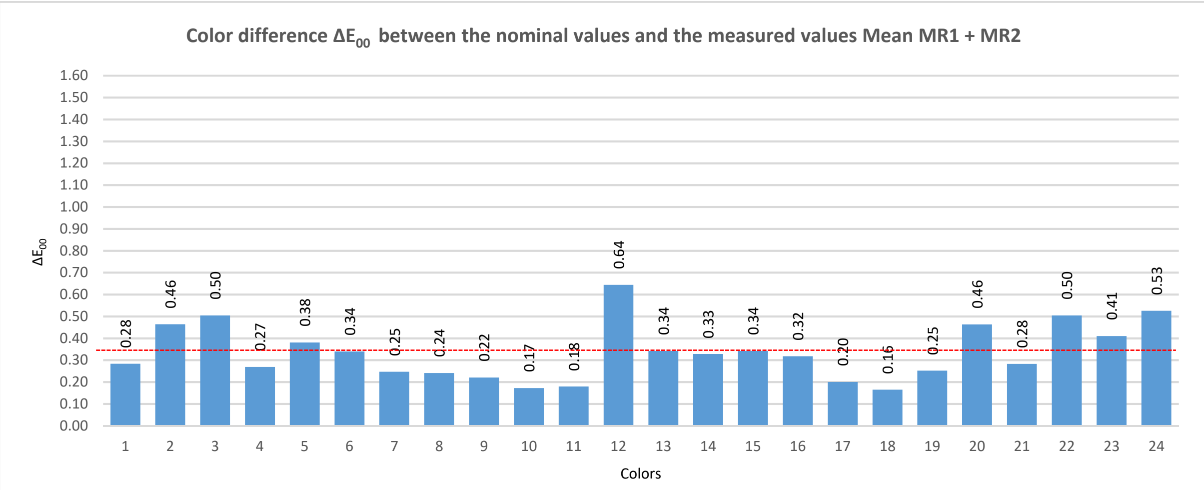


Figure 66. Visualization of determined color difference ΔE_{00} between the nominal values and the measured spectral values of the two control measurements for Display 2.

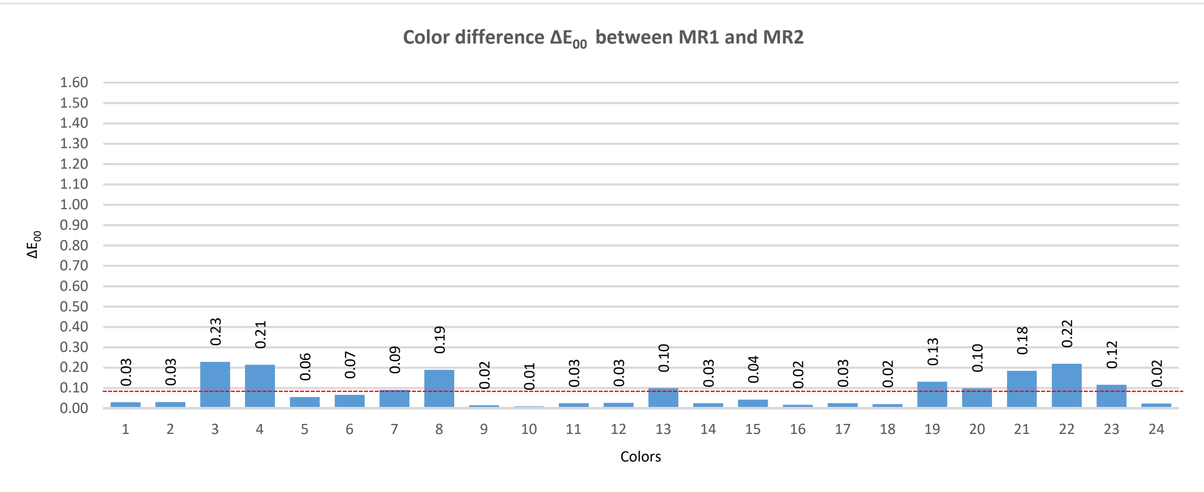


Figure 67. Visualization of determined color difference ΔE_{00} between the measured spectral values of the two control measurements, MR1 and MR2, for Display 2.

Comparing the nominal device-dependent values with the measured spectral values, different tendencies can be seen. Looking first at the chromatic colors, the results show that, with the exception of color 1, all the colors are quite uniformly saturated in the direction of the dominant color values. This means that the measured values tend to lie further away from the white point than the nominal values. This leads to an increase in luminance for the colors in the yellow to green spectrum, as well as a decrease in luminance for the colors in the blue to red spectrum. This tendency toward a more saturated representation is also evident when looking at the achromatic colors. With the exception of color 22, which is somewhat more reddish, the neutral colors show an increase in saturation toward the blue and green spectral range, while the luminance decreases compared to the nominal values.

	Device Values			Nominal Values					Mean Measured Values MR1 + MR2						
Color	R	G	B	L*	a*	b*	x	y	L*	a*	b*	x	y	ΔE_{00}	Rating
1	107	82	70	37.51	14.09	14.38	0.4350	0.3776	37.21	13.99	14.20	0.4347	0.3774	0.28	1
2	184	146	129	64.56	18.29	18.24	0.4220	0.3752	64.61	18.29	18.95	0.4234	0.3765	0.46	1
3	101	122	153	50.23	-2.51	-23.61	0.2771	0.2951	49.88	-2.13	-24.33	0.2758	0.2925	0.50	1
4	95	107	69	43.66	-15.49	24.94	0.3707	0.4632	43.39	-15.63	24.94	0.3704	0.4640	0.27	1
5	128	127	173	54.42	13.01	-29.25	0.2980	0.2725	54.15	13.30	-29.87	0.2968	0.2706	0.38	1
6	129	188	171	71.96	-34.53	2.26	0.2882	0.3980	71.95	-35.37	2.16	0.2865	0.3986	0.34	1
7	201	123	56	60.81	38.23	63.49	0.5452	0.4074	60.65	38.69	64.25	0.5473	0.4072	0.25	1
8	77	92	166	39.58	18.46	-51.20	0.2324	0.1929	39.41	18.92	-51.95	0.2310	0.1906	0.24	1
9	174	83	97	48.64	53.92	13.57	0.5126	0.3127	48.58	54.50	13.93	0.5150	0.3124	0.22	1
10	86	61	104	29.35	27.70	-25.89	0.3276	0.2283	29.15	27.84	-26.03	0.3273	0.2273	0.17	0
11	167	188	75	73.72	-28.96	68.42	0.4004	0.5245	73.76	-28.95	69.04	0.4011	0.5253	0.18	0
12	213	160	55	70.88	19.15	78.26	0.5068	0.4526	70.95	18.33	79.34	0.5061	0.4548	0.64	2
13	49	65	143	28.20	24.31	-55.88	0.2070	0.1498	27.86	24.92	-56.72	0.2050	0.1467	0.34	1
14	99	148	80	57.11	-42.63	38.50	0.3282	0.5264	57.13	-43.63	38.92	0.3264	0.5293	0.33	1
15	155	52	59	39.51	59.62	26.87	0.5898	0.3138	39.47	60.24	27.68	0.5935	0.3137	0.34	1
16	227	197	52	81.50	1.32	93.41	0.4758	0.4888	81.57	0.97	94.70	0.4760	0.4903	0.32	1
17	169	85	147	49.02	57.96	-21.16	0.4153	0.2451	49.02	58.68	-21.24	0.4166	0.2443	0.20	0
18	61	135	167	52.47	-24.69	-29.35	0.2216	0.2987	52.45	-25.00	-29.67	0.2203	0.2980	0.16	0
19	245	245	242	96.60	-0.58	1.70	0.3476	0.3618	96.58	-0.74	1.59	0.3472	0.3617	0.25	1
20	200	201	201	81.32	-0.53	-0.16	0.3446	0.3587	81.03	-0.82	-0.20	0.3440	0.3589	0.46	1
21	160	161	162	66.69	-0.32	-0.80	0.3434	0.3571	66.61	-0.43	-1.04	0.3427	0.3567	0.28	1
22	120	120	121	50.77	0.24	-0.69	0.3444	0.3563	50.27	0.25	-0.62	0.3446	0.3565	0.50	1
23	84	85	86	35.84	-0.36	-0.94	0.3414	0.3558	35.65	-0.61	-1.06	0.3402	0.3558	0.41	0
24	52	53	54	20.91	-0.41	-1.09	0.3387	0.3540	20.70	-0.34	-1.61	0.3365	0.3512	0.53	2

Table 31. Base values of target colors for Display 2 profiled based on the AdobeRGB color space as well as the averaged spectral values.

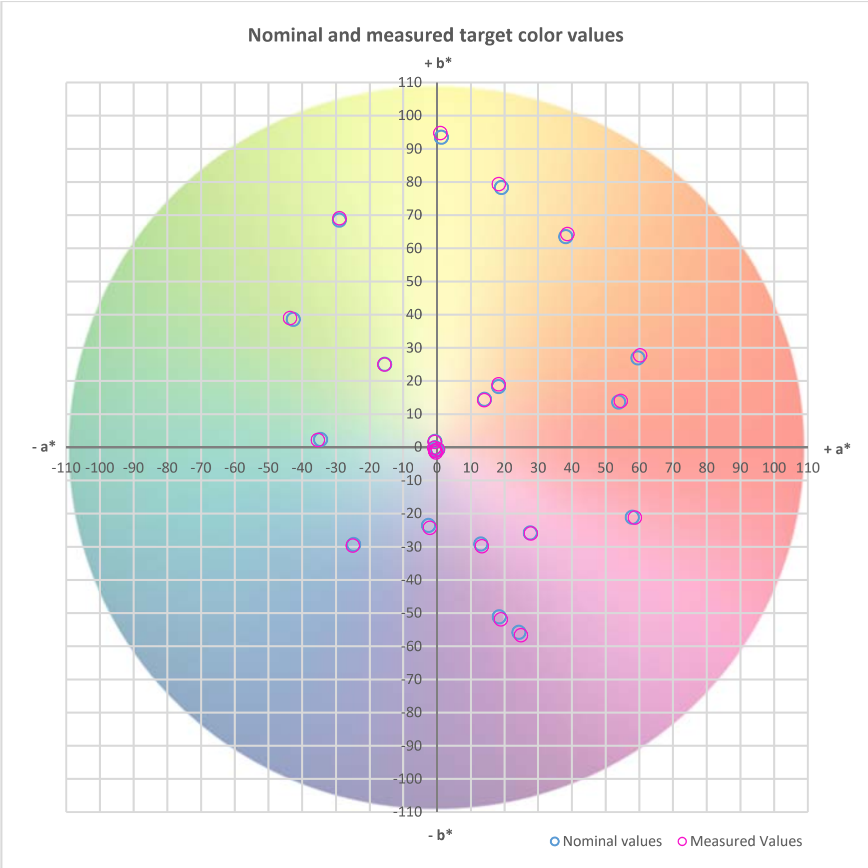


Figure 68. Plot of color locations of the nominal color values and the averaged measured spectral values for Display 2 in the a*b* plane (CIE Lab 1976).

4.7.6.4 Display 3

The profile "Display3_MD1_sRGB_80_V1" used for this display was created based on the sRGB color space. The corresponding values are shown in Table 32.

The results of the control measurements show a good, stable color representation. However, the neutral colors again drop off somewhat compared to the chromatic colors. The mean color difference of the determined spectral values to the nominal values is $\Delta E_{00} = 0.30$. The minimum $\Delta E_{00} = 0.03$ is observed in color 11, and the maximum $\Delta E_{00} = 0.59$ in color 22. The measured color difference only slightly exceeds the limit value of $\Delta E_{00} = 0.50$ in three colors. This leads to a rating of 0.8; the color differences are almost unnoticeable.

If the measurement results of the chromatic colors are separated from those of the achromatic colors, the mean color difference decreases to $\Delta E_{00} = 0.25$. In contrast, the mean color difference of the achromatic colors is $\Delta E_{00} = 0.45$. This is also reflected in the comparison of the measurement results from MR1 and MR2. Overall, the average color difference here is $\Delta E_{00} = 0.22$, with a minimum of $\Delta E_{00} = 0.03$ in color 11 and a maximum of $\Delta E_{00} = 0.75$ in the achromatic colors 19 and 22. The rating is 0.5. When viewed separately, the mean color difference between MR1 and MR2 for the chromatic colors is ΔE_{00} = 0.16 and a mean rating 0.3. For the neutral colors, the color difference is ΔE_{00} = 0.42, and the mean rating is 1.0.

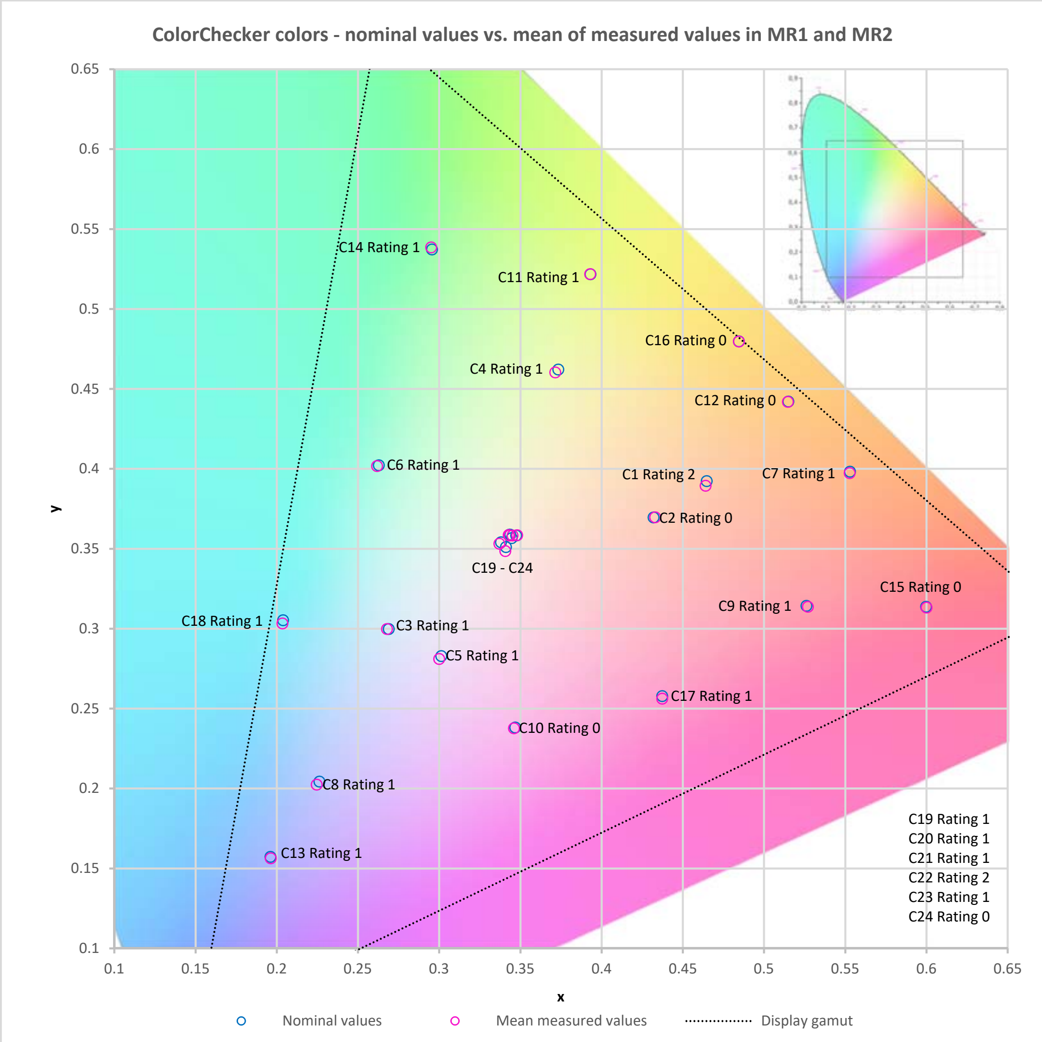


Figure 69. Presentation of color coordinates of the nominal color values and the averaged measured spectral values for Display 3 in the CIExy chromaticity diagram.

Comparing the spectral values shows that the luminance (L*) is lower with only two exceptions (colors 12 and 22). The chromatic colors are mostly displayed more saturated, except for the colors in the spectral range orange to yellow due to the increasing blue color value. A clear tendency in the direction of a certain color value proportion cannot be recognized, as this varies from color to color. A mixed picture also emerges for the neutral colors: colors 20, 21, 23 and 24 show a higher blue content, while colors 19 and 22 tend in the opposite direction, which then also leads to a higher luminance (L*) for color 22 and a lower saturation. In contrast, the remaining neutral colors are more saturated but with a lower luminance L*.

	Device Values			Nominal Values					Mean Measured Values MR1 + MR2						
Color	R	G	B	L*	a*	b*	x	y	L*	a*	b*	x	y	ΔE_{00}	Rating
1	116	81	57	38.46	16.67	22.38	0.4647	0.3923	38.26	17.10	21.92	0.4640	0.3894	0.54	2
2	199	147	129	65.92	23.40	18.83	0.4320	0.3696	65.77	23.60	19.00	0.4329	0.3697	0.17	0
3	91	122	156	49.73	-6.72	-23.09	0.2689	0.2998	49.61	-7.10	-23.16	0.2679	0.2998	0.33	1
4	94	108	64	43.97	-14.80	25.24	0.3733	0.4621	43.83	-14.87	24.52	0.3714	0.4603	0.41	1
5	130	128	176	55.15	10.34	-26.06	0.3013	0.2829	54.83	10.51	-26.62	0.3000	0.2811	0.41	1
6	92	190	172	70.05	-45.12	-0.49	0.2628	0.4022	69.98	-45.41	-0.77	0.2617	0.4017	0.20	0
7	224	124	47	63.45	44.26	64.39	0.5529	0.3982	63.30	44.41	63.69	0.5527	0.3974	0.35	1
8	68	91	170	39.46	11.28	-47.88	0.2262	0.2043	39.17	11.39	-48.37	0.2246	0.2024	0.30	1
9	198	82	97	51.75	58.97	17.44	0.5261	0.3143	51.57	59.20	17.40	0.5270	0.3137	0.20	0
10	94	58	106	30.55	29.55	-22.71	0.3468	0.2382	30.35	29.41	-22.80	0.3460	0.2377	0.19	0
11	159	189	63	72.35	-30.04	63.52	0.3931	0.5217	72.34	-30.12	63.54	0.3930	0.5218	0.03	0
12	230	162	39	72.30	24.74	77.57	0.5149	0.4421	72.33	24.73	77.42	0.5147	0.4420	0.04	0
13	35	63	147	27.69	16.87	-53.34	0.1961	0.1573	27.55	17.24	-53.46	0.1963	0.1564	0.23	1
14	67	149	74	55.01	-52.23	33.95	0.2955	0.5372	54.75	-52.37	34.03	0.2950	0.5385	0.25	1
15	180	49	57	42.90	65.08	31.01	0.5997	0.3137	42.87	65.24	30.95	0.6001	0.3133	0.08	0
16	238	198	20	81.70	6.51	92.91	0.4845	0.4798	81.68	6.55	92.81	0.4845	0.4797	0.03	0
17	193	84	151	52.35	61.02	-15.04	0.4373	0.2578	52.14	61.57	-15.50	0.4373	0.2563	0.30	1
18	0	136	170	51.11	-33.31	-28.83	0.2039	0.3053	50.84	-32.81	-29.28	0.2035	0.3033	0.44	1
19	245	243	243	95.99	0.90	0.28	0.3474	0.3583	95.70	1.05	0.50	0.3480	0.3585	0.35	1
20	200	202	202	81.15	-0.93	-0.27	0.3437	0.3588	80.66	-0.88	-0.56	0.3433	0.3583	0.45	1
21	161	163	163	66.83	-0.96	-0.29	0.3433	0.3589	66.47	-1.08	-0.46	0.3427	0.3586	0.37	1
22	121	121	122	50.92	0.18	-0.57	0.3446	0.3567	50.95	-0.10	-0.15	0.3451	0.3583	0.59	2
23	82	84	86	35.70	-0.74	-1.58	0.3380	0.3541	35.38	-0.77	-1.83	0.3371	0.3532	0.35	0
24	49	49	51	20.64	0.41	-1.30	0.3411	0.3511	20.37	0.71	-1.65	0.3407	0.3486	0.57	0

Table 32. Base values of target colors for Display 3 profiled based on the sRGB color space as well as the averaged spectral values.

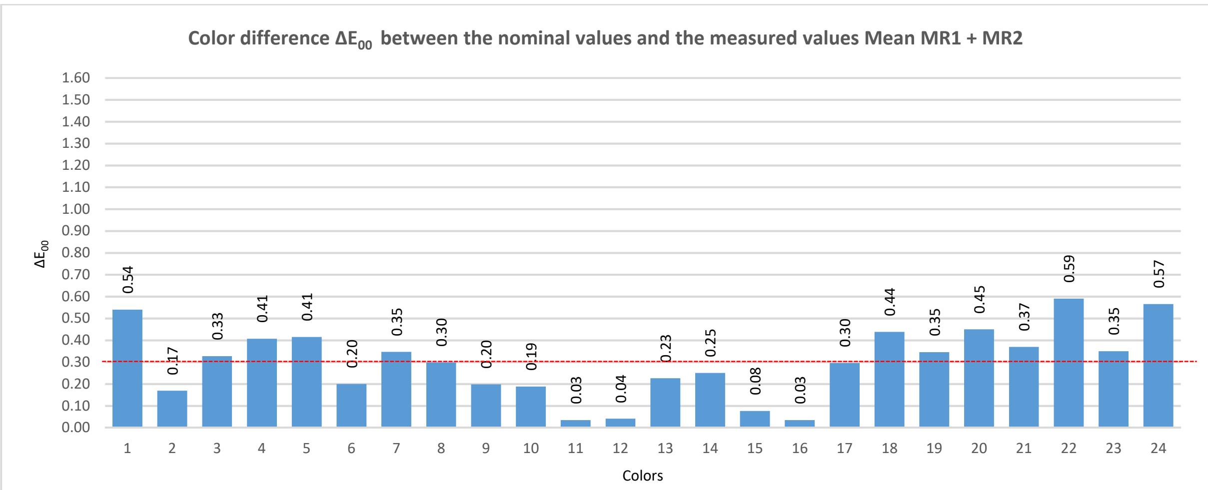


Figure 70. Visualization of the determined color difference ΔE_{00} between the nominal values and the measured spectral values of the two control measurements for Display 3.

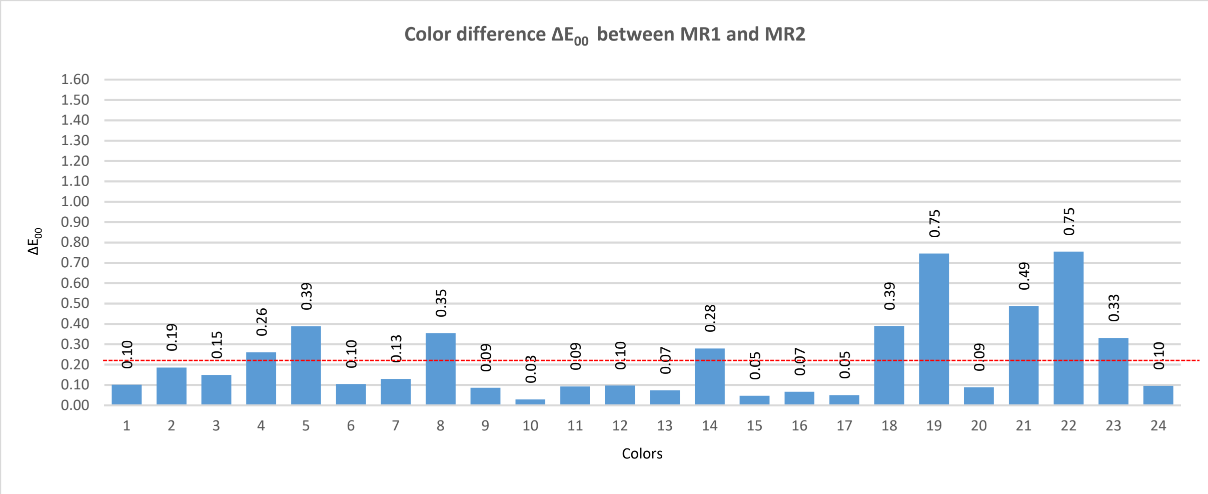


Figure 71. Visualization of the determined color difference ΔE00 between the measured spectral values of the two control measurements MR1 and MR2 for Display 3.

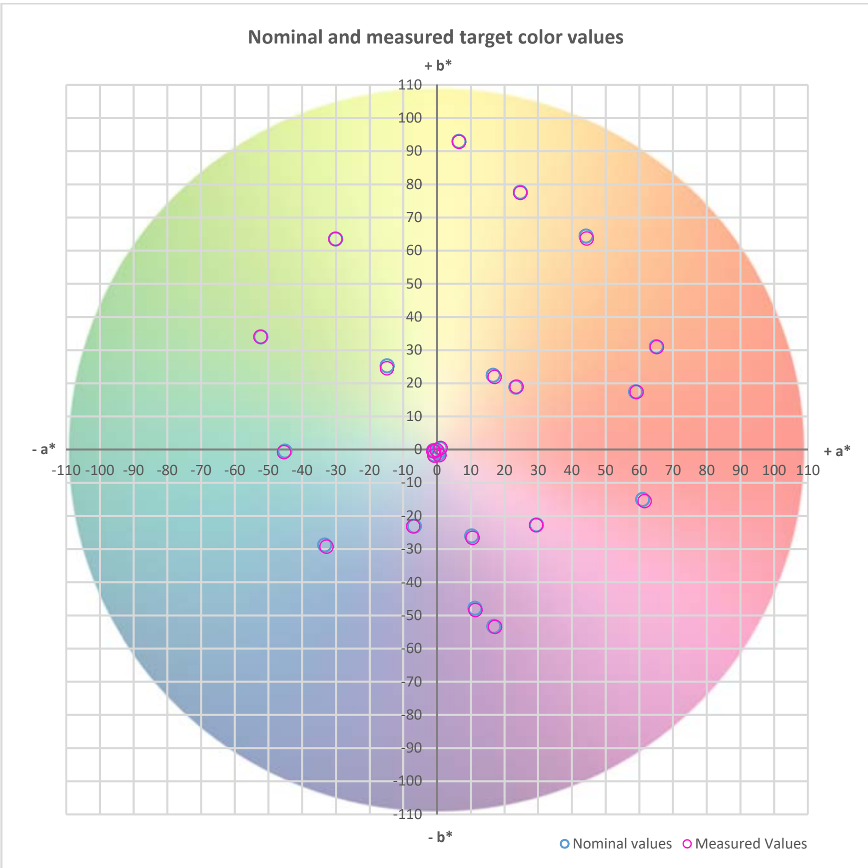


Figure 72. Plot of color locations of the nominal color values and the averaged measured spectral values for Display 2 in the a*b* plane (CIE Lab 1976).

4.7.6.5 Display 4

The profile "Display4_MD1_sRGB_80_V1" used for this display was created based on the sRGB standard color space. The corresponding values are shown in Table 33.

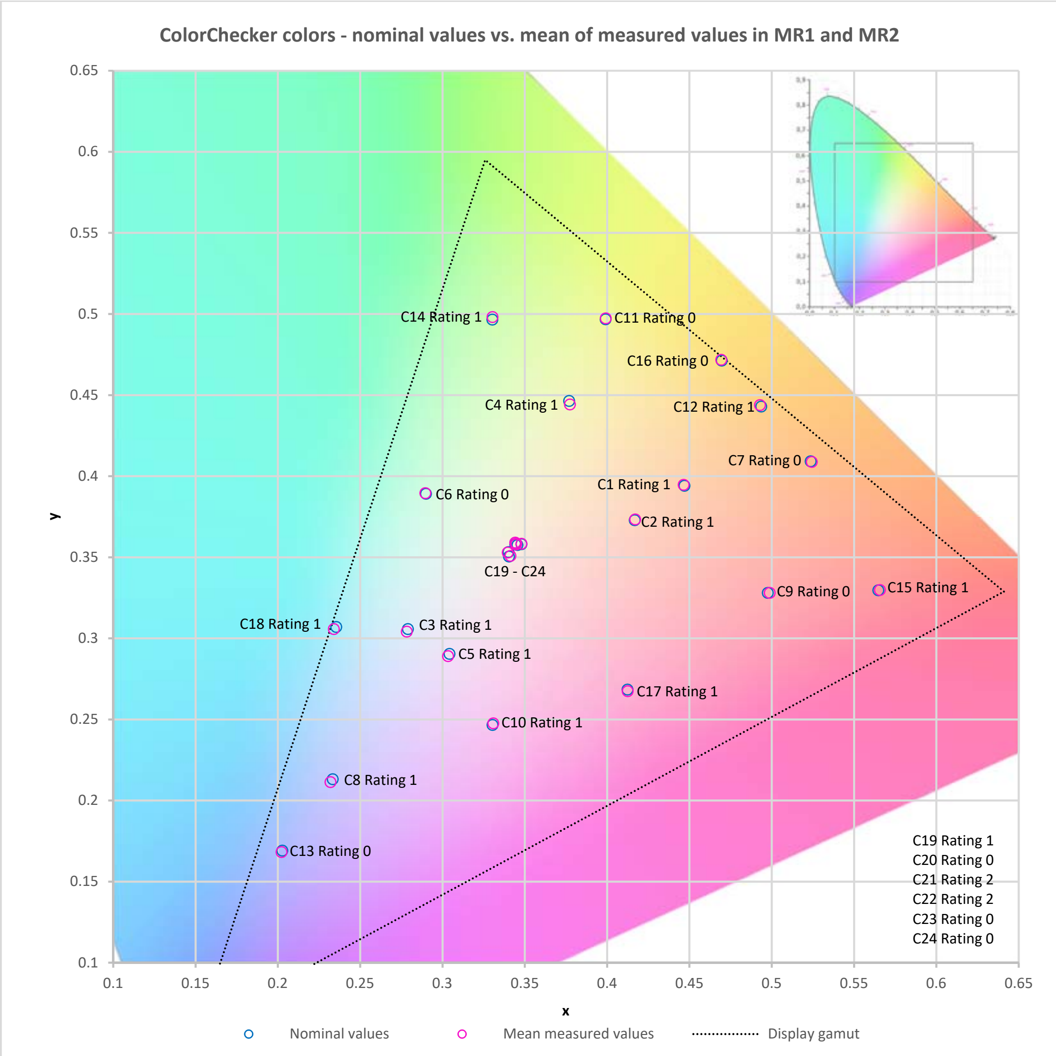


Figure 73. Presentation of color coordinates of the nominal color values and the averaged measured spectral values for Display 4 in the CIExy chromaticity diagram.

The two control measurements performed show a very good result. Comparing the nominal values with the mean spectral measured values gives a mean color difference of $\Delta E_{00} = 0.24$ over all 24 colors. The minimum is $\Delta E_{00} = 0.09$ (color 13), and the maximum is $\Delta E_{00} = 0.51$ (color 21). The mean rating is 0.7; the color differences are almost unnoticeable. The direct comparison of MR1 and MR2 shows that the color representation is very stable, with a mean color difference of $\Delta E_{00} = 0.10$, a minimum of $\Delta E_{00} = 0.02$ (in colors 9, 15, and 17), and a maximum of $\Delta E_{00} = 0.30$ in color 19. The mean overall rating is 0.2.

	Device Values			Nominal Values					Mean Measured Values MR1 + MR2						
#	R	G	B	L*	a*	b*	x	y	L*	a*	b*	x	y	ΔE_{00}	Rating
1	116	81	57	38.22	12.97	19.84	0.4469	0.3941	38.02	12.74	19.83	0.4465	0.3947	0.26	1
2	199	147	129	65.61	17.72	16.75	0.4167	0.3729	65.43	17.62	16.92	0.4171	0.3734	0.21	1
3	91	122	156	50.50	-5.19	-20.76	0.2790	0.3057	50.30	-4.97	-21.14	0.2783	0.3042	0.33	1
4	94	108	64	44.09	-11.21	22.49	0.3769	0.4464	43.79	-10.67	22.00	0.3774	0.4443	0.49	1
5	130	128	176	55.71	8.65	-23.69	0.3042	0.2904	55.44	8.81	-24.11	0.3033	0.2891	0.33	1
6	92	190	172	70.59	-30.73	0.00	0.2899	0.3891	70.66	-31.02	0.08	0.2896	0.3896	0.14	0
7	224	124	47	62.61	33.53	56.40	0.5236	0.4092	62.50	33.75	56.42	0.5243	0.4088	0.15	0
8	68	91	170	39.95	10.42	-44.93	0.2333	0.2131	39.77	10.63	-45.44	0.2320	0.2114	0.21	1
9	198	82	97	50.52	46.74	15.63	0.4976	0.3280	50.40	46.91	15.82	0.4987	0.3281	0.16	0
10	94	58	106	30.37	23.16	-22.09	0.3304	0.2466	30.14	22.87	-21.74	0.3309	0.2476	0.26	1
11	159	189	63	72.31	-22.47	55.74	0.3990	0.4967	72.36	-22.60	56.05	0.3991	0.4973	0.10	0
12	230	162	39	71.52	18.67	66.67	0.4936	0.4429	71.57	18.17	66.81	0.4928	0.4438	0.33	1
13	35	63	147	28.66	14.48	-50.16	0.2027	0.1691	28.57	14.64	-50.37	0.2022	0.1683	0.09	0
14	67	149	74	55.79	-35.99	30.87	0.3303	0.4965	55.54	-36.18	31.17	0.3304	0.4982	0.27	1
15	180	49	57	41.49	52.33	26.79	0.5647	0.3296	41.31	52.27	26.99	0.5657	0.3299	0.20	0
16	238	198	20	81.16	4.63	78.09	0.4696	0.4713	81.24	4.37	78.28	0.4693	0.4718	0.17	0
17	193	84	151	51.43	48.85	-15.08	0.4124	0.2684	51.25	49.13	-15.32	0.4125	0.2675	0.22	1
18	0	136	170	52.52	-21.71	-25.74	0.2354	0.3070	52.34	-21.83	-26.16	0.2340	0.3058	0.25	1
19	245	243	243	95.93	1.21	0.28	0.3479	0.3581	95.91	1.10	0.42	0.3479	0.3584	0.20	0
20	200	202	202	80.76	-0.32	-0.34	0.3446	0.3582	80.66	-0.30	-0.24	0.3448	0.3584	0.13	0
21	161	163	163	66.60	-0.39	-0.36	0.3442	0.3581	66.58	-0.69	-0.10	0.3442	0.3590	0.50	1
22	121	121	122	51.46	0.20	-0.25	0.3455	0.3576	51.39	-0.14	-0.29	0.3447	0.3579	0.51	2
23	82	84	86	35.66	-0.09	-1.54	0.3401	0.3532	35.63	-0.16	-1.65	0.3396	0.3529	0.14	0
24	49	49	51	20.71	0.39	-1.43	0.3404	0.3505	20.64	0.46	-1.33	0.3412	0.3508	0.16	0

Table 33. Base values of target colors for Display 4 profiled based on the sRGB color space as well as the averaged spectral values.

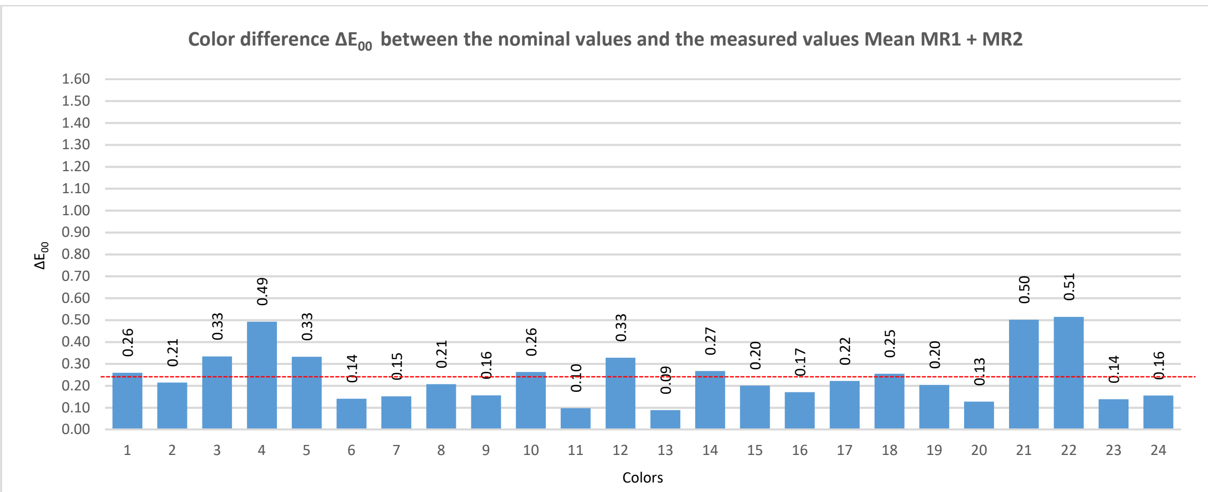


Figure 74. Visualization of the determined color difference ΔE_{00} between the nominal values and the measured spectral values of the two control measurements for Display 4.

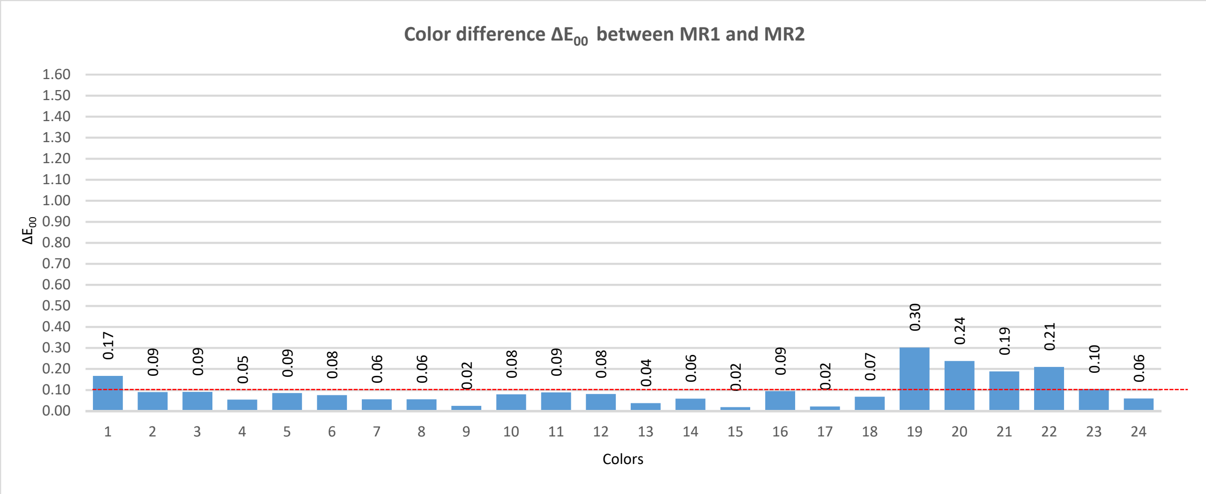


Figure 75. Visualization of the determined color difference ΔE_{00} between the measured spectral values of the two control measurements MR1 and MR2 for Display 4.

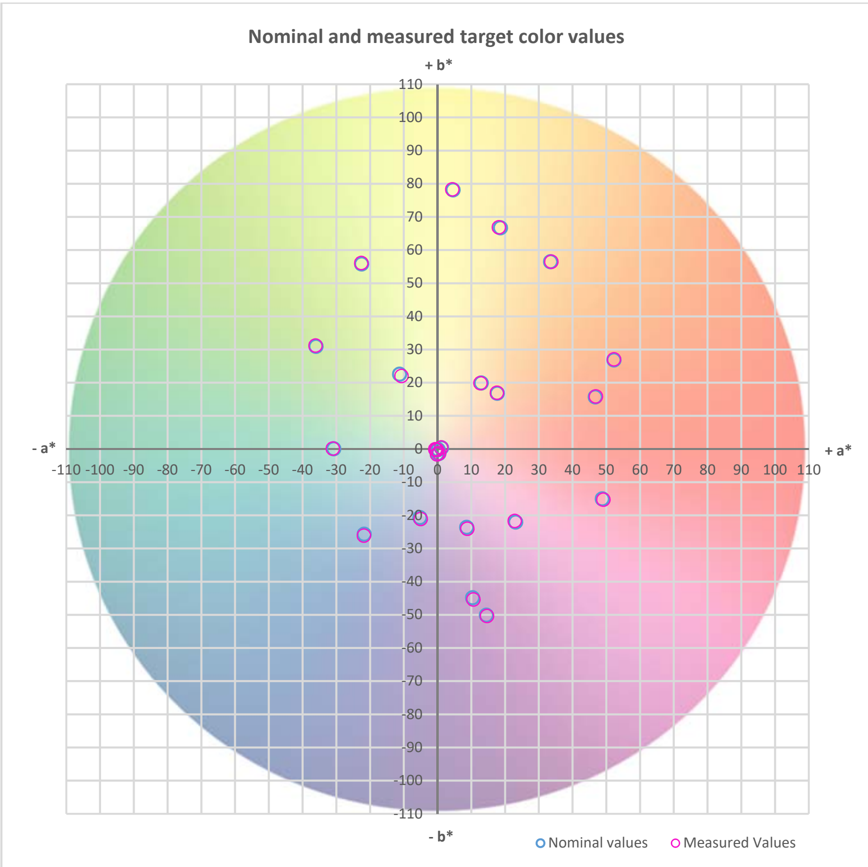


Figure 76. Plot of color locations of the nominal color values and the averaged measured spectral values for Display 4 in the a*b* plane (CIE Lab 1976).

In the analysis of the chromatic colors, the measured spectral values show slightly more saturated colors, with a few exceptions mainly found in the yellowish orange to yellowish green spectral range. The more saturated colors in the green to red spectral range are represented somewhat more yellowish, which leads to a higher luminance value (L*) for colors 6, 11, 12, and 16. For all other colors, the luminance decreases. The colors in the blue and violet range are represented more reddish and bluish, with the exception of color 10. The achromatic colors all show a lower luminance (L*) compared to the nominal values. Except for color 24, all other colors show a slight greenish tendency. An increase in saturation can be seen in colors 21–23.

4.7.6.6 Summary

The measurements and the subsequent analysis of the data show the extent to which the color representation of the target colors is device-dependent. The identical color values R, G, and B are converted spectrally to a greater or lesser extent on the basis of the display profiles, which in turn describe the color representation properties of the respective display.

In essence, it can be stated that all displays convert the nominal color values very well and that the stability in the repetition of the measurements is high. However, it is also noticeable that displays 1 to 3 usually show somewhat higher color differences in the achromatic colors 19–24 compared to the chromatic colors 1–18. The standard color gamut used for profiling also has an influence. Displays 1 and 2 are profiled based on the AdobeRGB standard color space and thus represent a significantly larger color gamut than displays 3 and 4. This is also reflected in a higher accuracy rating. Display 1 in particular shows larger deviations compared to displays 3 and 4, which are profiled based on the sRGB standard color space.

	Color representation			Stability		
	Total colors	Colors 1 - 18	Colors 19 - 22	Total colors	Colors 1 - 18	Colors 19 - 22
Display 1	1.5	1.3	2.3	0.2	0.2	0.2
Display 2	1.0	0.9	1.2	0.1	0.1	0.2
Display 3	0.8	0.6	1.0	0.5	0.3	1
Display 4	0.7	0.6	0.8	0.2	0.1	0.5

Table 34. Evaluation of color representation of the target colors.

In the analysis, a rating of 0.9 is obtained for Display 2 for the determined color difference ΔE_{00} of the measured spectral values to the nominal specifications. The determined color differences are thus almost unnoticeable for an observer. The two control measurements also show that the color representation of the display is very stable. The deviations between the results lead to a rating of 0.1. The measured color differences between the two measurement runs are not visually perceptible. The results for Display 1 show slightly larger color differences, with a rating of 1.5. The color representation as such is also very stable here. The rating for the deviations of the two control measurements is 0.2. Again, the measured color differences are not visually perceptible. Both displays show larger deviations in the achromatic colors compared to the chromatic colors. This is especially the case with Display 1, where the color differences of the chromatic colors are rated at 1.2, which means almost unnoticeable color differences. In contrast, the rating of the achromatic colors is 2.2, meaning that the measured color differences are perceptible to experienced viewers.

Comparing the device-dependent conversion of the digital color values into spectral values shows the influence of the device's own representable color gamut. Display 1 has a color gamut coverage of the AdobeRGB color space of 99.5%, while Display 2 achieves a value of 99.3%. Based on the determined tristimulus values, it can be seen that the ranges of representable colors differ. While Display 2 has a more saturated blue tristimulus value and thus more colors are represented in the blue-violet spectral range, the values for green and red in Display 1 are more saturated. This increases the number of representable colors in the red and even more so in the blue-green to green spectral ranges.

Considering first the nominal spectral values for the representation of the target colors on displays 1 and 2, Display 1 shows more saturated values in the direction of the dominant color values, with the exception of color 1. The chromatic colors also show a higher value for L* (luminance) for almost all colors; the exceptions here are colors 3, 5, and 10, which are in the rather unsaturated blue-violet spectral range. The values of the achromatic colors indicate a rather reddish representation for Display 1, which is then also confirmed by the measurement results obtained. Display 2 represents the achromatic colors more greenish and bluish in comparison.

The measurement results of the chromatic colors for Display 1 only show an increase in L* for colors 15, 16, and 17 compared to the nominal values. It can also be seen that almost all colors are represented more reddish. The less saturated colors 1, 2, 3, 5, and 6 in particular are represented with a higher saturation, whereas no tendency for the other colors is recognizable. As expected, the values of the achromatic colors clearly tend toward a more reddish direction, while the blue color value decreases (with the exception of color 19). However, this only leads to an increase in luminance in colors 23 and 24. The results for Display 2 are clearly different. With the exception of color 1, the chromatic colors are represented more saturated in the direction of the dominant color values. The luminance L* of the colors in the more saturated yellow to green spectrum is higher compared to the nominal specification, while it decreases in the remaining colors. The achromatic colors also demonstrate a tendency to become more saturated in almost all colors, mostly due to the increase of saturation toward the blue spectral range. The luminance decreases compared to the nominal values in all neutral colors.

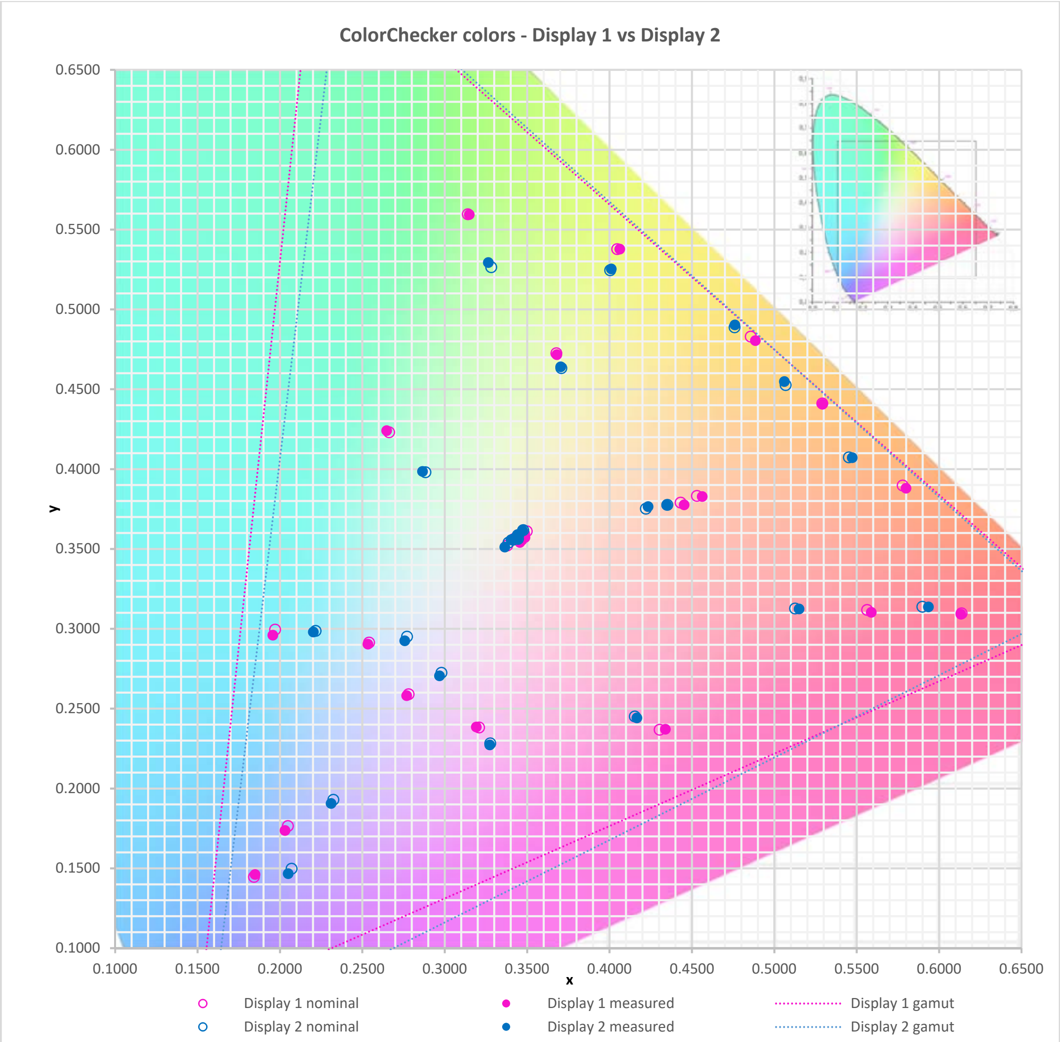


Figure 77. Presentation of color coordinates of the nominal color values and the averaged measured spectral values for displays 1 and 2 in the CIExy chromaticity diagram.

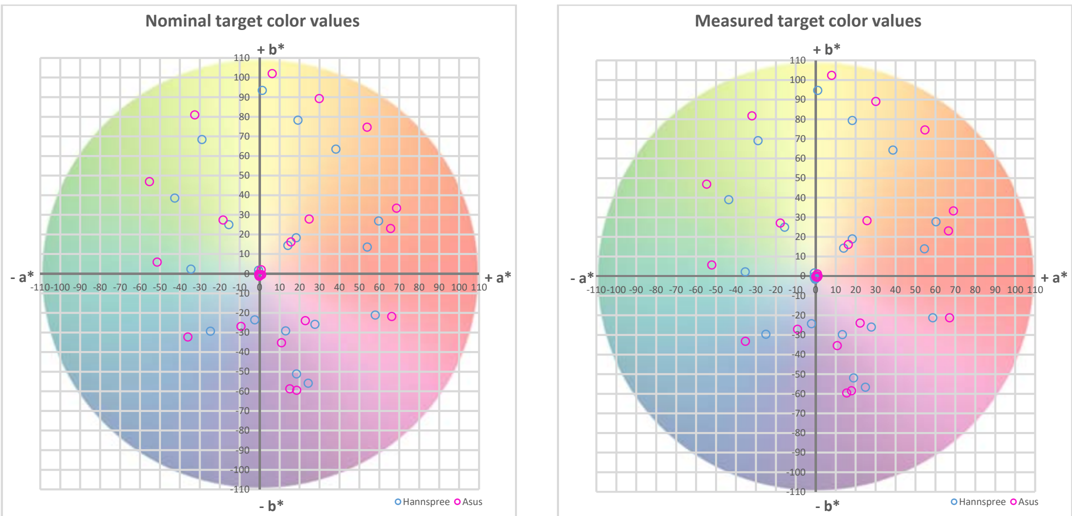


Figure 78. Plot of color locations of the nominal color values (left) and the averaged spectral values (right) for displays 1 and 2 in the a*b* plane (CIE Lab 1976).

Because displays 3 and 4 have a smaller device-dependent color gamut by comparison, they were profiled on the basis of the standard color gamut sRGB. For Display 4, the determined color difference ΔE_{00} of the measured spectral values to the nominal specifications yields a mean rating of 0.7 (i.e., the color differences are almost unnoticeable). This is also reflected in the excellent mean rating for the stability of the color representation at 0.2. The deviations between the measured values are therefore not visually perceptible.

The results for Display 3 show slightly larger color differences. With a mean rating of 0.8, the color representation is also very stable here. The rating for the deviations of the two control measurements is 0.5; the measured color differences are not visually perceptible. For both displays, the maxima of the determined values are found in the achromatic colors. It is particularly remarkable that, for Display 3, the measured color difference ΔE_{00} for all achromatic colors is above the mean color difference ΔE_{00} for all 24 colors. If only these colors are considered, the rating for the determined color difference to the nominal default increases to 1.3, as does the rating for the stability of the color representation (to 1).

Compared to Display 4, Display 3 has a much higher representable color gamut. However, this is only conditionally expressed in the color gamut coverage of the sRGB color space of 99% (compared to 95%). The tristimulus values lead to a significantly higher number of representable colors in all spectral ranges, but especially in the green range. Accordingly, it can be seen that the nominal spectral values for the representation of the target colors show significantly more saturated values in the direction of the dominant color values compared to Display 4. Several colors are even outside the representable color gamut of Display 4. Only the nominal values for colors 1, 19, and 24 show a higher saturation for Display 4.

In turn, the comparison of the nominal and measured spectral values for Display 3 shows that the measured luminance (L*) is mostly lower. The chromatic colors are more saturated, with the exception of the colors in the spectral range orange to yellow. A clear tendency in the direction of a certain color value proportion cannot be seen. This also applies to the neutral colors. With one exception, the neutral colors are more saturated but with a lower luminance L*. Display 4 also presents the colors rather more saturated, with some exceptions in the slightly extended spectral range yellowish orange to yellowish green. The more saturated colors in the green to red spectral range are displayed slightly less blue, which leads to a higher luminance value (L*). For all other colors, the luminance decreases. This also applies to the achromatic colors, which are represented slightly greener (except for color 24). An increase in saturation can only be seen for three colors.

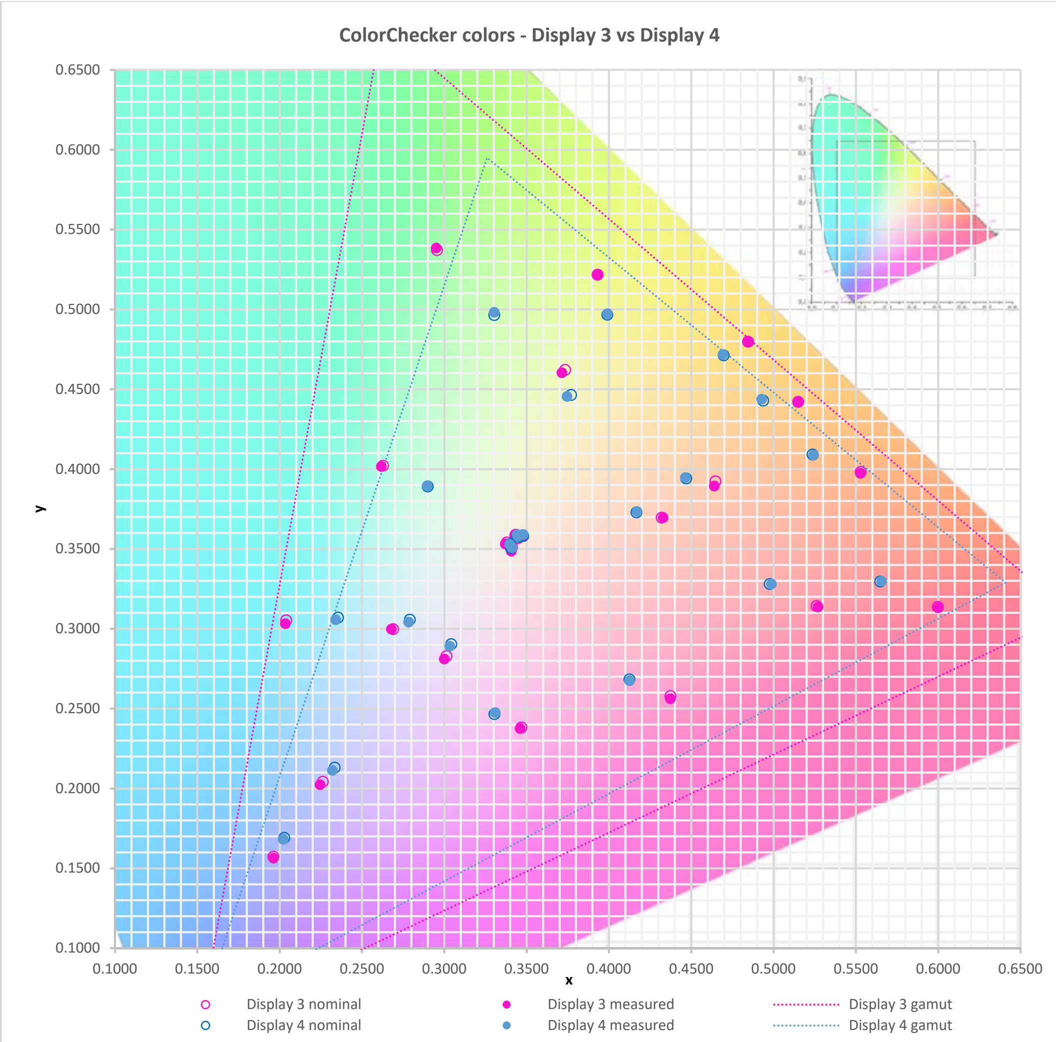


Figure 79. Presentation of color coordinates of the nominal color values and the averaged measured spectral values of displays 3 and 4 in the CIExy chromaticity diagram.

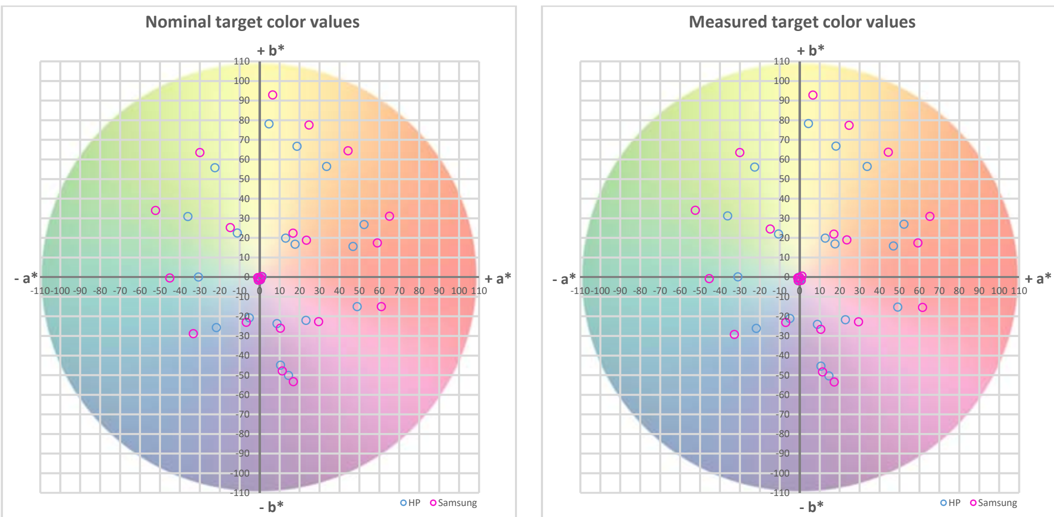


Figure 80. Plot of color locations of the nominal color values (left) and the averaged measured spectral values (right) for Displays 3 and 4 in the a*b* plane (CIE Lab 1976).

4.7.7 Analysis and evaluation of the color matching experiments

An example procedure is presented below for the participant with ID 01 using Display 2. As already mentioned, all data were collected anonymously and combined under an ID assigned to the participant. Participant ID 01 is male and belongs to the age group 30–39. He wears spectacles but has no other known limitations of the visual system. He is assessed as an experienced user of digital devices and applications with professional experience in the field of digital media production.

4.7.7.1 Task 1

The first step is to analyze Task 1. Twelve defined single colors had to be readjusted until the best possible visual match with the target color was achieved. The participant performed this task twice for each display used. For Display 2, the results are as follows.

For a first overview, the color differences of the color matches to the target colors made by the participant in MR1 and MR2 were averaged. The mean color difference over the 12 target colors is $\Delta E_{00} = 0.32$. The minimum $\Delta E_{00} = 0.10$ was determined for color 4, and the maximum $\Delta E_{00} = 0.76$ for color 17. The standard deviation is SD = 0.1848. Seven colors fall below the average value; four colors exceed it to a greater or lesser extent. Colors 1, 3, 4, and 5 have a color difference below $\Delta E_{00} = 0.2$, meaning they are not visually perceptible. Colors 6, 12, and 16 slightly exceed this threshold. Colors 2, 8, 11, and 17 exceed the mean value. Color 17 stands out particularly strongly here, with a maximum $\Delta E_{00} = 0.76$. All color differences remain below the limit value of $\Delta E_{00} = 1$, so they can only be recognized by an experienced observer.

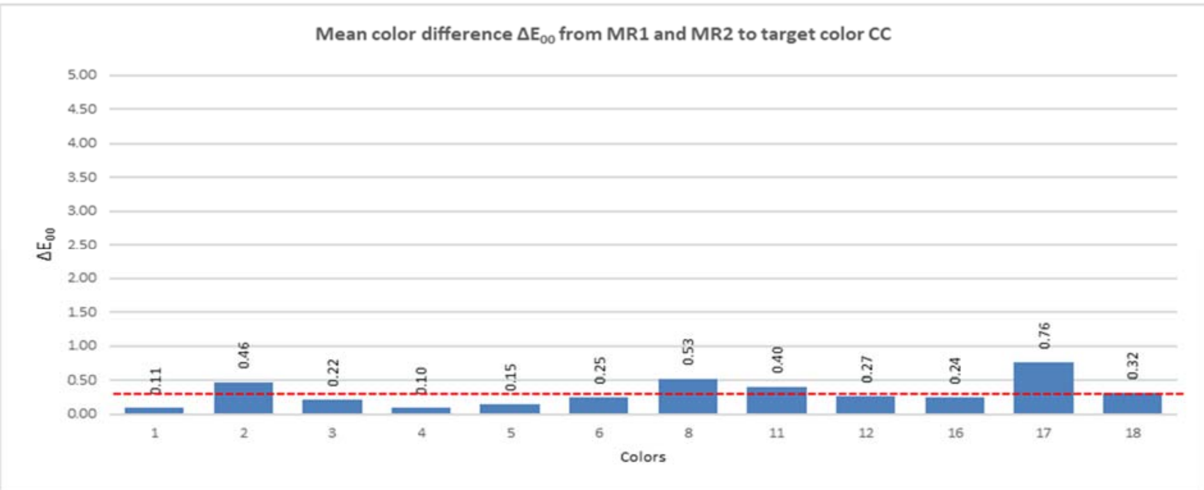


Figure 81. Visualization of the mean color difference ΔE_{00} from MR1 and MR2 to the respective target color from Task 1 using the example of participant ID 01.

Individual analysis of the two measurement runs shows clear differences. In MR1, the mean ΔE_{00} = 0.47, the minimum ΔE_{00} = 0.10, and the maximum ΔE_{00} = 1.22, with a standard deviation of SD = 0.3239. The results in MR2 are significantly better. In this case, the mean ΔE_{00} = 0.17 is below the limit value of 0.2. The minimum is ΔE_{00} = 0.01 and the maximum ΔE_{00} = 0.48, with a standard deviation SD = 0.1326. The determined color difference between the two values from MR1 and MR2 demonstrates a somewhat larger intrapersonal variation of the results for colors 6, 8, 11, and 17. The repeatability of the results is therefore more difficult for the participant here. For color 17, which shows the highest color difference in the consideration of the mean values, the maximum ΔE_{00} = 1.02 is also determined here. The other colors listed show color differences above the mean value of all 12 colors (ΔE_{00} = 0.48).

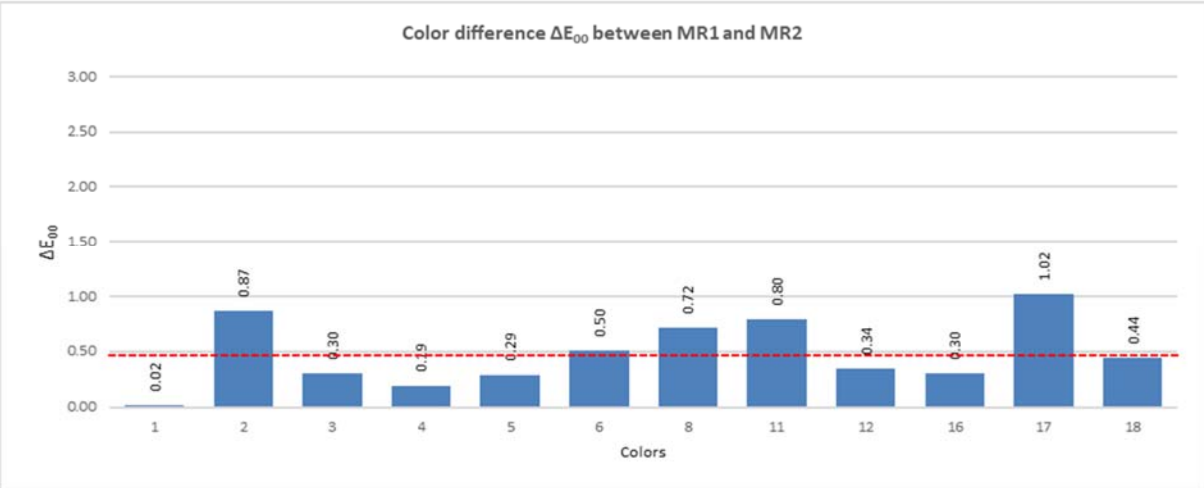


Figure 82. Visualization of the color differences ΔE_{00} of the colors from MR1 and MR2 from Task 1 using the example of participant ID 01.

The example of color 2 shows that it is important for the evaluation to also consider the color difference in the individual measurement passes. The mean color difference here is ΔE_{00} = 0.46, based on ΔE_{00} = 0.44 in MR1 and ΔE_{00} = 0.48 in MR2. If only these values are considered, the impression of high repeatability is created. However, if we compare the two values with each other, we obtain a color difference of ΔE_{00} = 0.87 between MR1 and MR2.
To make an exact statement about repeatability here, the measured spectral values from MR1 and MR2 were averaged, and the color difference ΔE_{00} of the two values to this mean value was calculated. The color difference of ΔE_{00} = 0.51 calculated in this way for color 17 remains the maximum, followed by color 2 with ΔE_{00} = 0.44. Over all 12 single colors, the mean is ΔE_{00} = 0.24, the minimum is ΔE_{00} = 0.01 in color 1, and the maximum is ΔE_{00} = 0.51 already mentioned in color 17. Six colors fall below the limit value ΔE_{00} = 0.2, which means that the

differences are not visually perceptible. The maximum is also difficult to perceive even for very experienced observers. In sum, the results obtained by this participant show excellent repeatability.

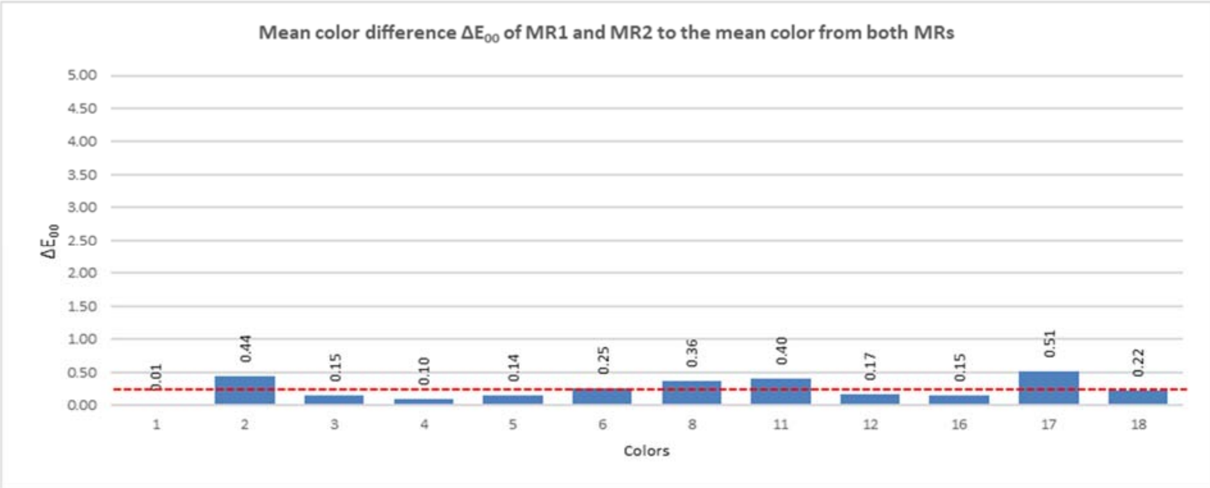


Figure 83. Visualization of the color difference ΔE_{00} between the colors from MR1 and MR2 to their mean color value from Task 1 using the example of participant ID 01.

For a detailed examination of the values obtained, the CIExy chromaticity diagram is used for each single color. The measured values of the target color (CC) and the two measurement runs MR1 and MR2 are shown, along with their mean value. It can already be seen from the color differences determined that the repeatability varies strongly from color to color in some cases. This impression is confirmed by looking at the distribution of the measured color coordinates in the plot.

A systematic tendency in all colors (e.g., a deviation in the same color orientation) is not to be recognized at first sight. The strong variation of the measured values in colors 2 and 17 is remarkable. These vary very strongly from the color orientation, which is given by the target color and the given mean value from MR1 and MR2. Similar deviations can be found in colors 12, 16, and 18. In colors 1, 3, 4, 5, 6, 8, and 11, such a deviation from the color orientation is hardly or only minimally noticeable.

In addition to the spectral values, the time required to achieve the results was also recorded for each color in both tasks. In Task 1, the processing time for MR1 was 5:07 min and 5:38 min for MR2. No significant deviation was found here. In the overall analysis, an average of 27 sec was spent on each color. The maximum was needed for color 17 (38 sec), and the minimum was 14 sec for color 16. In total, 24 colors were processed by the participant in the two runs.

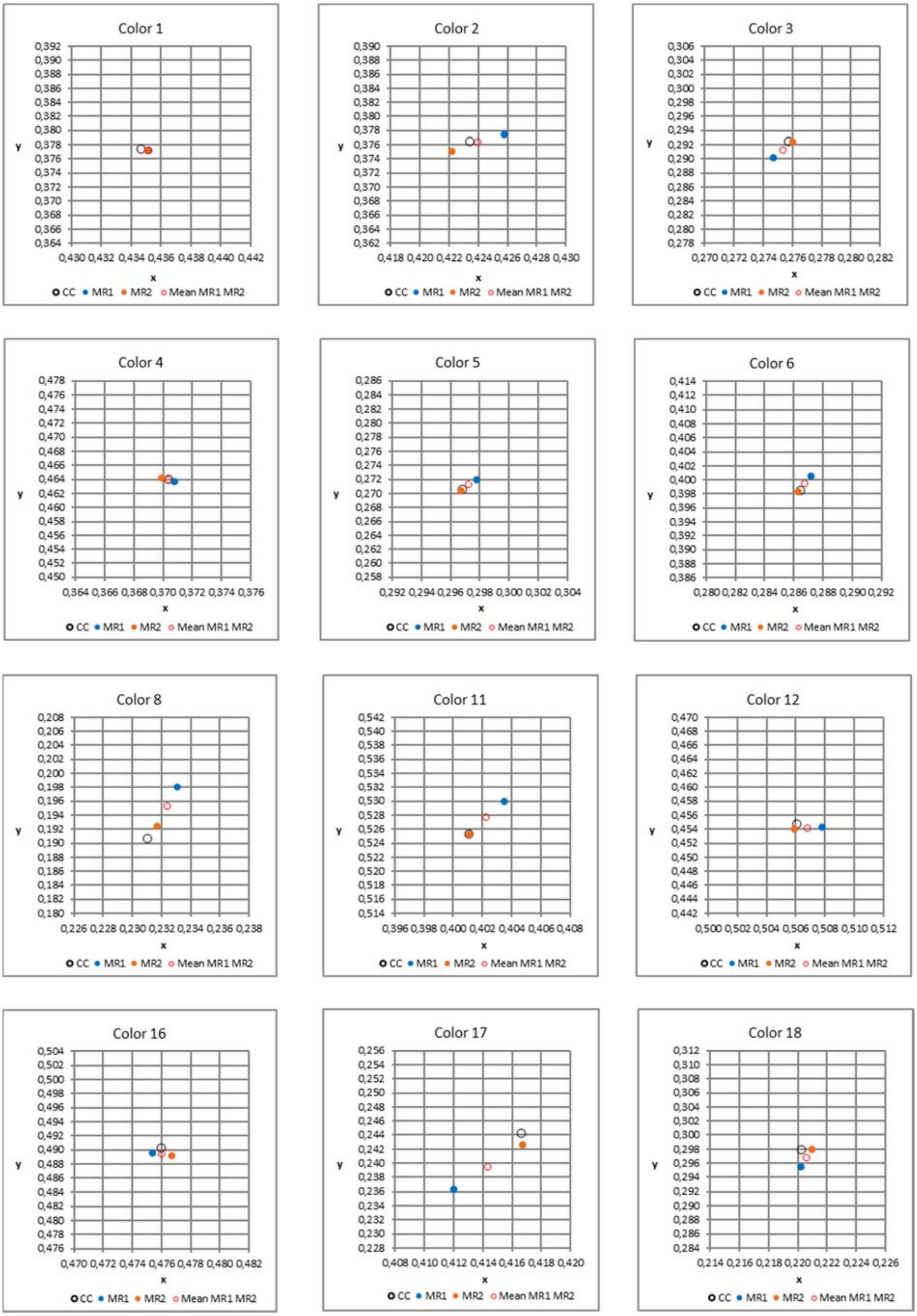


Figure 84. Presentation of measured color values from Task 1 of participant ID 01 in the CIExy chromaticity diagram.

Only five colors required more than 30 sec for color matching. When comparing MR1 and MR2, it can first be stated that less time was spent in MR1, and the achieved averaged color difference (ΔE_{00} = 0.47) is significantly higher than that achieved in MR2 (ΔE_{00} = 0.17). However, nothing generally or validly systematic can be derived from this, as shown by looking at the results obtained for all 24 single colors. Considering MR1, the largest amount of time (42 sec) was required for color 17, but the result with the largest color difference (ΔE_{00} = 1.21) was also achieved. By contrast, color 4 required the least amount of time, and at the same time also achieved the smallest color difference (ΔE_{00} = 0.03) to the specified target color. In MR2, the participant needed 24 sec for this color to achieve the (still best) result of ΔE_{00} = 0.02 for all colors. For color 17, the time required decreased to 33 sec, while the color difference also decreased to ΔE_{00} = 0.29.

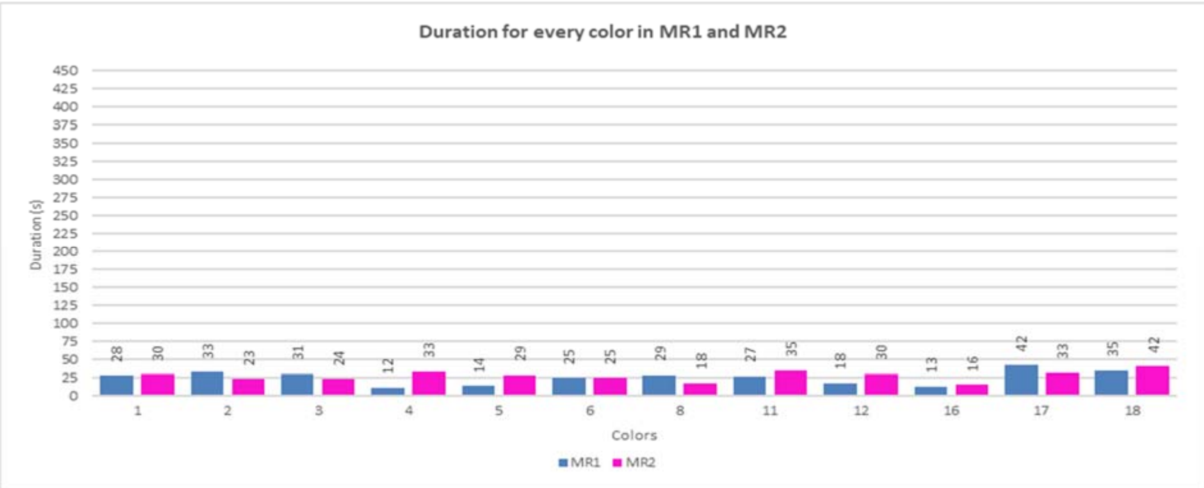


Figure 85. Time (sec) required in Task 1 for each single color in MR1 and MR2.

4.7.7.2 Task 2

In Task 2, all 24 colors were processed in one run in a modified basic structure. In contrast to Task 1, the participant is offered all colors simultaneously in a fixed arrangement for processing based on the ColorChecker Classic target. For this reason, the color patches (including the integrated masks) are significantly reduced in size. The order of processing is freely selectable. The results for both MR1 and MR2 show a mean color difference of ΔE_{00} = 0.81 (minimum ΔE_{00} = 0.34, maximum ΔE_{00} = 2.29), with a standard deviation SD = 0.3948. The minimum was determined for color 9, the maximum for color 13. Sixteen colors show a color difference that is below the mean ΔE_{00} = 0.81; eight colors exceed this, some significantly. Particularly noticeable here are the colors 13, 14, 19, and 23, which exceed the limit value ΔE_{00} = 1.0. Color

13, in particular, with a maximum ΔE_{00} = 2.29, is clearly above all other results. Colors 14 and 23 follow with a color difference of ΔE_{00} = 1.23 and ΔE_{00} = 1.20, respectively.

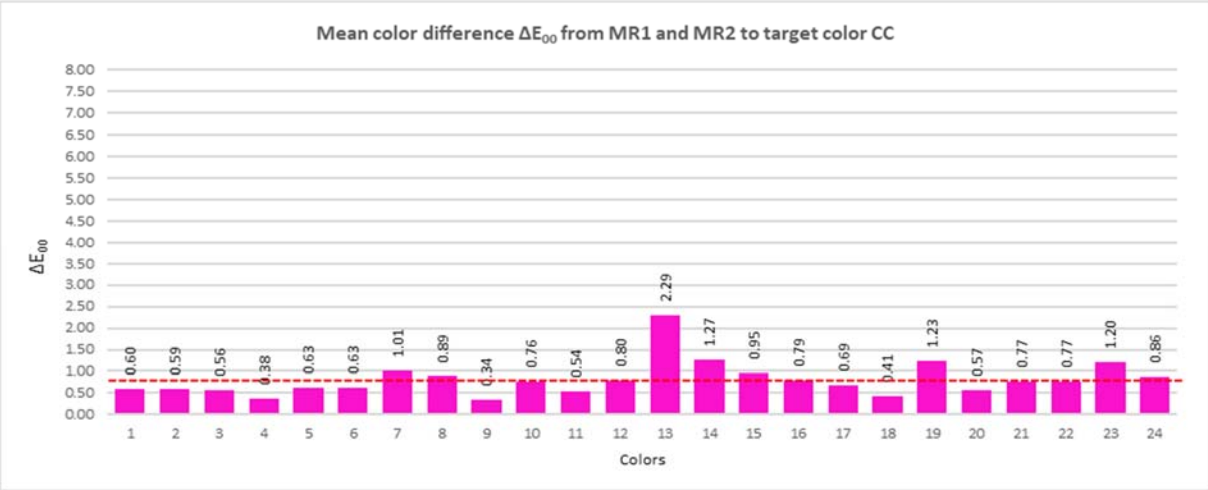


Figure 86. Visualization of the mean color difference ΔE_{00} from MR1 and MR2 to the respective target color from Task 2 using the example of participant ID 01.

The separate examination of MR1 and MR2 shows higher differences in different colors. The mean values for the two measurement runs are close to each other: ΔE_{00} = 0.85 for MR 1 (minimum ΔE_{00} = 0.25, maximum ΔE_{00} = 2.06) and the lower ΔE_{00} = 0.78 for MR2. The minimum ΔE_{00} = 0.07 in color 11 is also significantly lower. However, the maximum ΔE_{00} = 2.53 in color 13 is by far the highest measured value.

A clearer statement, however, is also possible in Task 2 using the color differences determined between the single colors from MR1 and MR2. Here, it can be seen that the intrapersonal variation in several colors is very high. The difference between results is particularly high in colors 7, 8, 14, and 15, although colors 2, 5, 6, 10, 12, and 16 also show remarkable differences. The mean color difference across all 24 colors is ΔE_{00} = 0.92, with a standard deviation SD = 0.6325. It can already be seen that colors 1, 4, 2, 22, and 24 have very high repeatability. The measured color difference for these colors is below or close to ΔE_{00} = 0.2 and thus not visually perceptible. In contrast, however, 11 colors show a color difference that is above the mean value and close to the limit value ΔE_{00} = 1.0. Colors 2, 5, 6, 7, 8, 10, 11, 12, 14, 15, and 16 exceed it, in some cases significantly. Particularly high color differences were determined for colors 14 (ΔE_{00} = 2.52), 7 (ΔE_{00} = 1.99), 15 (ΔE_{00} = 1.88), and 8 (ΔE_{00} = 1.77). Color 14 shows the absolute maximum ΔE_{00} = 2.52.

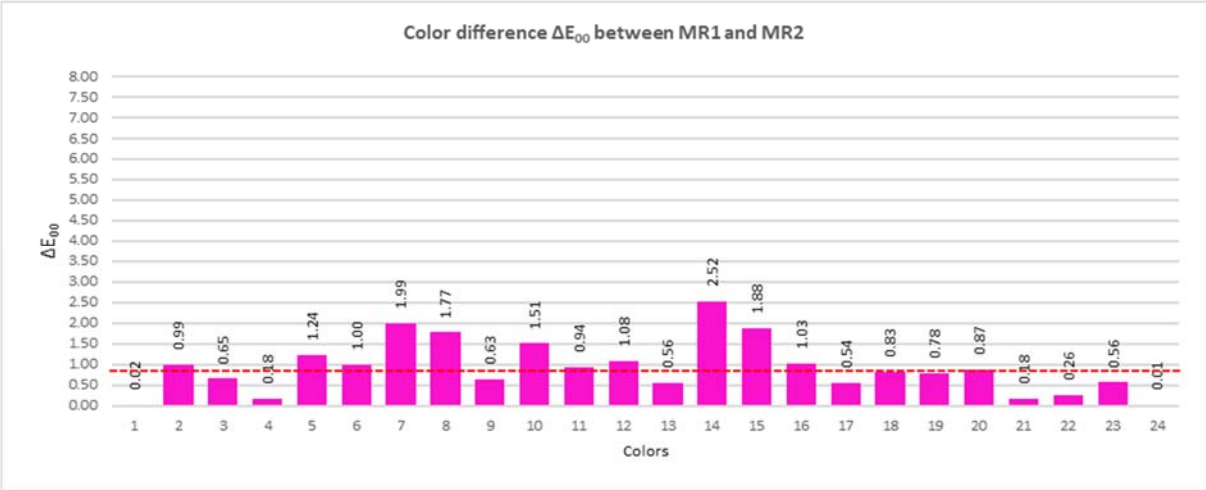


Figure 87. Visualization of the color differences ΔE_{00} between the colors from MR1 and MR2 from Task 2 using the example of participant ID 01.

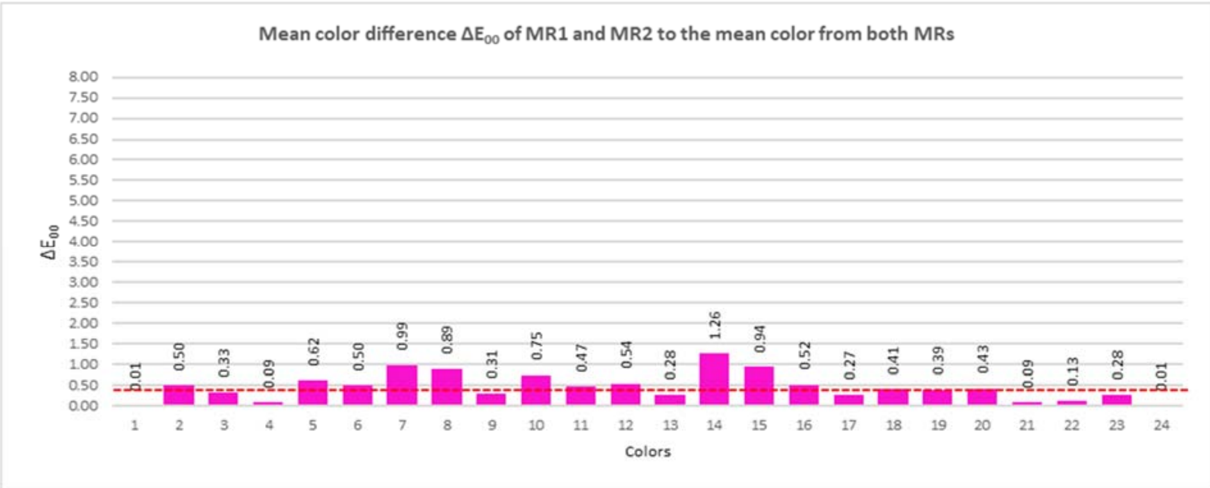


Figure 88. Visualization of the color difference ΔE_{00} of the colors from MR1 and MR2 to their mean color value from Task 2 using the example of participant ID 01.

For Task 2, the color differences of the measured values from MR1 and MR2 to their mean value were also calculated in the next step. The mean color difference for all 24 colors is $\Delta E_{00} = 0.46$. The minimum $\Delta E_{00} = 0.01$ is determined for colors 1 and 24, while the maximum in color 14 is $\Delta E_{00} = 1.26$. The standard deviation is SD = 0.3164. This shows that the color difference is not visually perceptible for colors 1, 4, 21, 22, and 24. The results for 11 colors exceed the mean value. Colors 7 and 15 show a color difference close to the limit value $\Delta E_{00} = 1.0$, but this is exceeded only for color 14 with $\Delta E_{00} = 1.26$. In sum, an overall evaluation of repeatability is very difficult here because the results vary too greatly.

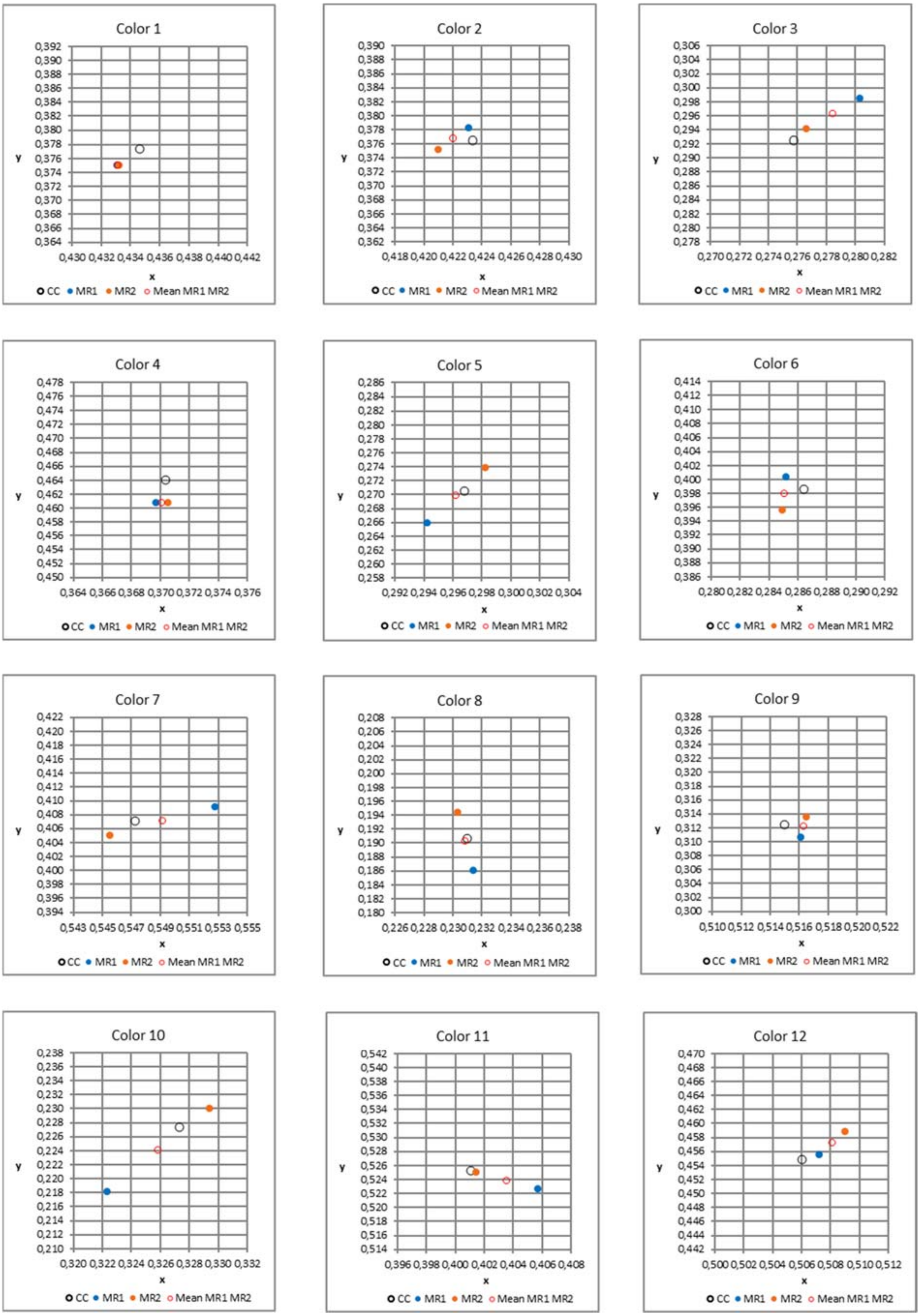


Figure 89. Presentation of the measured color values from Task 2 of participant ID 01 in the CIExy chromaticity diagram (Part 1: colors 1–12).

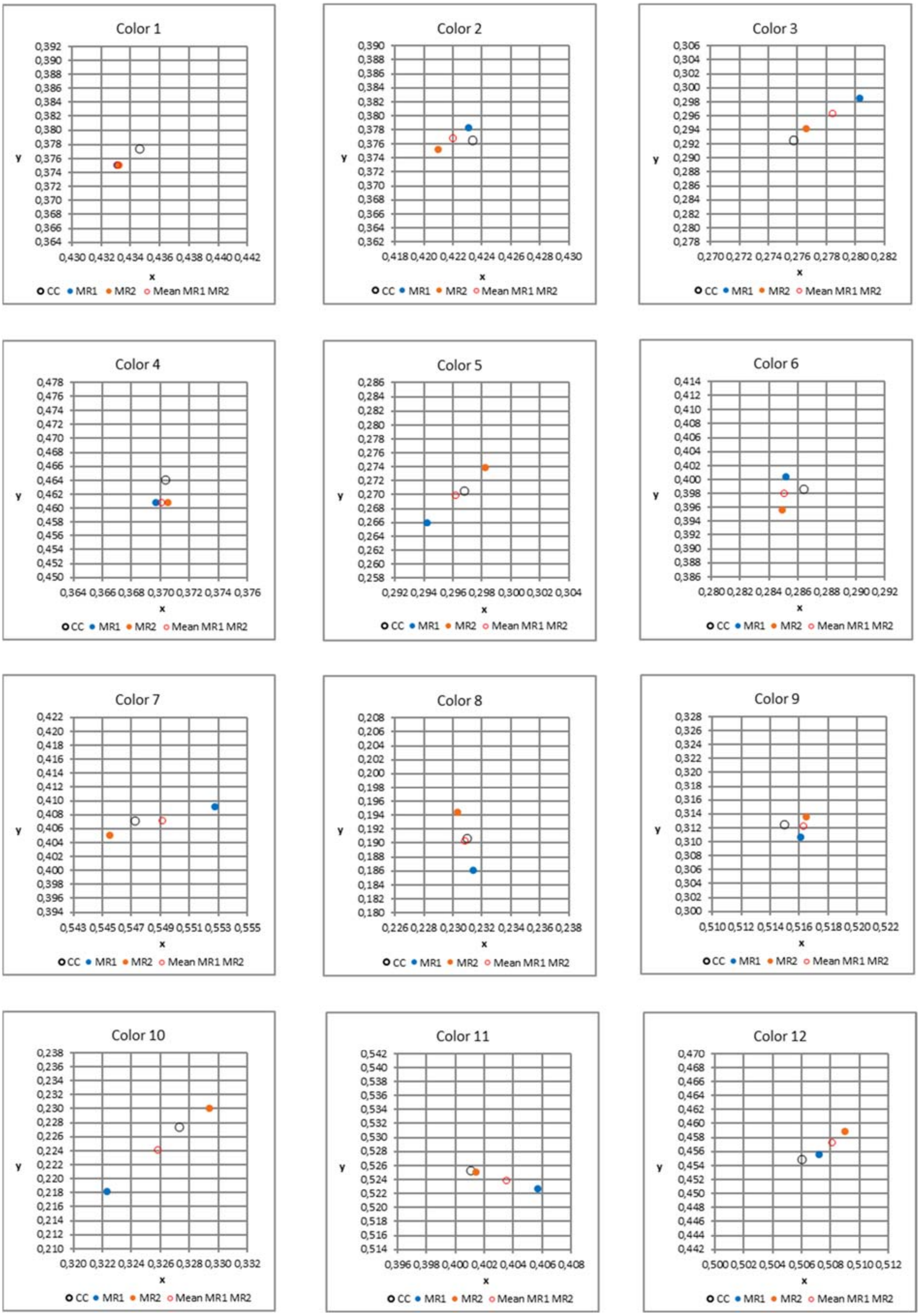


Figure 90. Presentation of the measured color values from Task 2 of participant ID 01 in the CIExy chromaticity diagram (Part 2: colors 13–24).

The position of the measured color values in the CIExy chromaticity diagram provides further insight. For example, at colors 19 to 24 (neutral achromatic colors), the position of the color values of this color group shows that, although they differ, they are very close to each other in relation to the color direction given by the mean value. This is also the case for some of the other colors. In contrast, colors 2, 6, 7, 8, 9, 15, 16, and 18 show strong variance, some deviating very clearly in opposite color orientations. As a result, as with Task 1, nothing systematic can be recognized in these variations in Task 2.
The processing time required for MR1 and MR2 hardly differs, which is also reflected in the mean values. For MR1, the participant needed 12:41 min to complete all colors, or 32 sec per color on average. The minimum is 10 sec, and the maximum is 124 sec. The averaged time for one color in MR2 of 33 sec is only slightly higher, as is the minimum of 12 sec, whereas the maximum of 72 sec is significantly lower. In MR1, the maximum of 124 sec was recorded for color 13, which also has the maximum color difference ($\Delta E_{00} = 2.09$). This time is an absolutely remarkable peak and is followed by color 8 with a processing time of 67 sec. For 16 of the colors, the participant needed less than 30 sec; six other colors remained below a processing time of 60 sec. In MR2, the processing time increases slightly: 13 colors show a processing time under 30 sec, with 10 further colors under 60 sec. No noticeable peak is observed, as in MR1. A maximum of 77 sec was recorded for color 7. In total, 48 colors were processed by the participant in the two runs.

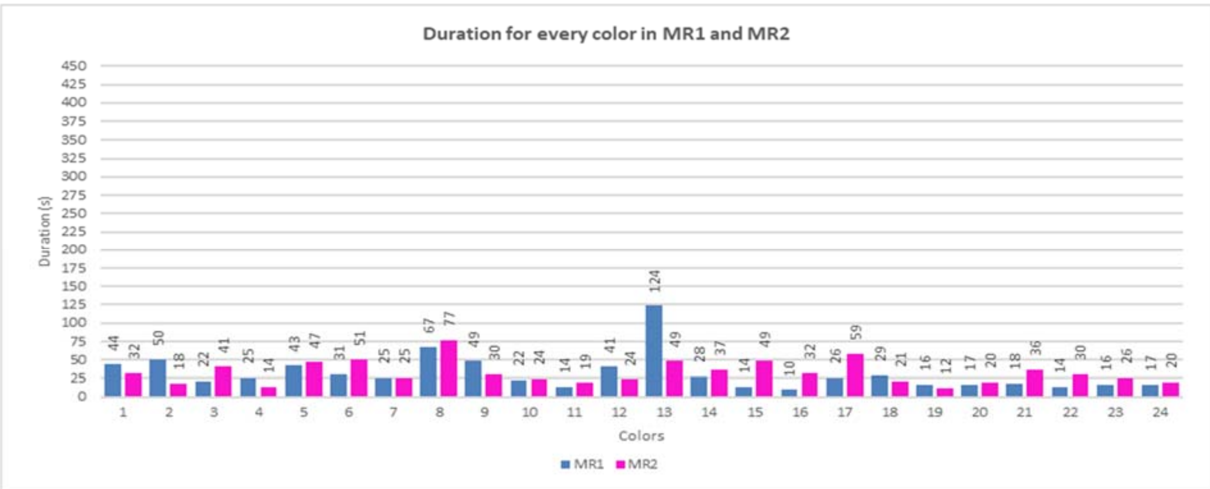


Figure 91. Time required in Task 1 and Task 2 for each single color in MR1 and MR2.

The recorded times for both measurement runs result in a mean processing time of 32 sec for each color, which is exceeded by 16 colors. The mean maximum of 86 sec is for color 13, but this is mainly due to the discordant value in MR1. Color 8 follows with an average processing time of 72 sec. Here, the values from MR1 and MR2 only differ by 10 sec. It is noteworthy that the achromatic neutral colors 19 to 24 consistently have the shortest processing times. No recognizable systematic correlation is observed between color difference ΔE_{00} and processing time required.

4.7.7.3 Summary of results from Task 1 and Task 2 in direct comparison

In this part of the analysis, the results from Tasks 1 and 2 are combined and compared with each other. Considering the mean color distance to the target color and the distribution in the defined limit values shows that the results from Task 1 deviate significantly from those from Task 2. The mean color difference $\Delta E_{00} = 0.32$ of the 12 colors from Task 1 is very good. Three colors show a value below $\Delta E_{00} = 0.2$, and six others show a value below $\Delta E_{00} = 0.5$. It is positive that no value is above $\Delta E_{00} = 1$. In sharp contrast, the mean color difference for Task 2 is $\Delta E_{00} = 0.81$, which is above even the maximum from Task 1. No value is below the limit value $\Delta E_{00} = 0.2$, but five values exceed the critical limit value $\Delta E_{00} = 1$, which makes visual perception of the color differences possible even for inexperienced observers. Given that Task 1 does not include any neutral colors, and therefore only the chromatic colors are considered for Task 2, the difference in the mean color difference is significantly smaller. For the chromatic colors 1–18, this is $\Delta E_{00} = 0.48$ and is thus significantly closer to the result from Task 1.

	Determined color differences				Distribution within defined limit values							
ΔE_{00}	Mean	Min	Max	SD	< 0,2	< 0,5	< 1	< 2	< 4	< 5	> 5	> Mean
Task 1	0,32	0,10	0,76	0,1848	3	7	2	0	0	0	0	5
Task 2	0,81	0,34	2,29	0,3948	0	3	16	4	1	0	0	8

Table 35. Comparison of mean color difference ΔE_{00} to the respective target color in Task 1 and Task 2.

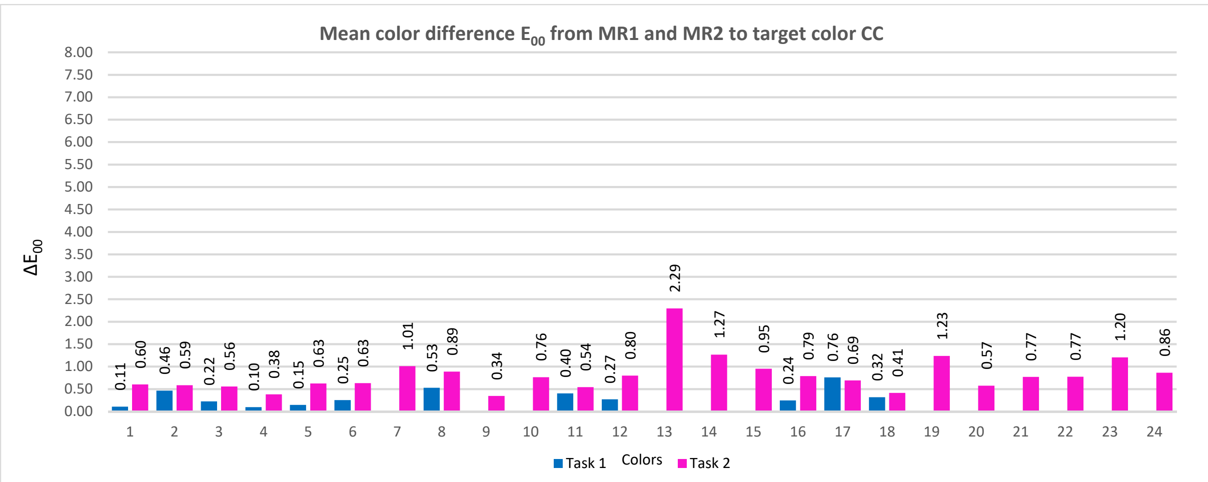


Figure 92. Visualization of the mean color difference ΔE_{00} to the respective target color in Task 1 and Task 2.

In the direct comparison of the determined color differences between the results from MR1 and MR2, Task 1 again shows better results. However, these differences are no longer quite so clear across all colors. On the one hand, the mean color difference for the single colors between MR1 and MR2 is significantly lower in Task 1 than in Task 2. On the other hand, Task 2 shows the best minimum value, even if the difference to Task 1 is only marginal.

Four colors in Task 2 show values below the limit $\Delta E_{00} = 0.2$, while another shows a value below $\Delta E_{00} = 0.5$. A similar result is provided by Task 1, where only two colors show a value below $\Delta E_{00} = 0.2$, although six others fall below the threshold of $\Delta E_{00} = 0.5$. Considering the results around the maximum, however, the situation changes significantly. In Task 1, only one color is slightly above the limit value $\Delta E_{00} = 1$; in Task 2, this limit is exceeded by eight colors, in some cases significantly. The maximum color difference, $\Delta E_{00} = 2.52$, is to be evaluated as a small color difference that can also be perceived by inexperienced observers. Here, the exclusive consideration of the chromatic colors from Task 2 also changes the evaluation: the difference between Task 1 and Task 2 increases. As a result, the mean color difference for colors 1–18 is $\Delta E_{00} = 1.08$ and thus even exceeds the critical threshold of $\Delta E_{00} = 1$.

	Determined color differences				Distribution within defined limit values							
ΔE_{00}	Mean	Min	Max	SD	< 0.2	< 0.5	< 1	< 2	< 4	< 5	> 5	> Mean
Task 1	0.48	0.02	1.02	0.2910	2	6	3	1	0	0	0	5
Task 2	0.92	0.01	2.52	0.6325	4	1	11	7	1	0	0	11

Table 36. Comparison of mean color differences ΔE00 between MR1 and MR2 in Task 1 and Task 2.

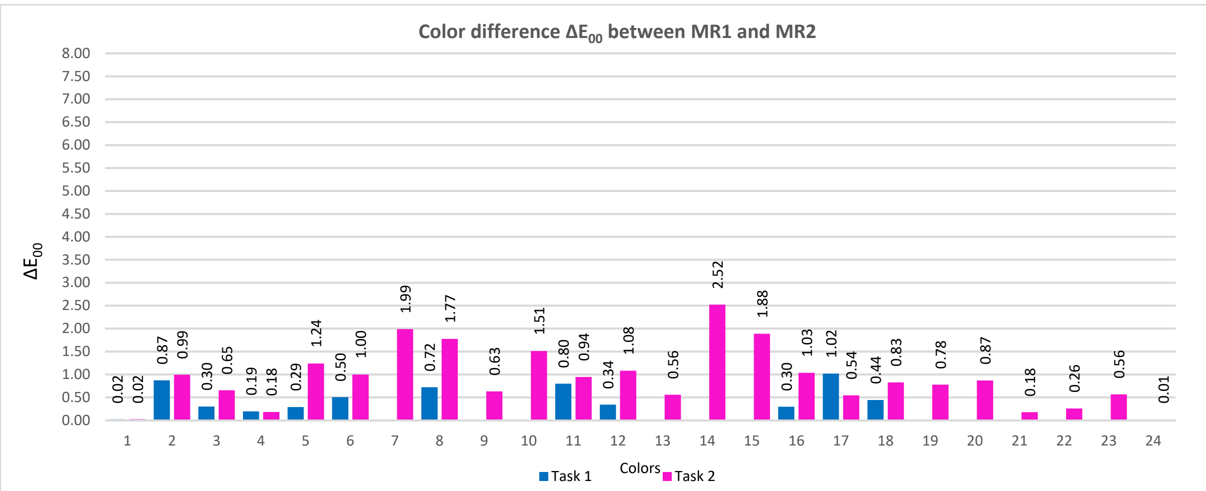


Figure 93. Visualization of mean color differences ΔE_{00} between MR1 and MR2 in Task 1 and Task 2.

When considering repeatability, Task 1 shows very good results. All results from MR1 and MR2 are close to the derived mean. The maximum $\Delta E_{00} = 0.51$ shows a color difference that can only be perceived visually by very experienced observers. In Task 2, the results lead to higher color differences, but the maximum $\Delta E_{00} = 1.26$ is the only value above the limit value $\Delta E_{00} = 1$. The overall result for Task 2 can be described as good since the color distances determined can, again, generally only be perceived by very experienced observers. Again, however, the difference between Task 1 and Task 2 increases when only the results for colors 1–18 are considered for Task 2 ($\Delta E_{00} = 0.54$).

	Determined color differences				Distribution within defined limit values							
ΔE_{00}	Mean	Min	Max	SD	< 0.2	< 0.5	< 1	< 2	< 4	< 5	> 5	> Mean
Task 1	0.24	0.01	0.51	0.1455	6	5	1	0	0	0	0	5
Task 2	0.46	0.01	1.26	0.3164	5	5	13	1	0	0	0	11

Table 37. Comparison of color difference ΔE_{00} of the colors from MR1 and MR2 to their mean color value.

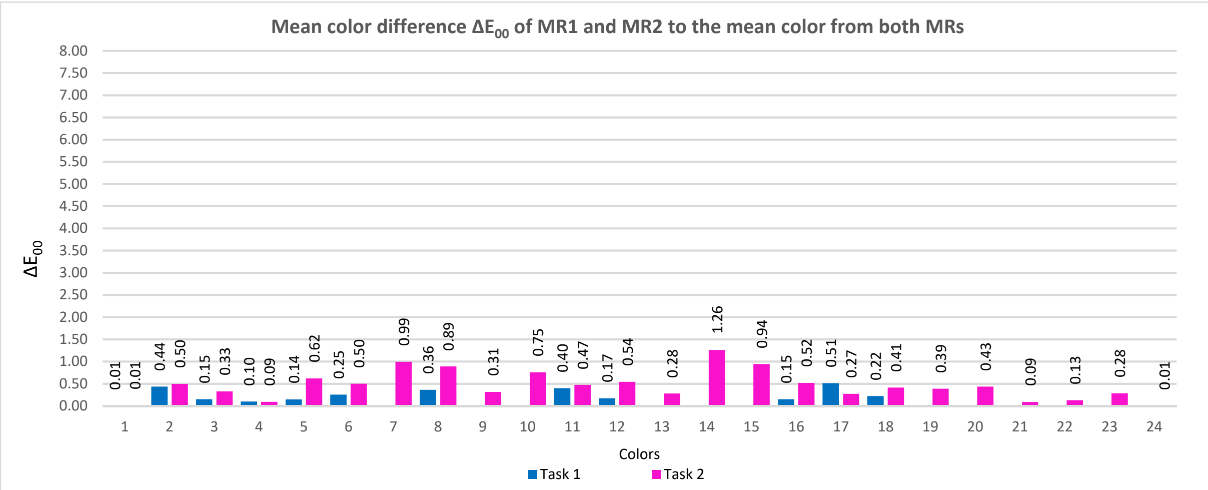


Figure 94. Visualization of color difference ΔE_{00} of the colors from MR1 and MR2 to their mean color value.

The processing times for Task 1 and Task 2 are almost equal and show only minor differences. The mean processing time for a single color is 27 seconds in Task 1 and 32 seconds in Task 2. However, this cannot be applied to all colors, because the participant in Task 2 needed less time for colors 4, 11, and 18. The somewhat higher average processing time for a single color in Task 2 is primarily due to colors 8 and 13, for which the participant required an unusually long processing time.

	Duration				Distribution within defined limit values				
Time in sec.	Total	M	Min	Max	< 30	< 60	< 90	> 90	> M
Task 1	331	27	14	42	9	3	0	0	4
Task 2	777	32	14	86	12	10	2	0	5

Table 38. Comparison of time (sec) required in Task 1 and Task 2 for each single color in MR1 and MR2.

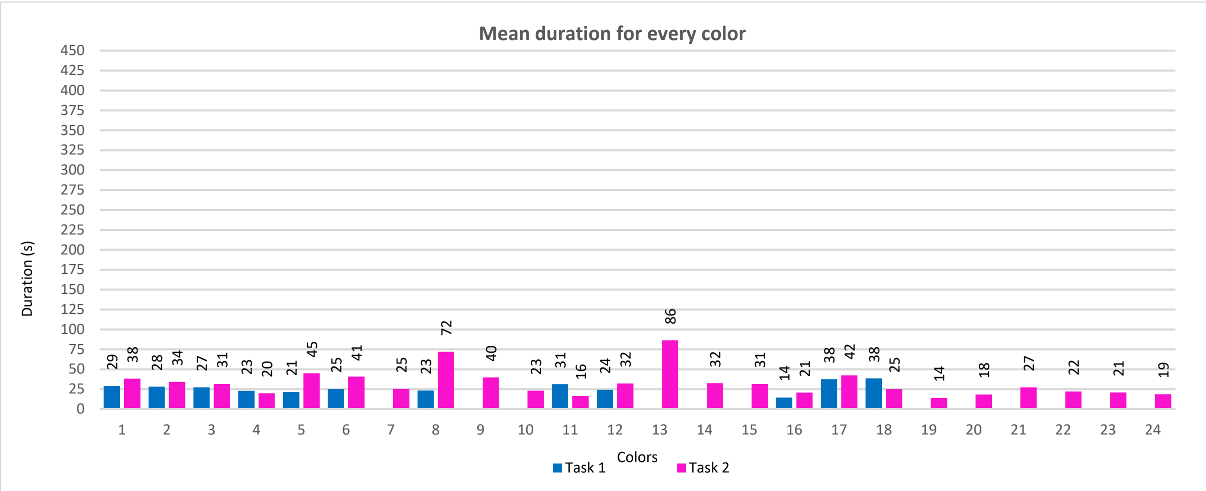


Figure 95. Visualization of time (sec) required in Task 1 and Task 2 for each single color in MR1 and MR2.

After the overall analysis, a more accurate conclusion requires the direct comparison of the 12 colors contained in both tasks, as shown in Table 39.

	Mean ΔE_{00} MR vs CC		ΔE_{00} MR1 vs MR2		ΔE_{00} $Mean_{MR1+MR2}$ vs MR		Duration (s)	
Color	Task1	Task 2	Task1	Task 2	Task1	Task 2	Task1	Task 2
1	0.11	0.60	0.02	0.02	0.01	0.01	29	41
2	0.46	0.59	0.87	0.99	0.44	0.50	28	42
3	0.22	0.56	0.30	0.65	0.15	0.33	27	27
4	0.10	0.38	0.19	0.18	0.10	0.09	23	23
5	0.15	0.63	0.29	1.24	0.14	0.62	21	44
6	0.25	0.63	0.50	1.00	0.25	0.50	25	36
8	0.53	0.89	0.72	1.77	0.36	0.89	23	69
11	0.40	0.54	0.80	0.94	0.40	0.47	31	15
12	0.27	0.80	0.34	1.08	0.17	0.54	24	36
16	0.24	0.79	0.30	1.03	0.15	0.52	14	15
17	0.76	0.69	1.02	0.54	0.51	0.27	38	34
18	0.32	0.41	0.44	0.83	0.22	0.41	38	27
Mean	0.32	0.63	0.48	0.86	0.24	0.43	26.87	34.10
Max	0.76	0.89	1.02	1.77	0.51	0.89	38.44	69.44
Min	0.10	0.38	0.02	0.02	0.01	0.01	14.35	15.18
SD	0.1848	0.1438	0.2910	0.4480	0.1455	0.2240	6.4597	14.1904

Table 39. Direct comparison of the 12 single colors contained in both tasks.

Considering the mean values first, the results of the overall observation are confirmed here. The mean color differences converge, while the mean value for the time required increases slightly for Task 2. In both tasks, the lowest color difference was obtained for color 4, although it is significantly higher in Task 2. In Task 1, it falls below the limit value $\Delta E_{00} = 0.2$ and is thus visually not perceptible. In Task 2, this limit value is exceeded with $\Delta E_{00} = 0.34$, although it remains visually almost unnoticeable. The values for assessing repeatability also fall below $\Delta E_{00} = 0.2$, so that for this color, the result can be described as very good. The time required differs by 3 sec (longer in Task 2) and is below the mean value obtained for the time required per color. Compared to the minimum, the maximum color difference to the target color can be seen in different colors. In Task 1, the maximum was determined for color 17, in Task 2 for color 8. Both colors also show the highest color differences for the repeatability evaluation and thus the worst results. In addition, the participant in the respective task also required the most processing time to achieve these results. Color 8 also shows high color differences in Task 1, and the same applies to color 17 in Task 2. The particularity here, however, is that color 17 is the only color for which lower color differences were determined in Task 2 than in Task 1 (i.e., a better result was achieved).

From this, it can be stated that colors 8 and 17 represent the greatest challenge for the participant in terms of accuracy and repeatability. Color 4, on the other hand, is the color with the best overall result. If only repeatability is evaluated, the result for color 1 is close to perfection in both tasks. However, the color difference to the target color in Task 2 deviates too far from the result in Task 1 and is much higher. The results for colors 2 and 4, for which values close to each other were achieved in Task 1 and Task 2, are also remarkable. The respective color difference to the target color is relatively high. The results for repeatability then show that the color coordinates in both tasks differ considerably from each other, which has a corresponding effect on the evaluation. These colors are also difficult for the participant to evaluate, regardless of the design of the task. For colors 1, 3, 5, 6, 12, 16, and 18, it should be noted that the participant achieved significantly better results in Task 1.

4.7.7.4 Evaluation of results

The results presented are now summarized in the evaluation. This is done using the rating scale in Table 29. The data gathered from the experimental tasks of each participant are used to rate the accuracy of the visual color matching, as well as the repeatability based on the determined color differences ΔE_{00}. Each single color is evaluated and summarized into an overall assessment of the two-part experiments.

	MR1 → CC	
Color	ΔE_{00}	Rating
1	0.11	0
2	0.44	1
3	0.34	1
4	0.10	0
5	0.27	1
6	0.44	1
8	0.87	2
11	0.80	2
12	0.33	1
16	0.18	0
17	1.22	3
18	0.52	1

	MR2 → CC	
Color	ΔE_{00}	Rating
1	0.10	0
2	0.48	1
3	0.11	0
4	0.09	0
5	0.02	0
6	0.06	0
8	0.18	0
11	0.01	0
12	0.21	1
16	0.30	1
17	0.29	1
18	0.12	0

	MCD → CC	
Color	ΔE_{00}	Rating
1	0.11	0
2	0.46	1
3	0.22	1
4	0.10	0
5	0.15	0
6	0.25	1
8	0.53	2
11	0.40	1
12	0.27	1
16	0.24	1
17	0.76	2
18	0.32	1

	MR1 → MR2	
Color	ΔE_{00}	Rating
1	0.02	0
2	0.87	2
3	0.30	1
4	0.19	0
5	0.29	1
6	0.50	2
8	0.72	2
11	0.80	2
12	0.34	1
16	0.30	1
17	1.02	3
18	0.44	1

	MCD → $M_{MR1+MR2}$	
Color	ΔE_{00}	Rating
1	0.01	0
2	0.44	1
3	0.15	0
4	0.10	0
5	0.14	0
6	0.25	1
8	0.36	1
11	0.40	1
12	0.17	0
16	0.15	0
17	0.51	2
18	0.22	1

Table 40. Rating of color differences of the single colors from Task 1 for user ID 01 and Display 2.

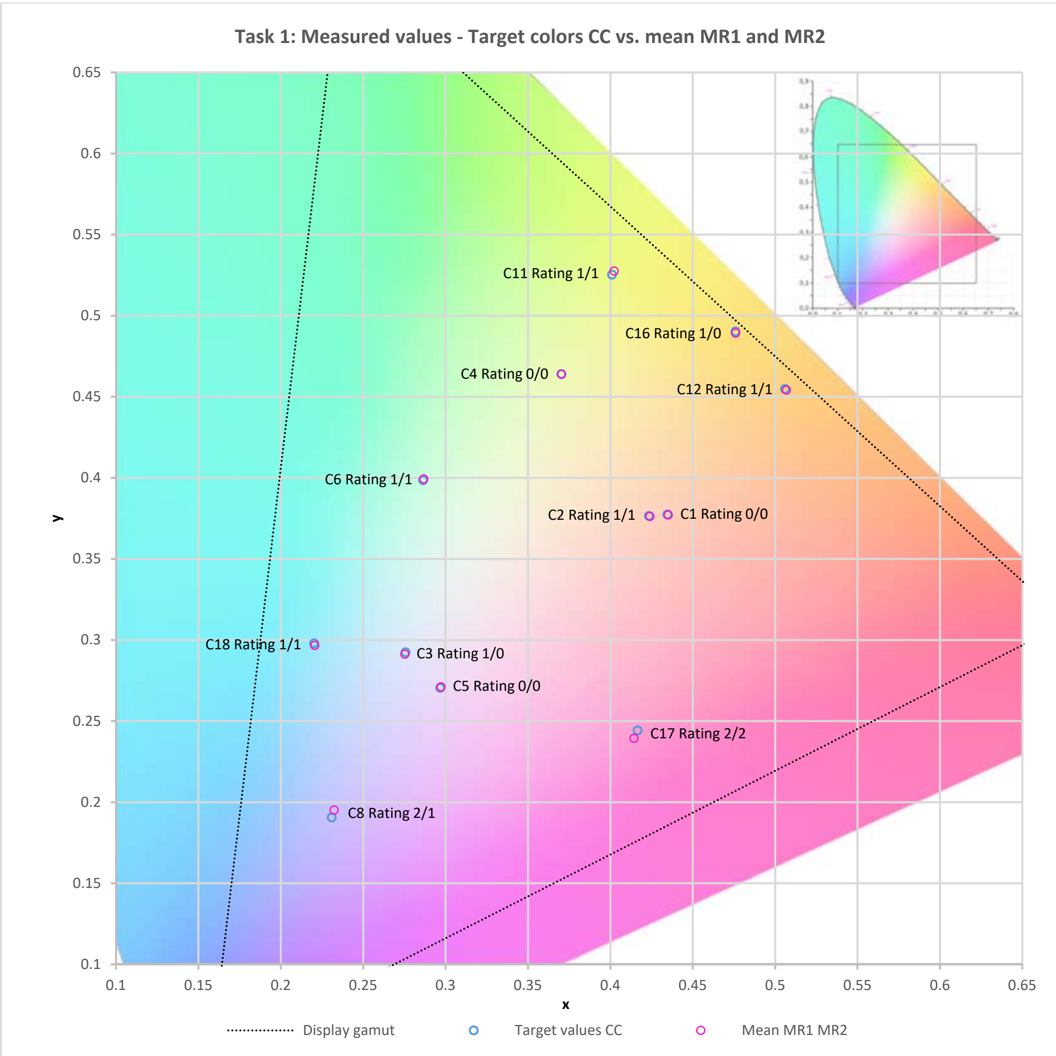


Figure 96. Visualization of target colors (CC) and the mean color match achieved by participant ID 01 in Task 1 in the CIExy chromaticity diagram. The designation of each color also contains the rating for accuracy/repeatability.

For Task 1, the results of participant ID 01 for Display 2 lead to an overall accuracy rating of 0.9 (mean color difference of ΔE_{00} = 0.32). The results obtained are very close to the target colors, and the measured color differences are almost unnoticeable. Only colors 8 and 17 show a color difference that can be perceived by an experienced observer. For repeatability, the overall rating of 0.6 (mean color difference ΔE_{00} = 0.24) is even better. Again, differences between the results of the single measurement runs are visually almost unnoticeable. The overall result can thus be rated as very good.

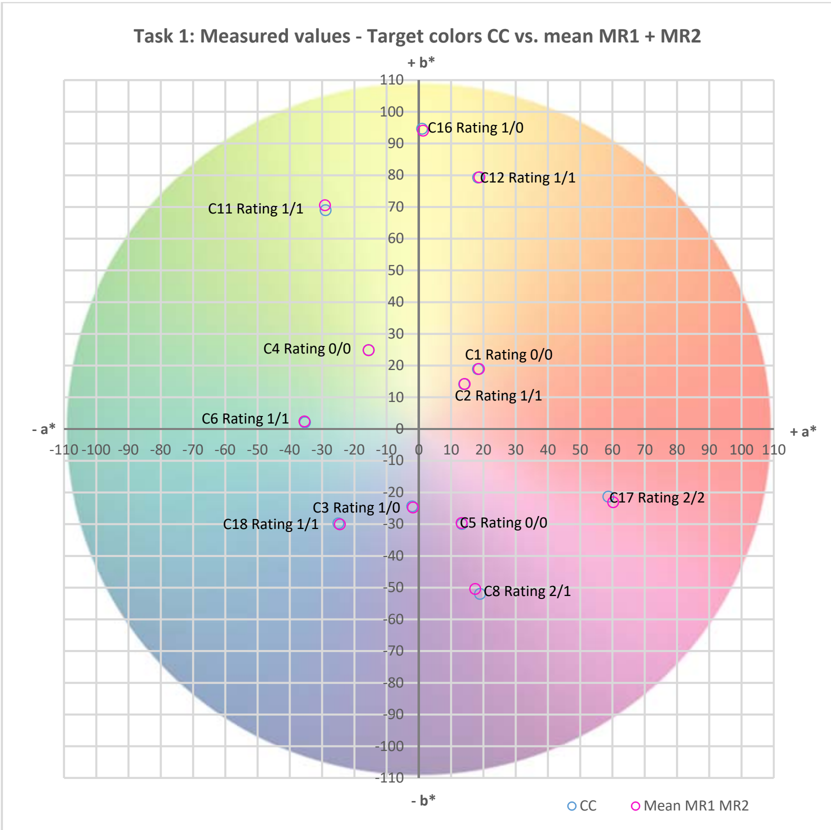


Figure 97. Visualization of target colors (CC) and the mean color match achieved by participant ID 01 in Task 1 in the CIE a*b* plane.

As expressed in the overall rating, the measured values from the color matching show a very good result. The color differences to the target color determined for the less saturated colors 1, 4, and 5 are visually imperceptible in terms of accuracy and repeatability (rating 0). Almost unnoticeable color differences (rating 1) with a rating of 0 for repeatability are shown for colors 3, 12, and 16. Ratings of 1 for accuracy and repeatability are shown for colors 2, 6, 11, and 18. Only colors 8 and 17 deviate perceptibly for experienced observers (rating 2). Both colors are more saturated and are located in the blue-violet and blue-red range, respectively. Color 8, however, receives a better rating for repeatability. Color 17 thus shows the worst result in Task

1. The color difference ΔE_{00} = 1.02 between the results of the two measurement runs is particularly remarkable here. This is rated as a small, visually perceptible color difference with a rating of 3. Overall, the less saturated colors show a better rating. The exception here is color 2, which comparatively shows a higher color difference of ΔE_{00} = 0.87, which can be visually perceived by an experienced observer.

When comparing the device-dependent nominal color values on which the presented measured spectral color values are based, the result is an almost identical ranking of 0.8, with a mean color difference of ΔE_{00} = 0.28 for accuracy. The ranking of the measured values of 0.9 is slightly higher. This difference is due to color 8, which shows a minimally higher color difference (ΔE_{00} +0.06) in the measured values and therefore falls into the next higher ranking level. Four colors show a slightly smaller color difference (maximum ΔE_{00} -0.04 in color 12) and eight colors a minimally higher one (maximum ΔE_{00} +0.11 in color 1). It is therefore not possible to derive a provable trend. This is transferable to the consideration of repeatability. The rating of the nominal values (0.5) is minimally lower, as is the mean color difference (ΔE_{00} = 0.23). The measured values for colors 6 and 18 (both in the blue-green spectral range) show a minimally higher color difference, which leads to a higher ranking.

	MR1 → CC	
Color	ΔE_{00}	Rating
1	0.60	2
2	0.67	2
3	0.86	2
4	0.38	1
5	0.73	2
6	0.51	2
7	1.20	3
8	0.91	2
9	0.36	1
10	1.13	3
11	1.01	3
12	0.27	1
13	2.06	4
14	1.38	3
15	1.18	3
16	0.90	2
17	0.49	1
18	0.52	2
19	1.59	3
20	0.25	1
21	0.76	2
22	0.79	2
23	0.98	2
24	0.86	2

	MR2 → CC	
Color	ΔE_{00}	Rating
1	0.61	2
2	0.50	2
3	0.25	1
4	0.38	1
5	0.52	2
6	0.75	2
7	0.82	2
8	0.87	2
9	0.33	1
10	0.39	1
11	0.07	0
12	1.33	3
13	2.53	4
14	1.15	3
15	0.72	2
16	0.67	2
17	0.90	2
18	0.31	1
19	0.88	2
20	0.89	2
21	0.78	2
22	0.76	2
23	1.42	3
24	0.87	2

	MCD → CC	
Color	ΔE_{00}	Rating
1	0.60	2
2	0.59	2
3	0.56	2
4	0.38	1
5	0.63	2
6	0.63	2
7	1.01	3
8	0.89	2
9	0.34	1
10	0.76	2
11	0.54	2
12	0.80	2
13	2.29	4
14	1.27	3
15	0.95	2
16	0.79	2
17	0.69	2
18	0.41	1
19	1.23	3
20	0.57	2
21	0.77	2
22	0.77	2
23	1.20	3
24	0.86	2

	MR1 → MR2	
Color	ΔE_{00}	Rating
1	0.02	0
2	0.99	2
3	0.65	2
4	0.18	0
5	1.24	3
6	1.00	3
7	1.99	3
8	1.77	3
9	0.63	2
10	1.51	3
11	0.94	2
12	1.08	3
13	0.56	2
14	2.52	4
15	1.88	3
16	1.03	3
17	0.54	2
18	0.83	2
19	0.78	2
20	0.87	2
21	0.18	0
22	0.26	1
23	0.56	2
24	0.01	0

	MCD → $M_{MR1+MR2}$	
Color	ΔE_{00}	Rating
1	0.01	0
2	0.50	2
3	0.33	1
4	0.09	0
5	0.62	2
6	0.50	2
7	0.99	2
8	0.89	2
9	0.31	1
10	0.75	2
11	0.47	1
12	0.54	2
13	0.28	1
14	1.26	3
15	0.94	2
16	0.52	2
17	0.27	1
18	0.41	1
19	0.39	1
20	0.43	1
21	0.09	0
22	0.13	0
23	0.28	1
24	0.01	0

Table 41. Rating of color differences of the single colors from Task 2 for user ID 01 and Display 2.

By comparison, the rating for Task 2 is less good in all areas. The overall rating for accuracy is 2.1, with a mean color difference of $\Delta E_{00} = 0.81$. The results obtained are more or less distant from the target colors.

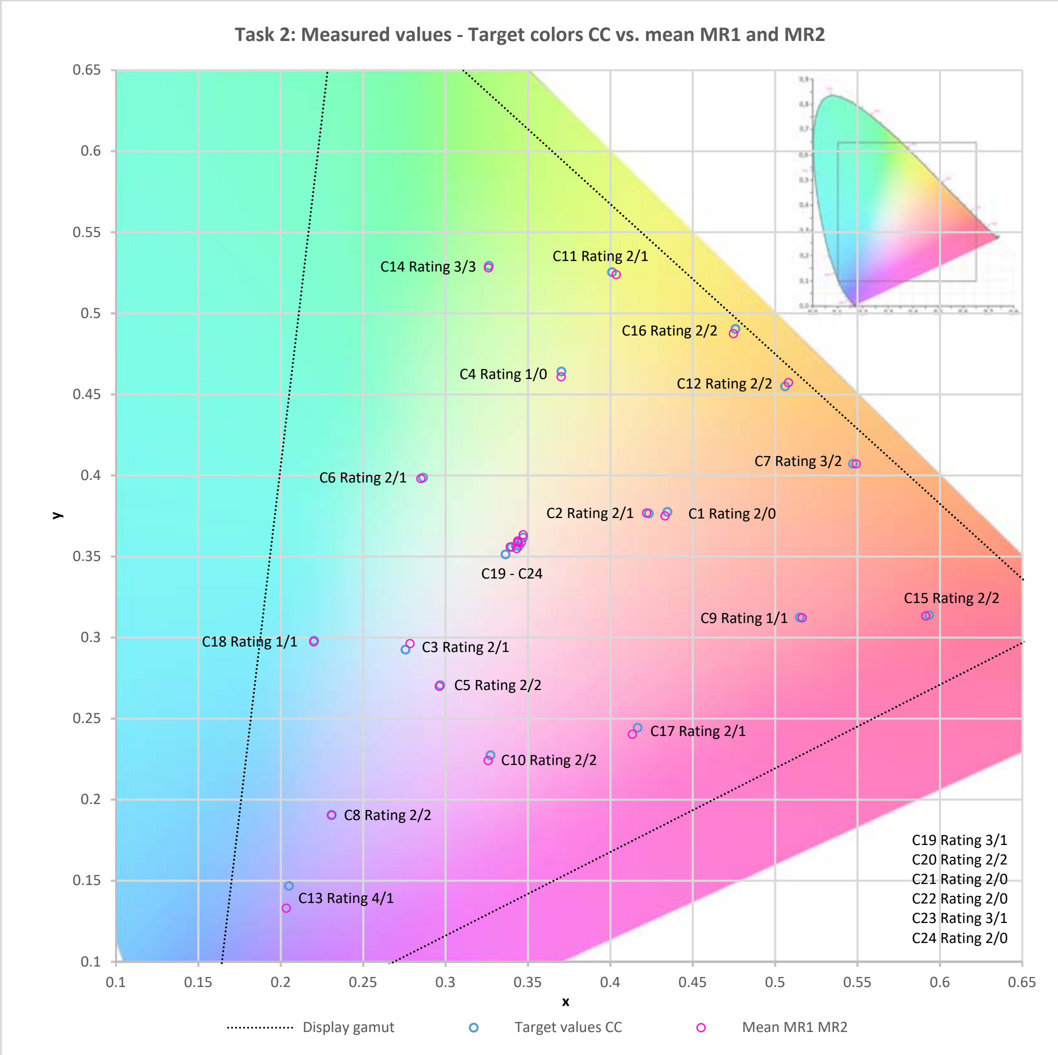


Figure 98. Visualization of target colors (CC) and the mean color match achieved by participant ID 01 in Task 2 in the CIExy chromaticity diagram. The designation of the individual colors also contains the rating for accuracy/repeatability.

With the exception of colors 4, 9, and 18, the measured color differences ΔE_{00} are more or less visually perceptible (rating 2–4). If only the chromatic colors (colors 1–18) are considered for evaluation, an almost identical ranking of 2.0 is obtained. An identical rating is achieved by the neutral colors 19–24. The overall rating for repeatability of 1.3 (mean color difference $\Delta E_{00} = 0.46$) shows that the differences between the results from MR1 and MR2 are almost imperceptible. Nine colors show a color difference that is perceptible by experienced observers (rating 2). For color 14, a small visually perceptible color difference (rating 3) is shown. If a differentiation is also made here between chromatic colors and neutral colors, the rating of 1.4 for the chromatic colors confirms the impression of almost unnoticeable color differences in the repeated task. The ranking of 0.5 for the neutral colors is very good. Here, the color differences are almost visually imperceptible. The overall impression is rather mixed, but a good result can still be declared.

Combining the ratings, 11 colors receive an identical rating for accuracy and repeatability. For 13 colors, repeatability is rated better than accuracy. It is notable that especially good repeatability results are achieved for the neutral colors. The differences between MR1 and MR2 are visually imperceptible or almost unnoticeable, as expressed by the respective ratings of 0 and 1. However, the color differences to the target color are visually perceptible to different degrees; the highest color differences of $\Delta E_{00} = 1.23$ and $\Delta E_{00} = 1.20$ are shown here by colors 19 and 23 (rating 3).

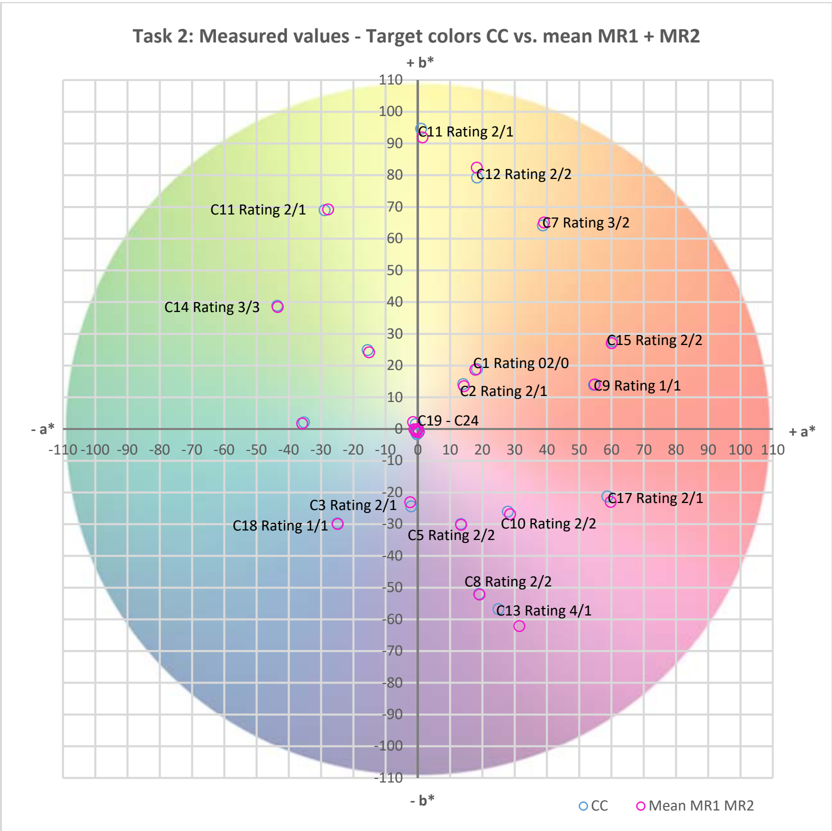


Figure 99. Visualization of target colors (CC) and the mean color match achieved by participant ID 01 in Task 2 in the CIE a*b* plane.

In the evaluation of the accuracy of the color matching, only three chromatic colors receive the ranking of 1. For colors 9 and 18, this ranking is also confirmed for repeatability. For color 4, it improves to 0. Eleven chromatic colors show a color difference that is visually perceptible to experienced observers in terms of accuracy (rating 2). The identical rating is confirmed for the repeatability of colors 2, 5, 6, 8, 10, 12, 15, and 16. This is rated better for colors 3 and 17 (rating 1). Color 1 is remarkable, with a mean color difference ΔE_{00} = 0.60 to the target color (rating 2) from the two measurement runs, whose results show an almost non-existent color difference ΔE_{00} = 0.02 (rating 0). Colors 7 and 14 receive a rating of 3 for accuracy and a rating of 2 for repeatability, with the color differences measured here only minimally falling below the limit value for the next higher rating. This is mainly due to the very different results of the two measurement runs. The color difference of ΔE_{00} = 1.99 determined for color 7 still means a rating 3, but the limit value ΔE_{00} = 2.0 results in close proximity to a transition on the rating scale from a small visually perceptible to a perceptible color difference (rating 4). Color 13 shows the highest visually perceptible deviation from the target color, with ΔE_{00} = 2.29 (rating 4) and very good repeatability (rating 1).

The best result is observed for color 4 in the yellow-green spectral range, with a rating of 1 for accuracy and a rating of 0 for repeatability. The more saturated color 11 from this spectral range also shows good ratings of 1 and 1, respectively. The worst result with small perceptible color differences (ratings 3 and 3) is obtained by color 14 in the yellow-green spectral range. It is noticeable that colors 7 and 15 in the more saturated orange and red spectral range show color differences that are close to the limit value for low perceptible color differences. Low visually perceptible color differences between the results from MR 1 and MR 2, rated 3, are shown by the differently saturated colors 5, 8, and 10 in the bluish purple and reddish purple spectral ranges. Color 13, for which the highest color difference to the target color was measured, is also in the bluish purple spectral range. In contrast to the other colors, however, the results here show good repeatability with a rating of 1.

In Task 2, the comparison of the device-dependent nominal values with the measured values results in an almost identical rating for the accuracy of 2.0, with a mean color difference of ΔE_{00} = 0.81. The rating of 2.1 for the measured values is minimally higher, which is explained by the results for colors 11 and 23. A higher color difference is measured for both colors, which is why the rating also increases by one rating level. For 13 colors, three of which are neutral, the color difference is reduced compared to the nominal values (max ΔE_{00} -0.12 in color 20). An increase in the color difference can be seen in nine colors (max ΔE_{00} +0.23 in color 23); three of these colors are neutral. The six chromatic colors are found in the strongly saturated spectral range orange to yellow and in the saturated spectral range blue-violet to red-purple. A very similar impression is obtained for repeatability. The rating of 1.3 for the nominal values is identical, while the mean color difference (ΔE_{00} = 0.45) is minimally lower. In four colors, shifts in the rating in a more positive or more negative direction can be seen. In 12 colors, the color difference decreases minimally in the measured values (maximum ΔE_{00} = -0.16 in color 4), and in 12 colors it increases (maximum ΔE_{00} = +0.17 in color 7). It is notable here that five of the six neutral color tones show an increased color difference; this also applies to the more saturated colors in the purplish blue and orange to yellow spectral ranges.

After completing the ratings, the 12 colors included in both tasks are also directly compared with each other. The rating confirms that Task 1 achieved better results overall. In a direct comparison, Task 2 receives the ratings of 1.8 for accuracy and 1.3 for repeatability. In contrast, Task 1 is rated 0.9 and 0.6, respectively. Focusing on target color accuracy in Task 2, only colors 4 and 18 show an almost unnoticeable color difference (rating 1); all 10 other colors receive a rating of 2, meaning the measured color differences are visually perceptible to an experienced observer. That said, the rating improves for repeatability: colors 1 and 4 demonstrate no visually perceptible differences (rating 0), with almost unnoticeable color differences found for colors 3, 11, 17, and 18 (rating 1). In the remaining six colors, the color differences become perceptible to experienced observers (rating 2).

	MCD → CC				MR1 → MR2				MCD → $M_{MR1+MR2}$			
	Task 1		Task 2		Task 1		Task 2		Task 1		Task 2	
Color	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
1	0.11	0	0.60	2	0.19	0	0.02	0	0.10	0	0.01	0
2	0.46	1	0.59	2	0.80	2	0.99	2	0.40	1	0.50	2
3	0.22	1	0.56	2	0.30	1	0.65	2	0.15	0	0.33	1
4	0.10	0	0.38	1	0.02	0	0.18	0	0.01	0	0.09	0
5	0.15	0	0.63	2	0.29	1	1.24	3	0.14	0	0.62	2
6	0.25	1	0.63	2	0.34	1	1.00	3	0.17	0	0.50	2
8	0.53	2	0.89	2	0.87	2	1.77	3	0.44	1	0.89	2
11	0.40	1	0.54	2	0.72	2	0.94	2	0.36	1	0.47	1
12	0.27	1	0.80	2	0.44	1	1.08	3	0.22	1	0.54	2
16	0.24	1	0.79	2	0.30	1	1.03	3	0.15	0	0.52	2
17	0.76	2	0.69	2	1.02	3	0.54	2	0.51	2	0.27	1
18	0.32	1	0.41	1	0.50	2	0.83	2	0.25	1	0.41	1

Table 42. Direct comparison of the 12 single colors contained in both tasks.

Initially comparing the results only in terms of color matching accuracy, the measured color differences in Task 2 are always higher than in Task 1, with the exception of color 17. This has a particular effect on the rating of colors 1 and 5. In Task 1, the rating is 0 (i.e., the differences are not visually perceptible), increasing to a rating of 2 in Task 2. The color differences are not only higher, they are now also visually perceptible to a trained observer. In colors 2, 3, 6, 11, 12, and 16, the ranking also shifts from 1 to 2. Identical ratings are observed in Task 1 and Task 2 for colors 8, 17, and 18.

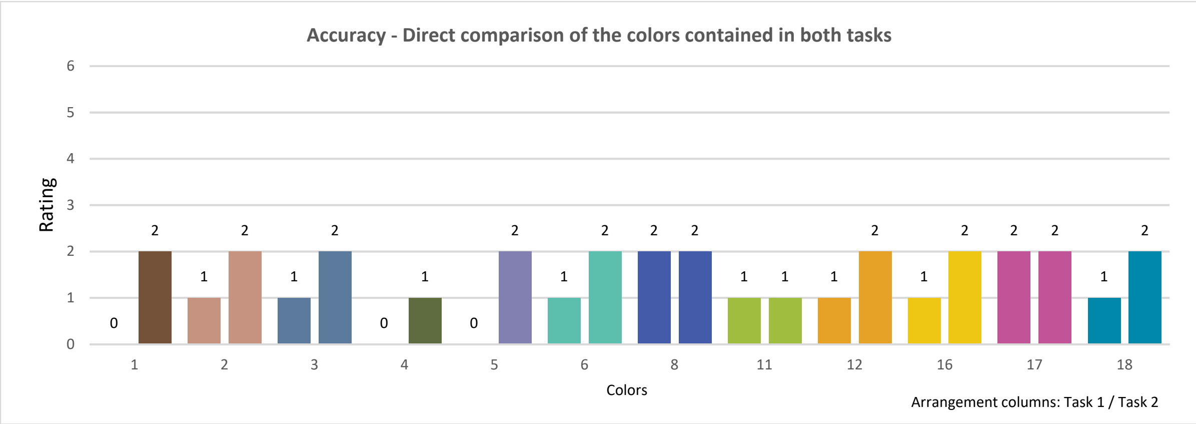


Figure 100. Visualization of accuracy of measured results for the 12 single colors included in both tasks (direct comparison).

A look at the repeatability also shows better results in Task 1. The exception here is again color 17, although color 1 also shows a better result in Task 2. The highest difference is found in colors 5, 6, and 16, which has a corresponding effect on the rating. In Task 1, the measurement results lead to a rating of 0, which increases to a rating of 2 in Task 2. In colors 2, 8, and 12, the rating increases from 1 to 2. Thus, in Task 2, six colors show color differences between MR1 and MR2 that are visually perceptible to an experienced observer. Colors 1 and 4 have an identical rating of 0 in both tasks, while colors 11 and 18 have an identical rating of 1.

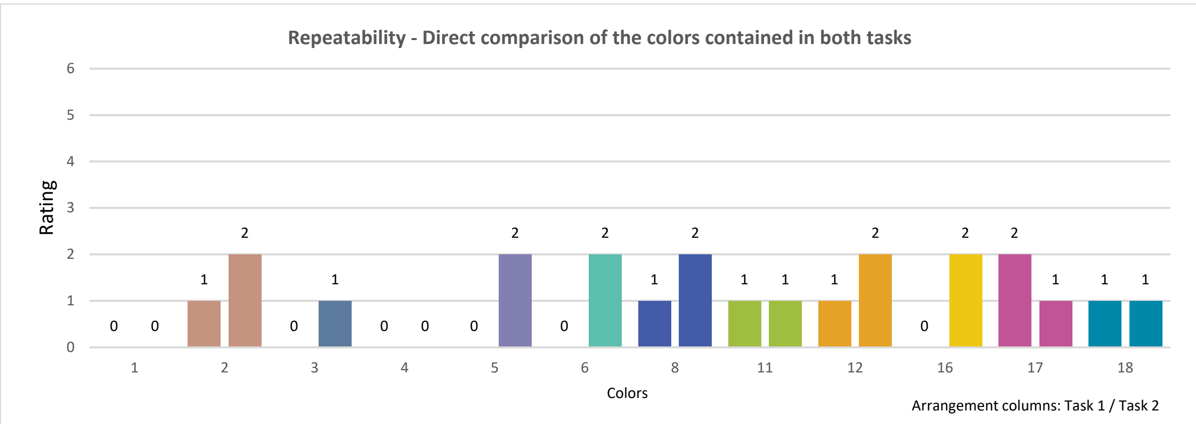


Figure 101. Visualization of repeatability of measured results for the 12 single colors included in both tasks (direct comparison).

Finally, the analysis concludes with a ranking for both tasks based on the determined color differences and the resulting ratings. This includes both the device-dependent nominal values and the measured values. The ranking of the results for accuracy is used as the basis for the rating. In the case of an equal rating, the determined color difference is used as a further reference value. The rating for repeatability is then assigned. In Task 2, the ranking is presented separately for the chromatic colors and the achromatic colors. The results of the analyses conducted are summarized in condensed form in a user-related report (see Annex 4).

	Rating chromatic colors											
Nominal values	1	4	5	3	6	12	16	18	11	8	2	17
Accuracy	0	0	0	0	1	1	1	1	1	1	2	2
Repeatability	0	0	0	0	1	0	0	0	1	1	1	2

	Rating chromatic colors											
Measured values	4	1	5	3	16	6	12	18	11	2	8	17
Accuracy	0	0	0	1	1	1	1	1	1	1	2	2
Repeatability	0	0	0	0	0	1	0	1	1	1	1	2

Table 43. Rating of single colors based on evaluation of the results achieved for Task 1 (nominal values and measured values).

	Rating chromatic colors																		Rating achromatic colors					
Nominal values	9	4	11	18	1	2	3	5	17	6	16	12	10	8	7	15	14	13	20	21	22	24	23	19
Accuracy	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	3	4	2	2	2	2	2	3
Repeatability	1	1	1	2	0	2	1	2	1	2	2	1	2	2	2	2	3	1	2	0	0	0	0	1

	Rating chromatic colors																		Rating achromatic colors					
Measured values	9	4	18	11	3	2	1	5	6	17	10	16	12	8	15	7	14	13	20	21	22	24	23	19
Accuracy	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	3	3	4	2	2	2	2	3	3
Repeatability	1	0	1	1	1	2	0	2	2	1	2	2	2	2	2	2	3	1	1	0	0	0	1	1

Table 44. Rating of single colors based on evaluation of the results achieved for Task 2 (nominal values and measured values). Chromatic and achromatic colors are presented separately.

4.7.8 Summary of analysis for all displays used

The results from Task 1 and Task 2 for participant ID 01 demonstrate the expected differences for all displays used. It can be seen that the participant always achieves better results and thus a better rating in Task 1. This difference in the results obtained is due to the setup of the experiments. In Task 1, the models and definitions of Hunt and Fairchild are considered for the structure and representation of the single colors: only one color field (stimulus) is shown to be processed, and the specifications for the proximal field, background, surround, and adapting field are implemented. The structure of Task 2 deviates significantly from this: the size of the color fields is significantly reduced, and 24 different color fields are represented at the same time. In particular, the high number of different stimuli displayed simultaneously influences the color perception of the participants.[19, 60, 308, 309]

Task 1	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	0.67	1.8	0.92	2.3	0.46	1.3
Display 2	0.32	0.9	0.48	1.3	0.24	0.6
Display 3	0.49	1.6	0.71	1.8	0.36	1.0
Display 4	0.29	0.8	0.40	1.3	0.20	0.6

Task 2	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	1.23	2.5	1.71	2.8	0.85	2.0
Display 2	0.81	2.1	0.92	2.0	0.46	1.3
Display 3	0.83	2.1	1.03	2.2	0.51	1.3
Display 4	0.52	1.5	0.68	1.8	0.34	0.9

Table 45. Total rating from Task 1 and Task 2 for each display used.

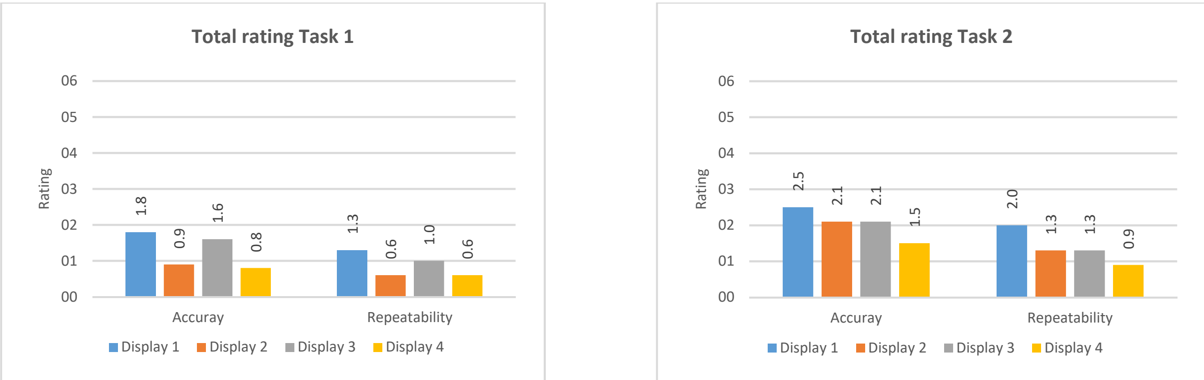


Figure 102. Visualization of total ratings from Task 1 and Task 2 for each display used.

4.7.8.1 Summary: Display 1

In Task 1, the overall ratings of 1.8 for accuracy (mean ΔE_{00} = 0.67) and 1.3 for repeatability (mean ΔE_{00} = 0.46) are good. In Task 2, the rating for accuracy increases to 2.5 (mean ΔE_{00} = 1.23) and for repeatability to 2.0 (mean ΔE_{00} = 0.85). Noticeable differences between MR1 and MR2 in certain colors are expressed in an overall rating of 2.42 for MR1 (mean ΔE_{00} = 0.98) and 0.75 for MR2 (mean ΔE_{00} = 0.35) for Task 1. The same, although not as strongly expressed, can be observed in Task 2.

The rating of 1.8 achieved by participant ID 01 in Task 1 means that the match achieved to the target colors has an almost imperceptible color distance, and this with very good repeatability. It can be seen that the results achieved—especially with the more saturated colors—mostly show a higher saturation compared to the target color, while this tends to be lower for the less saturated colors near the white point. Only four colors showed a result with an almost imperceptible color difference (rating 1). Color 11 shows the most exact match to the target color with very good repeatability. Six colors receive a rating of 2, and two other colors receive a rating of 3. Colors 8 and 17 are the two colors with the highest saturation, and both show a color difference that exceeds the limit ΔE_{00} = 1 and is thus rated as a small perceptible color difference. It should be noted here that the repeatability for color 8 is very high (rating 0), whereas the two values recorded for color 17 from MR1 and MR2 are perceptibly different (rating 2). The color difference $\Delta E_{00} = 2.15$ determined in MR1 contrasts with a color difference of $\Delta E_{00} = 0.19$ in MR2.

Display 1	Rating chromatic colors											
Task 1	11	1	5	2	16	6	3	4	18	12	17	8
Accuray	1	1	1	1	2	2	2	2	2	2	3	3
Repeatability	0	1	1	1	2	2	1	2	2	2	2	0

Table 46. Rating of single colors based on evaluation of results achieved for Task 1 (Display 1).

The overall rating of 2.5 for accuracy in Task 2 is worse than in Task 1. Here, the mean color difference almost doubles to $\Delta E_{00} = 1.23$, meaning that the measured color differences are perceptible to experienced observers. Only four colors show a color difference to the target color that is not or almost not perceptible. The rating 2.0 for repeatability is satisfactory but remains higher than the equivalent value from Task 1.

Display 1	Rating chromatic colors																	Rating achromatic colors					
Task 2	10	6	16	5	14	1	3	9	2	4	11	8	17	12	7	12	18	13	23	24	20	21	22	19
Accuray	0	1	1	1	2	2	2	2	2	2	3	3	3	3	3	3	4	4	3	3	3	3	3	5
Repeatability	0	0	1	1	1	2	2	1	2	2	2	2	1	2	2	1	1	3	2	3	3	3	3	5

Table 47. Rating of single colors based on evaluation of results achieved for Task 2 (Display 1).

Higher color differences are primarily found in the more saturated chromatic colors, which are close to the limits of the maximum representable colors of the native display gamut (except color 16). The color difference to the target color is low but perceptible in colors 7, 8, 11, 12, 15, and 17 (rating 3). The repeatability of these colors varies from rating 1 to rating 2. Colors 13 and 18 even exceed the limit $\Delta E_{00} = 2$, which corresponds to a perceived color difference. The repeatability rating for color 18 is very good (rating 1), whereas the two values recorded for color 13 differ greatly (rating 3). Color 13 is the most saturated of all 24 colors to be processed and shows the poorest result. The best result with ratings of 0 for both accuracy and repeatability is achieved by color 10. By contrast, high difficulties for the participant in achieving a color match are indicated by the results for the achromatic colors: colors 20–24 show perceived color differences (rating 3) for both accuracy and repeatability. Color 19 even shows a significant color difference for both evaluation criteria (rating 5).

Direct comparison of the 12 single colors included in both tasks confirms these findings. The overall rating for Task 2 improves to 2.3 for accuracy (mean $\Delta E_{00} = 0.91$) and to 1.5 for repeatability (mean $\Delta E_{00} = 0.5$). A clear convergence to Task 1 takes place, and the quality of repeatability is almost equal. Identical ratings for accuracy and repeatability in both tasks are given to colors 4 and 5. Color 3 shows a rating of 2 for accuracy in both tasks, colors 8 and 17 a rating of 3. The largest difference in the rating for accuracy is shown by color 18: while the color difference in Task 1 is only perceptible to experienced observers (rating 2), it is rated as perceived color difference in Task 2 (rating 4). Significantly, colors 6 and 16 show a better overall result in Task 2 compared to Task 1. The best overall result in terms of accuracy and repeatability is achieved for both tasks in color 5, while color 17 scores the worst.

4.7.8.2 Summary: Display 2

The overall ratings of 0.9 for accuracy (mean $\Delta E_{00} = 0.32$) and 0.6 for repeatability (mean $\Delta E_{00} = 0.24$) in Task 1 are excellent. In Task 2, the overall rating for accuracy increases to 2.1 (mean $\Delta E_{00} = 0.81$) and for repeatability to 1.3 (mean $\Delta E_{00} = 0.46$). No significant differences between MR1 and MR2 are observed.

Display 2	Rating chromatic colors											
Task 1	4	1	5	3	16	6	12	18	11	2	8	17
Accuray	0	0	0	1	1	1	1	1	1	1	2	2
Repeatability	0	0	0	0	0	1	0	1	1	1	1	2

Table 48. Rating of single colors based on evaluation of results achieved for Task 1 (Display 2).

The overall rating of 0.9 for accuracy in Task 1 means that existing color differences to the target colors are not visually perceptible. This is also expressed in the very good rating for repeatability. Correlations for lower or higher saturation compared to the target color cannot be derived from the results obtained. Indeed, the quality of the target color matching is so strong across the board that the color differences are not or almost not perceptible for 10 colors. Only the two most saturated colors (8 and 17) show a color difference that can be perceived by an experienced observer (rating 2). If the rating for repeatability is also taken into account, color 17 poses the hardest challenge for the participant, as the results achieved in MR1 and MR2 are reasonably far apart, which also leads to a rating of 2 for repeatability. The best ratings—0 for both accuracy and repeatability—are shown by colors 1, 4, and 5.

Display 2	Rating chromatic colors																		Rating achromatic colors					
Task 2	9	4	18	11	3	2	1	5	6	17	10	16	12	8	15	7	14	13	20	21	22	24	23	19
Accuray	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	3	3	4	2	2	2	2	3	3
Repeatability	1	0	1	1	1	2	0	2	2	1	2	2	2	2	2	2	3	2	1	0	0	0	1	1

Table 49. Rating of single colors based on evaluation of results achieved for Task 2 (Display 2).

For Task 2, the overall result is less well represented. The overall rating of 2.1 (mean ΔE_{00} = 0.81) means that the existing color differences are not perceptible to experienced observers. Only in three colors are they almost imperceptible. It can be seen that the chromatic colors with lower saturation also show lower color differences in comparison. The rating 1.3 (ΔE_{00} = 0.46) for repeatability is good, but it is also clearly above the equivalent value from Task 1.

A rating of 2 for color matching accuracy is given to 12 colors. Colors 7 and 14 receive a rating of 3, so the measured color difference is small but visible. Color 14 also receives a rating of 3 for repeatability, which means that the color difference of the results from MR1 and MR2 is higher by comparison, and thus this color was difficult for the participant to process. Color 13 shows the highest visible color difference (ΔE_{00} = 2.29) to the target color, with a rating of 1 for repeatability. It is also the color with the highest saturation of all 24 single colors. In comparison, the best overall result for accuracy and repeatability is shown by color 4.

An overall view of the results shows that the color ranges purplish blue to pink show a higher saturation compared to the target colors. In contrast, the saturation of the colors in the color ranges red to green is lower than that of the target colors, with one exception (color 12). For the less saturated colors with corresponding proximity to the white point, no tendency can be observed. The achromatic colors all show varying degrees of perceptible color differences at the level of the chromatic colors. However, the results show very good repeatability. The worst overall rating with the highest deviation from the target color is given to color 19.

These results are also confirmed by the direct comparison of the 12 single colors contained in both tasks. The 1.8 rating (mean ΔE_{00} = 0.6) approaches that of Task 1, while the 1.3 rating (mean ΔE_{00} = 43) for repeatability remains identical. Color 18 is the only color whose ratings are identical in both tasks. Colors 8 and 17 show an identical rating of 2 for accuracy in both tasks. It should be noted that color 17 is the only color in Task 2, with a smaller color difference from the target color compared to Task 1, while also receiving a better rating for repeatability. The best result in terms of accuracy and repeatability is achieved for both tasks in color 4.

4.7.8.3 Summary: Display 3

The overall ratings of 1.6 for accuracy (mean ΔE_{00} = 0.49) and 1.0 for repeatability (mean ΔE_{00} = 0.36) in Task 1 show a good result. In Task 2, the rating for accuracy increases to 2.1 (mean ΔE_{00} = 0.83) and for repeatability to 1.3 (mean ΔE_{00} = 0.51). Again, no noticeable differences between MR1 and MR2 are found.

Display 3	Rating chromatic colors											
Task 1	11	4	18	2	16	5	1	6	12	3	8	17
Accuray	1	1	1	1	1	1	2	2	2	2	2	3
Repeatability	0	1	0	1	0	1	1	0	1	2	2	3

Table 50. Rating of single colors based on evaluation of results achieved for Task 1 (Display 3).

The overall rating for Task 1 shows that a good color match is achieved and the color differences are almost imperceptible. With three exceptions (colors 1, 2, and 11), the results obtained are less saturated compared to the target color. The repeatability for performing the set task is high. Five colors show a rating of 2, so the existing color differences to the target color can be perceived by an experienced observer. The highest color difference to the target color is found in color 17. The limit value ΔE_{00} = 1.0 is slightly exceeded, resulting in a rating of 3. If the rating 3 for repeatability is also taken into account, the poorest result is obtained in Task 1. Moreover, it should be noted here that the two most saturated colors (8 and 17) show the highest color difference to the target color and also the poorest values for repeatability. By contrast, color 11 shows the best result with ratings of 1 for accuracy and 0 for repeatability.

Again, the overall result for Task 2 presents less well. The overall rating of 2.1 (mean ΔE_{00} = 0.83) for accuracy shows that the existing color differences are perceptible to experienced observers. The colors in the spectral ranges purple to blue and yellow to yellowish orange show a higher saturation in the results. In the other spectral ranges, this is mostly lower than the target values. The rating of 1.3 (mean ΔE_{00} = 0.51) for repeatability is very good and only slightly above the equivalent value from Task 1.

Display 3	Rating chromatic colors																		Rating achromatic colors					
Task 2	9	1	11	12	4	5	7	2	16	18	3	15	8	17	6	10	13	14	20	23	21	22	19	24
Accuray	1	1	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3	4	1	2	2	2	2	3
Repeatability	0	1	1	1	1	1	0	2	1	0	1	2	2	3	3	1	1	3	0	1	1	2	2	2

Table 51. Rating of single colors based on evaluation of results achieved for Task 2 (Display 3).

Four chromatic colors show almost imperceptible color differences to the target color. A rating of 2 is given to eight other colors, with mostly good repeatability. Perceived color differences (rating 3) are shown for colors 6, 8, 10, 13, and 17. Colors 6 and 17 also show this rating for repeatability. The poorest result is found in color 14, where the color difference ΔE_{00} = 2.67 is rated as significant (rating 4). A rating of 3 for repeatability also shows the significant difference between the results obtained in MR1 and MR2. The higher differences to the target color are mainly found in the more saturated colors in the spectral ranges green to purple and red to reddish purple. The exception here is color 9, which receives the best overall rating. The achromatic colors 19–24 are on the same level as the chromatic colors in terms of overall rating.

Color 20 shows a very good result; color 24, on the other hand, yields the poorest result with ratings of 3 for accuracy and 2 for repeatability.

In a direct comparison of the 12 single colors contained in both tasks, the overall rating for accuracy improves slightly to 1.9 (ΔE_{00} = 0.69) for Task 2, while repeatability deteriorates minimally to an overall rating of 1.4 (ΔE_{00} = 0.51). Identical ratings for accuracy and repeatability in both tasks are obtained for colors 4 and 17. Colors 3 and 11 show the same rating for accuracy in both tasks. Colors 1 and 12 show a lower color difference to the target color in Task 2 compared to Task 1, with an identical rating for repeatability. The best result in terms of accuracy and repeatability is achieved for both tasks in color 11. Color 17, on the other hand, has the poorest overall rating.

4.7.8.4 Summary: Display 4

In Task 1, excellent results are obtained, as shown by the accuracy rating of 0.8 (mean ΔE_{00} = 0.29) and the repeatability rating of 0.6 (mean ΔE_{00} = 0.20). In Task 2, the rating for accuracy increases to 1.5 (mean ΔE_{00} = 0.52) and for repeatability to 0.9 (mean ΔE_{00} = 0.34). The results in MR1 and MR2 differ only minimally.

The overall accuracy rating of 0.8 in Task 1 means that existing color differences to the target colors are not visually perceptible, as reinforced by the very good rating for repeatability. Conclusions about a lower or higher saturation compared to the target color cannot be drawn from the results. The quality of the match to the target color is so strong across the board that the color differences in 11 colors are not or almost not perceptible. Only the most saturated color 17 shows a color difference to the target color that can be perceived by an experienced observer (rating 2). The strength of this overall result is confirmed by the fact that three colors receive the best rating (0) for both accuracy and repeatability.

Display 4	Rating chromatic colors											
Task 1	1	11	16	5	8	6	2	4	12	3	18	17
Accuray	0	0	0	1	1	1	1	1	1	1	1	2
Repeatability	0	0	0	1	1	1	0	1	1	0	1	1

Table 52. Rating of single colors based on evaluation of results achieved for Task 1 (Display 4).

Task 2 also shows a good overall result, even if (as expected) it performs less well compared to Task 1. The overall rating of 1.5 (mean ΔE_{00} = 0.52) means that the existing color differences are almost not perceptible. This is especially the case for the less saturated colors. Increased color differences are particularly noticeable in the saturated colors in the spectral range blue-green to purple and pink to purple. The rating 0.9 (ΔE_{00} = 0.34) for repeatability is very good and is only minimally higher than in Task 1.

Display 4	Rating chromatic colors																		Rating achromatic colors					
Task 2	4	7	6	5	9	14	1	3	11	12	15	2	8	16	18	10	17	13	24	20	22	19	23	21
Accuray	0	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2
Repeatability	0	1	1	1	1	0	1	1	1	1	1	1	1	1	2	2	1	0	1	1	0	0	1	2

Table 53. Rating of single colors based on evaluation of results achieved for Task 2 (Display 4).

The best overall rating of 0 for accuracy and repeatability is given to color 4, while 10 other chromatic colors (rating 1) show color differences that are almost not perceptible. The rating 2 for the color matching accuracy is given to seven other colors. The closest color match to the target color is achieved by the most saturated color, color 13. Repeatability is very high here; the results from MR1 and MR2 hardly differ. In contrast, colors 10, 17, and 18 show greater weaknesses in repeatability with similar color differences to the target color. The poorest overall result with a rating of 2 for accuracy and repeatability is shown by colors 10 and 18. The achromatic colors consistently show color differences that are perceptible to experienced observers with good repeatability. Only color 21 falls off somewhat here.

The differences already presented between Task 1 and Task 2 are confirmed in the direct comparison of the 12 single colors contained in both tasks. The overall rating for Task 2 improves slightly to 1.3 for accuracy (mean ΔE_{00} = 0.43), while it actually deteriorates minimally to 1.0 for repeatability (mean ΔE_{00} = 0.32). Identical ratings for accuracy and repeatability in both tasks are shown here in colors 5, 6, 12, and 17. Color 3 shows a rating of 1 for accuracy in both tasks. It is noteworthy that colors 6 and 16 show a better overall result in Task 2 compared to Task 1. The best overall result in terms of accuracy and repeatability is achieved for both tasks in colors 1 and 4, while color 17 shows the poorest overall ranking across both tasks.

4.7.9 Compilation of obtained data and final analysis of participants

To make a statement about the individual color perception of the participants, initially only the results obtained on all displays from Task 1 are used for analysis. Here, the structure of the experiment corresponds to the scientifically defined and usual procedure for obtaining individual perceived spectral values.

In the comparison of the color differences determined for each display and the resulting ratings, clear differences can be seen in some cases. The color representation of the displays depends on the device and is largely determined by the specially created display profiles, which describe the color representation properties of the respective display (i.e., they define how the nominal color values R, G, and B are converted spectrally). This section considers the influence this has on the color perception of the individual participants. Broadly, it should be noted once again that the performance benchmarking (see Annex 3) confirms very good and stable color representation for all the test displays used. The measurements carried out to determine the spectral base values of the ColorChecker target colors also show very good and stable conversion of the nominal color values for the single colors used (see Annex 4).

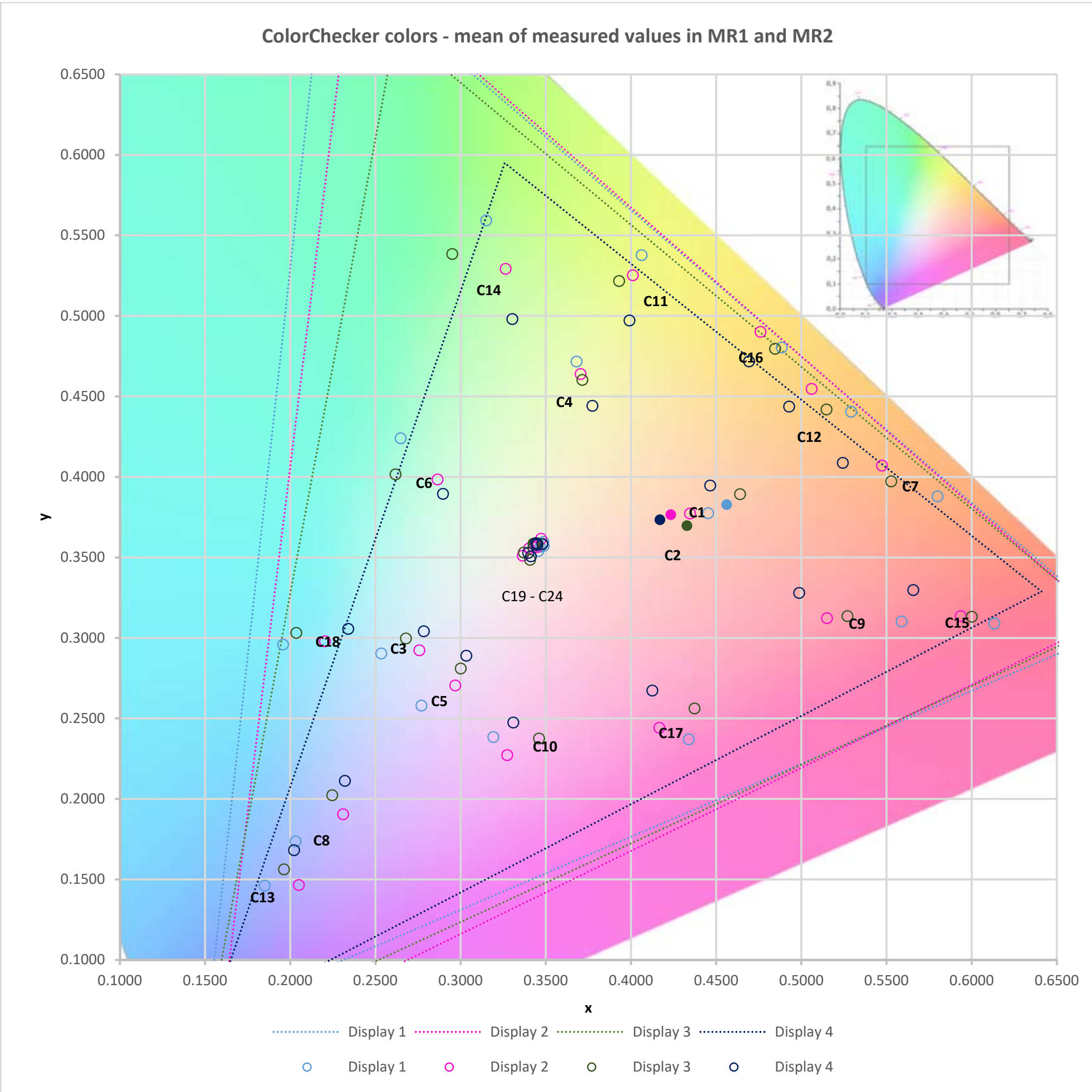


Figure 103. Visualization of target colors in the CIExy chromaticity diagram based on the measured values for displays 1–4.

The native color gamut of the displays has a significant influence on the implementation of the target colors defined for the color matching experiments. These differ from display to display, sometimes very significantly. Display 4 offers by far the smallest range of representable colors.

The native color gamut of Display 3 is already significantly higher but is surpassed again by displays 1 and 2. These differences are due to the display primaries for red, green, and blue. While the differences for red are still very small, the values for blue and especially for green deviate more strongly from each other. Using the AdobeRGB standard color space as a basis for comparison, Display 1 covers 99.3% (vol. 113%) of this. The missing colors are due to the representable primary color blue. The white point is close to the target white point D65 by comparison, but slightly shifted in a greenish direction. The representable native gamut of Display 2 covers 91.6% (vol. 115.5%) of the AdobeRGB standard color space. Here, the primary colors blue and especially green cause a part of the colors in the blue-green spectral range not to be covered. The white point almost exactly covers the target white point D65. The native color gamut of Display 3 only covers 87.9% (vol. 99.3%) of the AdobeRGB standard color space due to the representable primary color green. The white point is almost identical to the target white point D65. Finally, Display 4 only covers 65.4% (vol. 65.6%) of the AdobeRGB standard color space, and the white point is slightly more reddish and bluish by comparison.

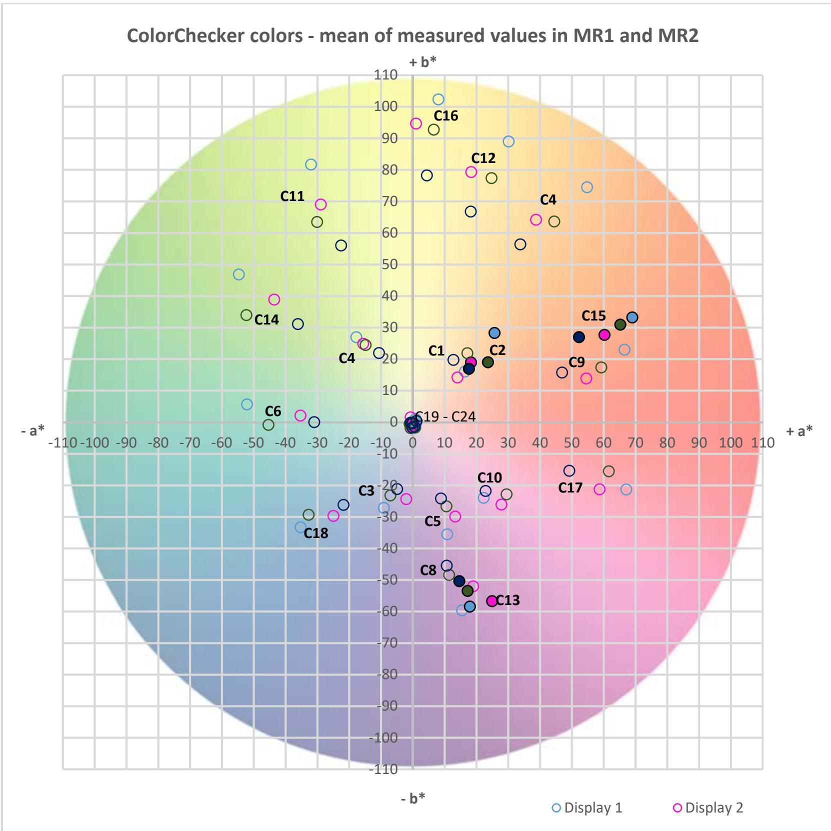


Figure 104. Visualization of measured target color values for all four test displays used in the CIE a*b* plane.

Based on this data, the decision was made to profile displays 1 and 2 on the basis of the AdobeRGB gamut and displays 3 and 4 on the basis of the sRGB gamut. These profiles determine the conversion of the digital spectral value proportions R, G, and B defined for the target colors into the nominal color values to be represented. The different color representation properties of the displays—in conjunction with the standard color spaces used for profiling—lead to a device-dependent definition of the target colors.

The measurements conducted to determine the spectral target values for the displayed single colors show the extent to which the color representation of the target colors is device-dependent (see Annex 4). The nominal color values for Display 1, with the exception of colors 1 and 10, have the highest saturation of the chromatic colors (colors 1–18) and therefore the highest number of representable colors. This can also be seen in the measurements performed. Only for colors 10 and 13 does Display 2 show a higher saturation, which is due to the significantly more saturated primary color blue and a higher number of representable colors in this spectral range. Compared to Display 3, the nominal values of Display 2 show higher saturation in the spectral ranges purplish blue to purplish pink and yellowish orange to yellowish green. These differences are also due to the native color gamuts presented. Display 4 has the smallest representable color gamut, and (except for color 1) all chromatic colors are nominally and measurably the least saturated. The achromatic colors (colors 19–24) are represented slightly differently from display to display depending on the white point of the profile.

4.7.9.1 Participant ID 01

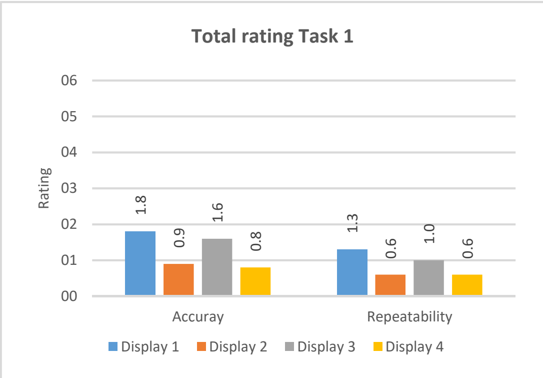
Participant ID 01 is male and belongs to the age group 30–39 years. He wears glasses and reports no other known limitations to the visual system. In essence, the participant can be rated as an experienced user of digital devices and applications, with professional experience in the field of digital media production.

The results of the color matching lead to quite different results. Displays 2 and 4 show an overall ranking of 1 for accuracy with good repeatability (rating 1) in Task 1, with Display 4 showing slightly better results. Displays 1 and 3 show an overall rating of 2 for good repeatability (rating 1). Here, Display 1 falls slightly by comparison. For Task 2, an increase in the overall rating can be seen for all displays. Display 1 shows the highest rating of 3 for slight, not perceptible color differences to the target color. Display 1 also performs the poorest in the repeatability evaluation (rating 3). Display 4 again shows the best result.

Task 1	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE00	Rating	ΔE00	Rating	ΔE00	Rating
Display 1	0.67	1.8	0.92	2.3	0.46	1.3
Display 2	0.32	0.9	0.48	1.3	0.24	0.6
Display 3	0.49	1.6	0.71	1.8	0.36	1.0
Display 4	0.29	0.8	0.40	1.3	0.20	0.6

Task 2	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE00	Rating	ΔE00	Rating	ΔE00	Rating
Display 1	1.23	2.5	1.71	2.8	0.85	2.0
Display 2	0.81	2.1	0.92	2.0	0.46	1.3
Display 3	0.83	2.1	1.03	2.2	0.51	1.3
Display 4	0.52	1.5	0.68	1.8	0.34	0.9

Table 54. Total rating for Task 1 and Task 2 for each display used (participant ID 01).



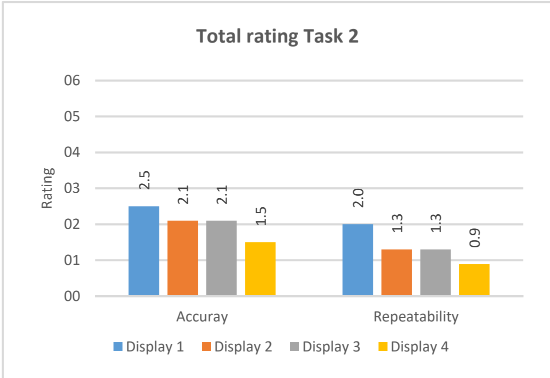


Figure 105. Visualization of total rating for Task 1 and Task 2 for each display used (participant ID 01).

Analysis of the results for Display 1 shows that, with the exception of colors 2 and 17, the color matches obtained by the participant are more saturated and more reddish (except for colors 2, 11, 16, and 18) and bluish (except for color 12). This corresponds to the tendency for the spectral conversion of the nominal color values, which was previously determined in the measurements for the definition of the target colors. The luminance L* increases in the spectral ranges blue green to yellowish green compared to the target colors. This results in six color matches receiving a rating of 2 for a color difference that is not perceptible to experienced observers. Perceptible differences (rating 3) are seen in the two most saturated colors 8 and 12. The results for Display 2 show a much more mixed picture. It is not possible to make a general tendency statement about all colors for the position in a certain color direction. This varies from color to color. Colors 1, 2, 4, and 6 with the lowest saturation are represented as more saturated. This also applies to the saturated colors 12 and 17 or 11, which are closest to the primary red or primary green, respectively. The colors in local proximity to primary blue are less saturated compared to the target color. Only the two most saturated colors (8 and 17) show a level of color not perceptible to experienced observers. While color 8 represents less red and blue, the opposite is true for color 17.

For Display 3, it can be noted that the color matches are less saturated compared to the target color, with three exceptions. This is contrasted by a higher value L* for luminance, except for color 12. The saturated colors mostly show a reduced red color value and tend toward a greenish direction (except color 18). The less saturated colors near the white point are represented more bluish (except color 6). Five colors show a rating of 2. These colors are represented more bluish and greenish; only color 8, the color with the highest proportion of blue, and color 6, the color with the highest proportion of green, show somewhat reduced values. The perceptible color difference in the color match of color 17 is also based on a more reddish and bluish representation.

Display 1

	MCD → CC	
Color	ΔE_{00}	Rating
1	0.32	1
2	0.38	1
3	0.65	2
4	0.69	2
5	0.38	1
6	0.63	2
8	1.24	3
11	0.24	1
12	0.87	2
16	0.57	2
17	1.17	3
18	0.84	2
Mean	0.67	1.83

Display 2

	MCD → CC	
Color	ΔE_{00}	Rating
1	0.11	0
2	0.46	1
3	0.22	1
4	0.10	0
5	0.15	0
6	0.25	1
8	0.53	2
11	0.40	1
12	0.27	1
16	0.24	1
17	0.76	2
18	0.32	1
Mean	0.32	0.92

Display 3

	MCD → CC	
Color	ΔE_{00}	Rating
1	0.54	2
2	0.36	1
3	0.64	2
4	0.27	1
5	0.48	1
6	0.54	2
8	0.64	2
11	0.20	1
12	0.56	2
16	0.36	1
17	1.04	3
18	0.31	1
Mean	0.49	1.58

Display 4

	MCD → CC	
Color	ΔE_{00}	Rating
1	0.07	0
2	0.28	1
3	0.37	1
4	0.28	1
5	0.25	1
6	0.27	1
8	0.27	1
11	0.12	0
12	0.36	1
16	0.16	0
17	0.59	2
18	0.48	1
Mean	0.29	0.83

Table 55. Overview of mean color differences and ratings obtained in Task 1 to evaluate the accuracy for each single color with the test displays used (participant ID 01).

The best overall result is shown by the results for Display 4. Only color 17 receives a rating of 2 due to the color difference to the target color, which is slightly above the limit value ΔE_{00} = 0.5. The color values for red and blue are reduced in the representation. With a few exceptions, the color matches are represented as more saturated and with a higher luminance L*. Here, too, it is not possible to make a general statement about all colors for the position in a certain color direction.

Considering the rating from display to display for each single color, the color matches of colors 2, 5, and 11 show the best results. All color differences measured are not perceptible or almost not perceptible. Colors 1, 4, 16, and 18 show very similar results overall, but the limit value ΔE_{00} = 0.5 is exceeded once for each display, which means that the color difference here is perceptible to an experienced observer. In colors 3 and 12, this limit value is exceeded for two displays. The highest color differences and thus the highest ratings are found in colors 8 and

17. For color 8, the results differ more clearly depending on the display (rating 1–3). For color 17, the determined color differences are always more or less perceptible (rating 2–3).

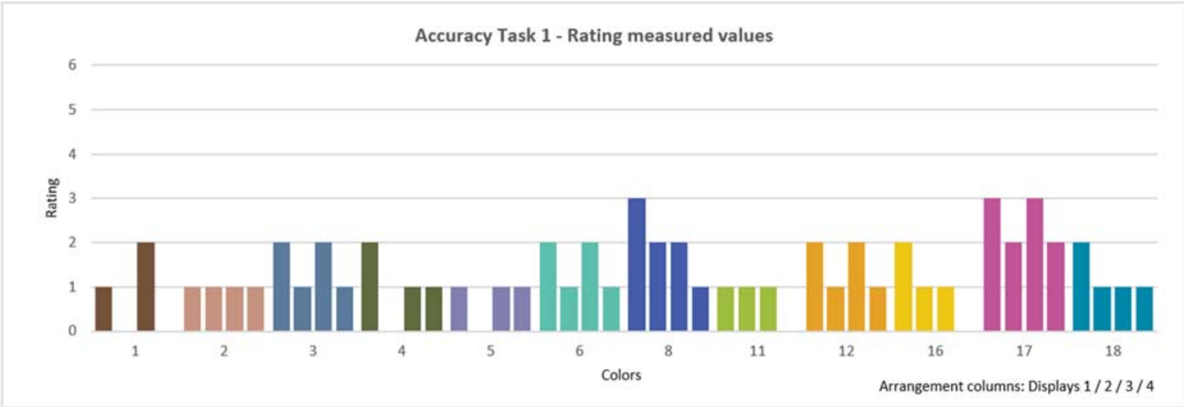


Figure 106. Visualization of ratings achieved by participant ID 01 in tasks for accuracy using all displays.

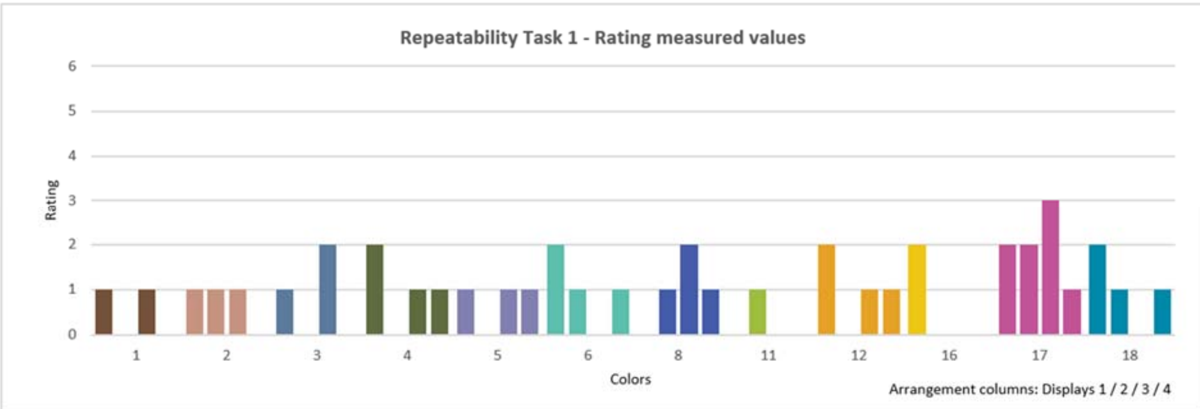


Figure 107. Visualization of ratings achieved by participant ID 01 in tasks for repeatability using all displays.

The evaluation of the repeatability shows differences from display to display but still a good picture overall. Colors 1, 2, 5, and 11 show the best results across all displays. Color 17 shows the highest rating (3) for Display 3, which indicates clear differences between the results in MR1 and MR2, as also expressed in the rating for accuracy. Color 16 is also remarkable: showing a rating of 2 for Display 1 and a rating of 0 for the other displays.

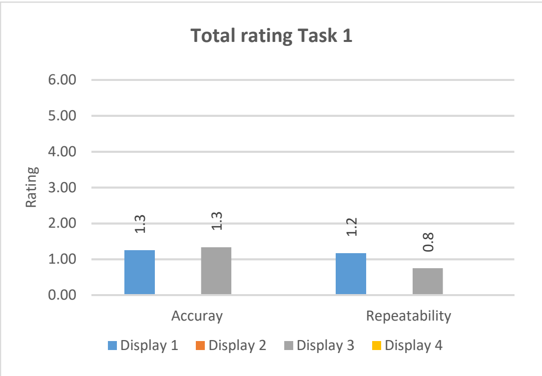
4.7.9.2 Participant ID 02

The participant with ID 02 is female and belongs to the age group 20–29 years. She wears glasses (farsightedness); no other limitations of the visual system are known. The participant is an experienced and savvy user of digital devices and applications. During her studies, she gained experience in digital media production, with a focus on word processing and layout design as well as web and app development. She is used to working with digital color, but not in the sense of using it in color image editing.

Task 1	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	0.51	1.25	0.90	2.00	0.45	1.17
Display 2						
Display 3	0.51	1.33	0.55	1.58	0.27	0.75
Display 4						

Task 2	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	1.47	2.83	1.56	2.75	0.78	1.79
Display 2						
Display 3	1.55	2.79	2.00	3.29	1.00	2.25
Display 4						

Table 56. Total rating for Task 1 and Task 2 for each display used (participant ID 02).



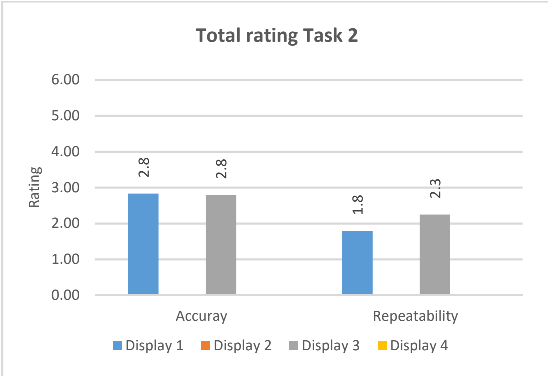


Figure 108. Visualization of total rating for Task 1 and Task 2 for each display used (participant ID 02).

Looking at the measurement results obtained, it can be seen for Display 1 that the color matches in Task 1 are all represented more greenish, except color 1. In the saturated colors near the display primaries blue and green, a reduced color value blue can be observed, while the other more saturated colors are represented more bluish. Even the less saturated colors represent themselves differently; the further they are from the white point, the more the blue color value is reduced. A more highly saturated representation can be seen, especially in the colors in the spectral range green blue to yellowish green. Color 1 shows the best match to the target color (ΔE_{00} 00 = 0.03; rating 0) with very good repeatability (rating 0). Colors 4 and 5 also show similarly good results. Four other color matches receive a rating of 1 for almost imperceptible color differences. It should be noted that the lowest color differences are found in the less saturated colors (1–6). Four other color matches show a rating of 2. The highest color difference (ΔE_{00} = 1.41) can be seen in color 16. Crucially, the color differences compared to the target color increase the closer the colors are to the maximum of the display's native representable color gamut.

Display 1

	MCD → CC	
Task 1	ΔE_{00}	Rating
1	0.03	0
2	0.41	1
3	0.30	1
4	0.04	0
5	0.16	0
6	0.22	1
8	0.45	1
11	0.77	2
12	0.72	2
16	1.41	3
17	0.84	2
18	0.75	2
Mean	0.51	1.25

Display 2

	MCD → CC	
Task 1	ΔE_{00}	Rating
1		
2		
3		
4		
5		
6		
8		
11		
12		
16		
17		
18		
Mean		

Display 3

	MCD → CC	
Task 1	ΔE_{00}	Rating
1	0.28	1
2	0.42	1
3	0.54	2
4	0.29	1
5	0.66	2
6	0.38	1
8	0.47	1
11	0.40	1
12	0.16	0
16	0.36	1
17	1.30	3
18	0.85	2
Mean	0.51	1.33

Display 4

	MCD → CC	
Task 1	ΔE_{00}	Rating
1		
2		
3		
4		
5		
6		
8		
11		
12		
16		
17		
18		
Mean		

Table 57. Overview of mean color differences and ratings obtained in Task 1 to evaluate the accuracy for each single color with the test displays used (participant ID 02).

The results for Display 3 show a more diverse picture. In the spectral range blue green to yellowish green, the colors are represented more reddish. The colors in the spectral ranges purplish blue to purplish pink and yellowish green show a reduced color value blue. The values for the luminance L* increase, with a few exceptions. Saturation mostly decreases in the color matches. Color 12, with a color difference of ΔE_{00} = 0.16 (rating 0), shows the most accurate color match with very good repeatability (rating 0). Seven other color matches receive a rating of 1 for almost imperceptible color differences. The colors in the spectral value range blue green to purplish pink show the highest color differences by comparison. Four color matches receive a rating of 2 for a color difference that is perceptible to experienced observers. The highest color difference (ΔE_{00} = 1.30, with a rating of 0) for repeatability is seen in color 17.

In the overall view of all displays used, colors 1, 2, 4, 6, and 8 show the best results. Colors 2, 6, 8, and 18 have identical ratings. Colors 12 and 6, in particular, show high differences. While they have ratings of 2 and 3 for Display 1, no perceptible or almost imperceptible differences are observed for Display 3. For both displays, colors 17 and 18 show the highest color differences compared to the target color. The repeatability rating shows higher deviations in some cases. The rating 3 for color 17 is the poorest result and thus shows clear differences between the individual results from MR1 and MR2, which then result in a rating 3 for accuracy. The opposite is seen in color 17 for Display 3. Despite the difference in color, which is perceptible to experienced observers, the repeatability is very good (rating 0).

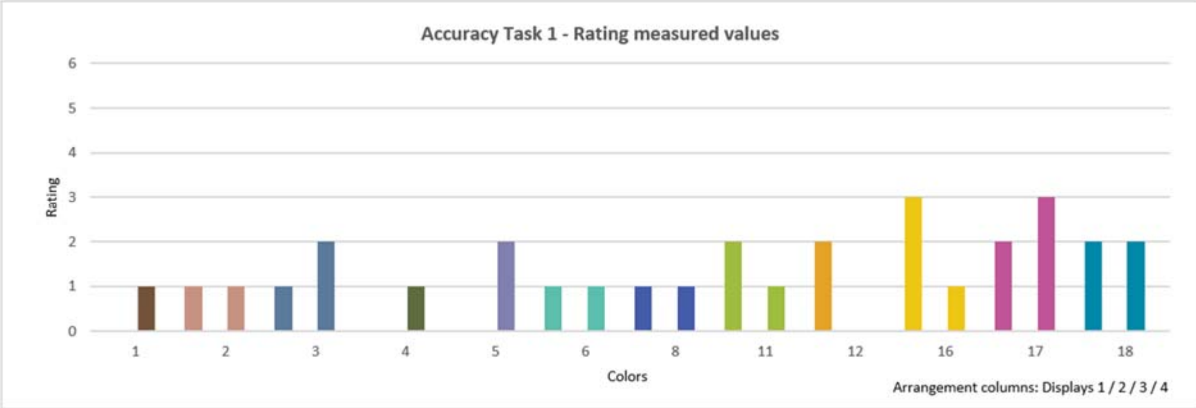


Figure 109. Visualization of ratings achieved by participant ID 02 in tasks for accuracy using all displays.

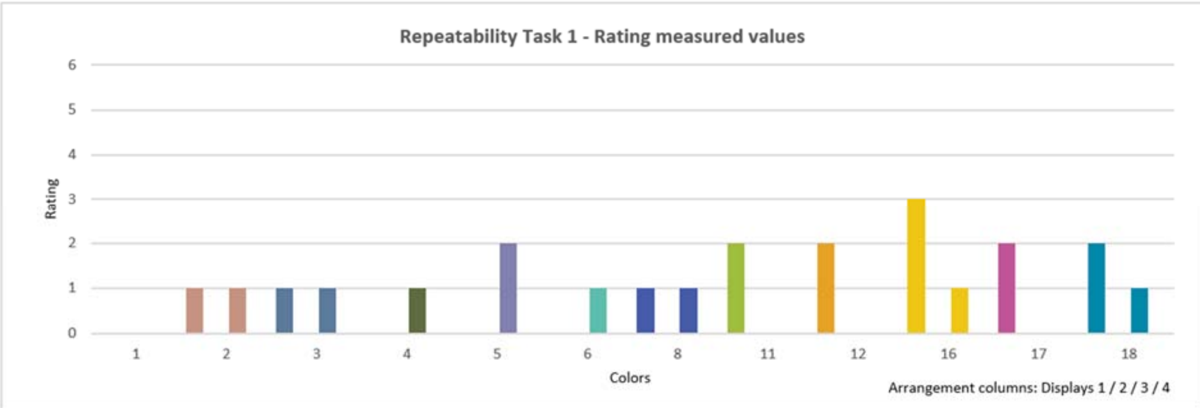


Figure 110. Visualization of ratings achieved by participant ID 02 in tasks for repeatability using all displays.

4.7.9.3 Participant ID 03

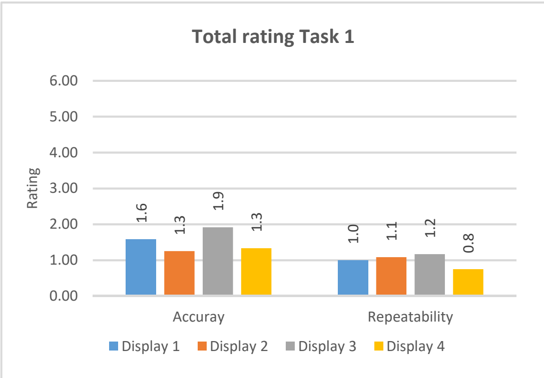
The participant with ID 03 is female and belongs to the age group 20–29 years. She wears glasses (farsightedness); no other limitations of the visual system are known. The participant uses digital devices in her private environment as a matter of course. Professionally, digital applications are limited to word editing and administration. No experience in digital media production or working with digital color is given.

Display 1 shows overall ratings of 1.6 for accuracy (mean ΔE_{00} = 0.59) and 1.0 (mean ΔE_{00} = 0.34) for repeatability in Task 1, implying that the color matches obtained show color differences that are perceptible to experienced observers with good repeatability. The same is true for Display 3, although this display shows somewhat weaker values. Displays 2 and 4 show an overall rating of 1.3 for accuracy (mean ΔE_{00} = 0.52) with good repeatability (rating 1) and thus the differences determined are almost imperceptible.

Task 1	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	0.59	1.58	0.68	1.58	0.34	1.00
Display 2	0.52	1.25	0.73	1.58	0.37	1.08
Display 3	0.73	1.92	0.91	1.83	0.46	1.17
Display 4	0.53	1.33	0.58	1.33	0.29	0.75

Task 2	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	1.36	2.83	1.66	3.08	0.83	2.08
Display 2	1.13	2.38	1.41	2.58	0.70	1.71
Display 3	1.16	1.38	1.90	1.25	0.93	0.75
Display 4	1.02	2.33	1.42	2.75	0.71	1.75

Table 58. Total rating for Task 1 and Task 2 for each display used (participant ID 03).



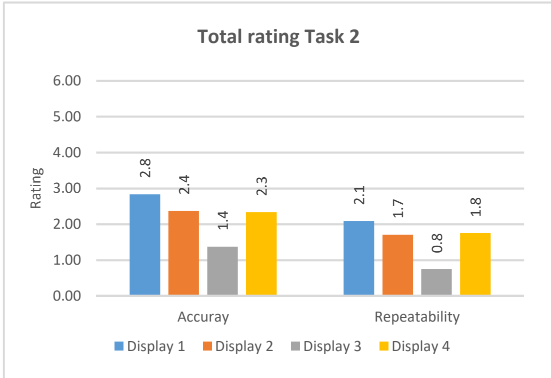


Figure 111. Visualization of total rating for Task 1 and Task 2 for each display used (ID 03).

Examining the color matches obtained in Task 1 for Display 1, all present an increased value for luminance L* except colors 3 and 4. Additionally, with the exception of colors 8 and 11, which are closest to the primaries blue and green, the colors are represented with higher saturation. The basic tendency is that the color matches are represented somewhat more yellowish. The more saturated colors in the spectral ranges yellow to yellowish orange and purplish pink show a more reddish representation, while the colors in the spectral range purplish blue to yellowish green show a more greenish representation. The best match to the target color is shown by color 1 with a color difference of ΔE_{00} = 0.16 (rating 0), with very good repeatability (rating 0). Six further color matches receive a rating of 1 for almost imperceptible color differences, while two receive a rating of 2 for a color difference that is not perceptible to experienced observers. The highest color difference (ΔE_{00} = 1.48) is seen in color 17. Colors 16 and 18 also show larger color differences to the target color (accuracy rating 3). Differences can also be seen here in the rating for repeatability. As a tendency, it can be noted that higher color differences can typically be seen in the spectral range blue green to purplish pink.

For Display 2, the results present a very mixed picture. The saturated colors near the primaries blue and green are represented more greenish and yellowish, which turns into a more reddish and bluish representation near the primary red. The representation of the colors is somewhat more saturated. The best color match in Task 1 comes from color 4, with a color difference of ΔE_{00} = 0.04 (rating 0) and very good repeatability (rating 0). Colors 1, 2, and 12 also show similarly good results, with four color matches receiving a rating of 1 and color 11 receiving a rating of 2. The highest color difference (ΔE_{00} = 1.43) is seen in color 17 (rating 3), while colors 8 and 18 also show higher color differences to a rating of 3. These are the saturated colors in the spectral range blue green to purplish pink. The repeatability rating is also rather less good here, which proves that the results achieved in the measurement runs show mostly larger gaps.

Display 1

	MCD → CC	
Task 1	ΔE_{00}	Rating
1	0.16	0
2	0.35	1
3	0.63	2
4	0.48	1
5	0.34	1
6	0.26	1
8	0.59	2
11	0.30	1
12	0.37	1
16	1.00	3
17	1.48	3
18	1.07	3
Mean	0.59	1.58

Display 2

	MCD → CC	
Task 1	ΔE_{00}	Rating
1	0.07	0
2	0.06	0
3	0.49	1
4	0.04	0
5	0.41	1
6	0.23	1
8	1.21	3
11	0.78	2
12	0.15	0
16	0.36	1
17	1.43	3
18	1.01	3
Mean	0.52	1.25

Display 3

	MCD → CC	
Task 1	ΔE_{00}	Rating
1	1.55	3
2	0.65	2
3	0.80	2
4	0.28	1
5	0.48	1
6	0.62	2
8	1.04	3
11	0.55	2
12	0.47	1
16	0.21	1
17	1.25	3
18	0.77	2
Mean	0.73	1.92

Display 4

	MCD → CC	
Task 1	ΔE_{00}	Rating
1	0.39	1
2	0.34	1
3	0.46	1
4	0.44	1
5	0.42	1
6	0.79	2
8	0.48	1
11	0.42	1
12	0.21	1
16	0.23	1
17	0.75	2
18	1.48	3
Mean	0.53	1.33

Table 59. Overview of mean color differences and ratings obtained in Task 1 to evaluate the accuracy for each single color with the test displays used (participant ID 03).

The color matches for Display 3 all show a higher value for the luminance L*. As a basic tendency, it can be seen that the color matches mostly show a higher blue color value and are accordingly represented more bluish. The less saturated colors near the white point tend to be represented more reddish, while the more saturated colors in the spectral ranges yellowish green to yellowish orange and purplish pink are represented more greenish. This leads to a higher saturation only in the spectral range purplish blue. Color 16 shows the best color matching to the target color, with a color difference of ΔE_{00} = 0.21 (rating 1) and very good repeatability (rating 0). Thus, no color match receives an accuracy rating of 0. In total, only four colors show a rating of 1. Five other colors show the rating 2 for a color difference that is perceptible to experienced observers. The highest color difference (ΔE_{00} = 1.55) can be seen in color 1 (rating 3). However, the two most saturated colors (8 and 17) also receive ratings of 3 for slight perceptible differences in color matching. In contrast to the other two colors, color 8 shows a good rating (1) for repeatability.

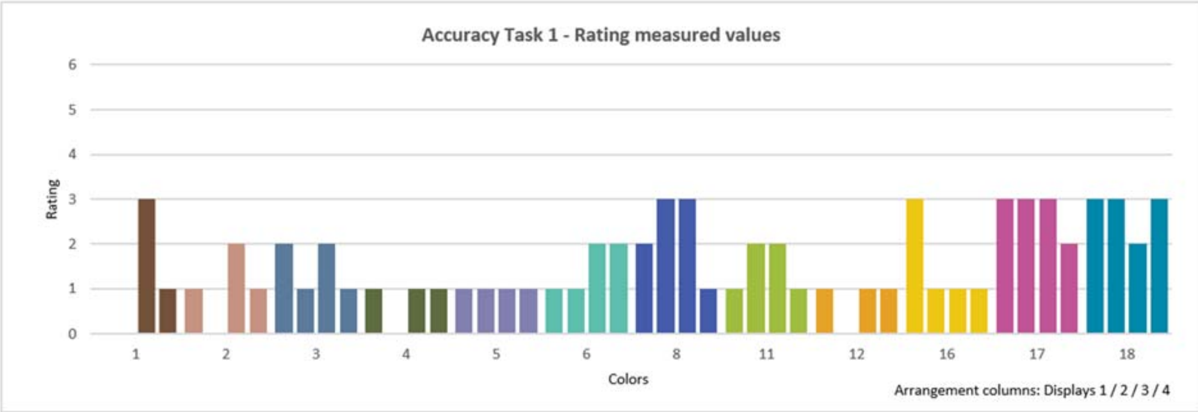


Figure 112. Visualization of ratings achieved by participant ID 03 in tasks for accuracy for all displays.

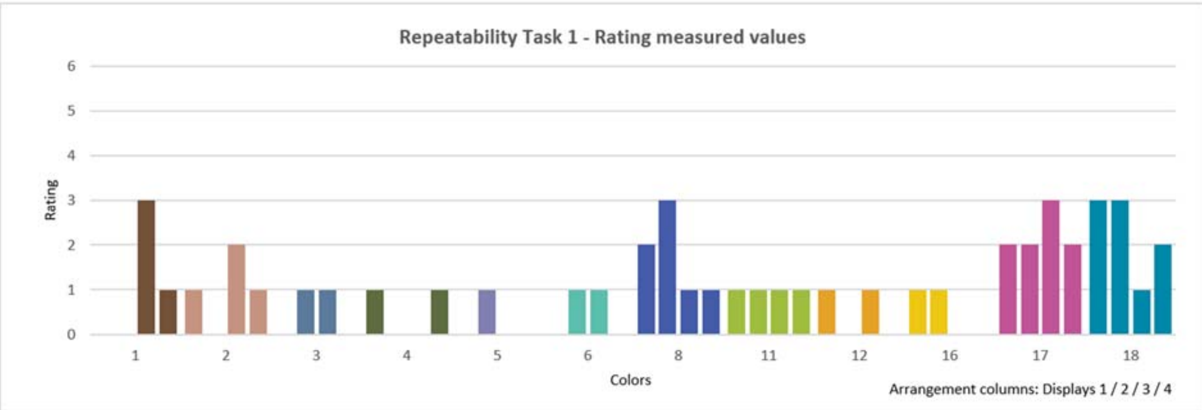


Figure 113. Visualization of ratings achieved by participant ID 03 in tasks for repeatability for all displays.

The results for Display 4 show a reddish representation in total for the achieved color matches. Only colors 4 and 12 show a reduced red color value proportion, and only color 17 shows a reduced blue color value proportion. The value for luminance L* is generally lower, as is the value for saturation. Again, it should first be noted that no color match receives a rating of 0. The best color match in Task 1 is shown by color 12, with a color match of ΔE_{00} = 0.21 (rating 1) and very good repeatability (rating 0). Color 16 also shows an almost identical result. Both colors are more saturated and are in the yellow to yellowish orange spectral range. In total, nine colors show a rating of 1. Colors 6 and 17 show a rating of 2, while the highest color difference (ΔE_{00} = 1.48) is seen in color 18 (rating 3).

Combining the achieved ratings for accuracy across all displays, colors 4, 5, and 12 offer the best results, with either no perceptible or almost imperceptible color differences to the target color. Only color 5 shows an identical rating for all displays. Colors 17 and 18 show the highest ratings for all displays and thus the highest color differences to the target color. Color 8 shows a similar level, except for Display 3. The results for colors 1 and 16 are striking. Color 1 shows a slight perceptible color difference for Display 3 (rating 3), which deviates strongly from the very good results for the other displays. The same applies to the result for color 16 for Display 1. The repeatability evaluation shows good to very good results for colors 3, 4, 5, 6, 11, 12, and 16, although there are some high deviations. The repeatability in colors 17 and 18 is less good. For color 8, the picture is a more mixed one. For displays 1 and 2, the color matches achieve a rating of 2 and 3, respectively, which coincides with an identical rating for accuracy. Display 3, on the other hand, shows good repeatability (rating 1) with an accuracy rating of 3. Color 1 is again striking, with a rating of 3 for Display 3.

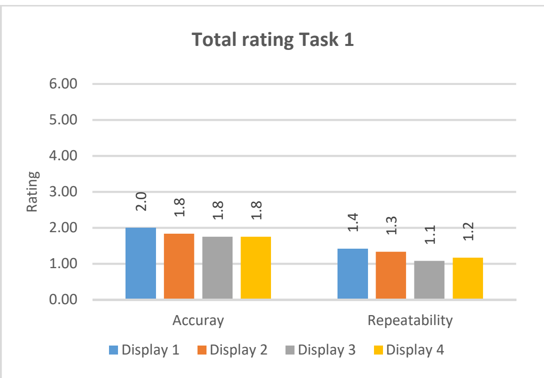
4.7.9.4 Participant ID 04

The participant with ID 04 is male and belongs to the age group 40–49 years. Limitations of the visual system are not known. He has broad technical and application experience in various areas of media production. The use of digital devices and applications comes naturally, and he has experience with digital color and color image editing.

Task 1	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	0.91	2.00	1.30	2.33	0.65	1.42
Display 2	0.78	1.83	1.26	2.25	0.63	1.33
Display 3	0.65	1.75	0.76	1.83	0.38	1.08
Display 4	0.65	1.75	0.77	1.92	0.38	1.17

Task 2	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	1.67	2.96	2.14	3.13	1.07	2.13
Display 2	1.13	2.58	1.42	2.75	0.71	1.83
Display 3	1.46	2.79	1.62	2.83	0.81	1.92
Display 4	1.26	2.67	1.63	2.83	0.82	1.88

Table 60. Total ratings for Task 1 and Task 2 for each display used (ID 04).



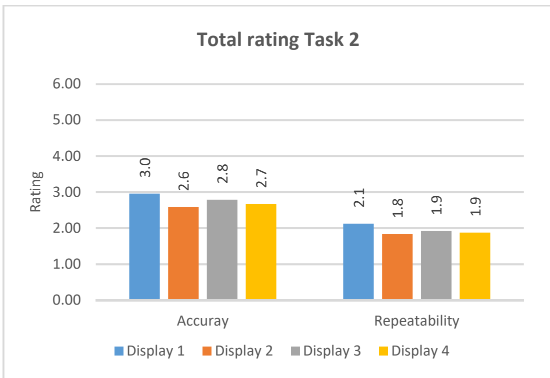


Figure 114. Visualization of total rating for Task 1 and Task 2 for each display used (participant ID 04).

Display 1 shows overall ratings of 2.0 for accuracy (mean $\Delta E_{00} = 0.91$) and 1.4 for repeatability (mean $\Delta E_{00} = 0.65$) in Task 1. The color matches show perceptible color differences for experienced observers with good repeatability. This is also true for all other displays. Display 3 shows the best result here. Task 2 shows a similar result with significantly increased ratings. Display 1 shows an overall rating of 3 for accuracy (mean ΔE_{00} = 1.67) and a rating of 2 for repeatability (mean ΔE_{00} = 1.07). The color matches thus show small color differences to the target color, which is also true for the other displays.

Display 1

	MCD → CC	
Task 1	ΔE_{00}	Rating
1	0.40	1
2	0.56	2
3	0.54	2
4	0.43	1
5	0.24	1
6	0.11	0
8	0.72	2
11	0.79	2
12	0.71	2
16	1.53	3
17	2.82	4
18	2.04	4
Mean	0.91	2.00

Display 2

	MCD → CC	
Task 1	ΔE_{00}	Rating
1	0.35	1
2	0.53	2
3	0.39	1
4	0.24	1
5	0.28	1
6	0.32	1
8	0.82	2
11	1.02	3
12	0.36	1
16	0.30	1
17	2.61	4
18	2.18	4
Mean	0.78	1.83

Display 3

	MCD → CC	
Task 1	ΔE_{00}	Rating
1	0.36	1
2	0.50	2
3	0.40	1
4	0.22	1
5	0.43	1
6	0.31	2
8	0.32	1
11	1.38	3
12	0.73	2
16	0.96	2
17	0.71	2
18	1.44	3
Mean	0.65	1.75

Display 4

	MCD → CC	
Task 1	ΔE_{00}	Rating
1	0.26	1
2	0.63	2
3	1.14	3
4	0.23	1
5	0.52	2
6	0.80	2
8	0.43	1
11	0.81	2
12	0.30	1
16	0.70	2
17	0.24	1
18	1.78	3
Mean	0.65	1.75

Table 61. Overview of mean color differences and ratings obtained in Task 1 to evaluate the accuracy for each single color with the test displays used (participant ID 04).

For Display 1, the results of the color matching in Task 1 show a mixed picture. In the spectral range blue green to yellowish orange, the colors are represented almost more bluish. The more saturated colors near the primaries red and blue show a reduced blue color value proportion and are represented more yellowish. A greenish representation is mainly represented by the color matches in the spectral ranges purplish blue and green and yellow to yellow orange. A majority of colors show an increased value for the luminance L*, while the saturation tends to decrease in comparison. The best color match in Task 1 is color 6, with a color difference of ΔE_{00} = 0.11 (rating 0) and very good repeatability (rating 0). Three other color matches receive a rating of 1 for almost imperceptible color differences. Five color matches receive a rating of 2, color 16 a rating of 3. The highest color difference (ΔE_{00} = 2.82; rating 4) is seen in color 17, while the color match for color 18 also receives a rating of 4. It should be noted here that the lowest color differences are found in the less saturated colors, while all the more saturated colors have more or less perceptible color differences from the target color.

The color matches for Display 2 show a more bluish representation, especially in the less saturated colors. This is also true for the more saturated colors 11 and 18. A more reddish representation is shown in the more saturated colors in the spectral range blue green to yellowish orange, while the less saturated colors show a reduced red color value. The two most saturated colors, 8 and 17, are both represented as more greenish and yellowish and thus less saturated. Colors 12, 16, and 18, which are also more saturated, show higher saturation values compared to the target color. This also applies to the less saturated colors in the blue to green spectral range. An increase in the luminance L* can be seen, especially in the more saturated colors. Since no color match receives a rating of 0, color 4 shows the best color match to the target color, with a color match value of ΔE_{00} = 0.24 (rating 1) and very good repeatability (rating 0). In total, seven color matches receive a rating of 1 for almost imperceptible color differences. Colors 2 and 8 receive a rating of 2, and color 11 receives a rating of 3 for a small perceptible color difference from the target color. The highest color difference (ΔE_{00} = 2.61; rating 4) is seen in color 17, but the color match for color 18 also receives a rating of 4. Both also show a poorer rating for repeatability. The more saturated colors show the highest differences in comparison, except the colors in the yellow to yellowish orange spectral range.
The color matches for Display 3 show that the less saturated colors in particular are represented more bluish. This is also true for the more saturated colors 16, 17, and 18. With a few exceptions, the color matches are also represented more greenish. An increase in luminance L* can be seen, especially in the less saturated colors. Saturation also increases in most cases, with the exception of the more saturated colors near primary blue. Again, color 4 shows the best color matching, with a color difference of ΔE_{00} = 0.22 (rating 1) and very good repeatability (rating 0). In total, six color matches show a rating of 1 for almost imperceptible color differences. Four other, more saturated colors receive a rating of 2. The highest color difference (ΔE_{00} = 1.44; rating 3) is seen in color 18, while color 11 also receives an accuracy rating of 3. A clear difference can be seen for these two colors, however, in the rating for repeatability. The more saturated colors show the highest differences by comparison, with the exception of the most saturated color, color 8.
The color matching for Display 4 shows a more bluish representation, especially in the spectral range green blue to yellowish orange. The colors in the spectral ranges green blue to yellowish green and purplish pink are represented more reddish. In the spectral ranges purplish blue and yellow to yellowish orange, on the other hand, the representation is more greenish. An increase in the luminance L* can be seen in almost all color matches. An increase in saturation is especially noticeable in the spectral ranges purplish blue and purplish pink. The best match to

the target color is again color 4, with a color difference of ΔE_{00} = 0.23 (rating 1) and good repeatability (rating 1). In total, five color matches show a rating of 1 and five more show a rating of 2. The highest color difference (ΔE_{00} = 1.78; rating 3) is seen in color 18, but the color match for color 3 also receives a rating of 3. Both colors are in the green blue spectral range and are represented more reddish and bluish. This applies to all colors that show a more or less perceptible color difference from the target color.

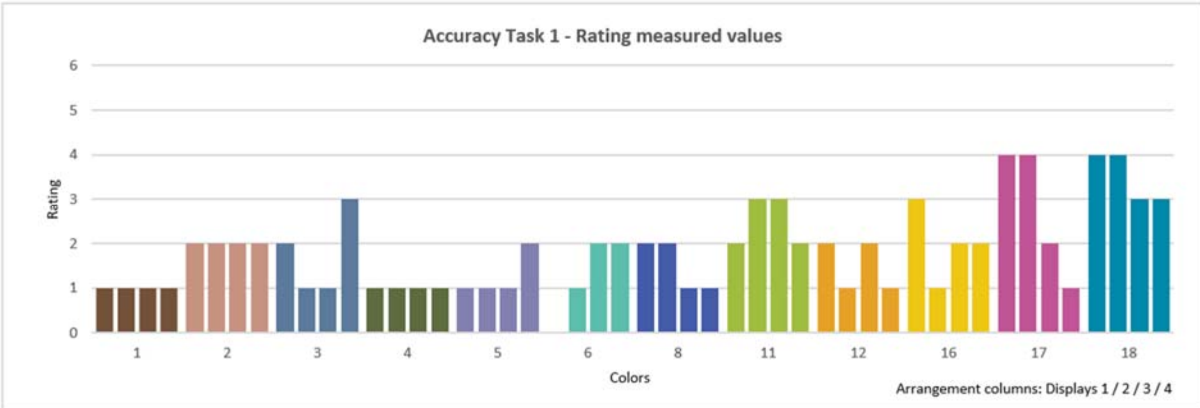


Figure 115. Visualization of ratings achieved by participant ID 04 in tasks for accuracy for all displays.

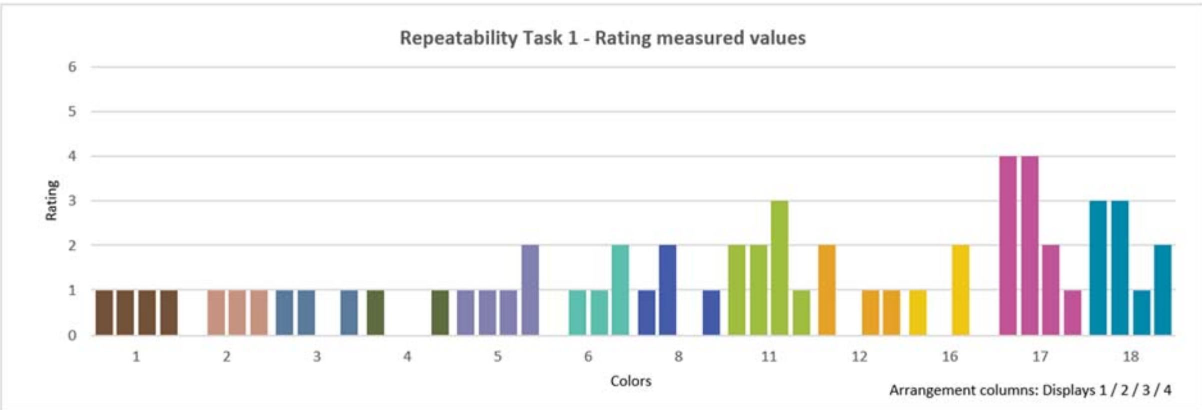


Figure 116. Visualization of ratings achieved by participant ID 04 in tasks for repeatability for all displays.

An examination of the ratings achieved for each single color for accuracy across all displays shows the best results for colors 1 and 4; the occurring color differences to the target color are almost imperceptible. An identical rating for all displays is also observed for color 2 (rating 2). Colors 17 and 18 show the highest ratings for all displays and thus the highest color deviations from the target color. It is noteworthy here that color 17 represents a miniscule deviation for Display 4 (rating 1) by comparison. However, colors 3 and 16 also show a very varied image.

In terms of repeatability, the ratings show good to very good results for colors 1, 2, 3, and 4. Color 17 receives a rating of 4 for displays 1 and 2 and is thus the poorest result. Colors 11 and 18 also show poorer results.

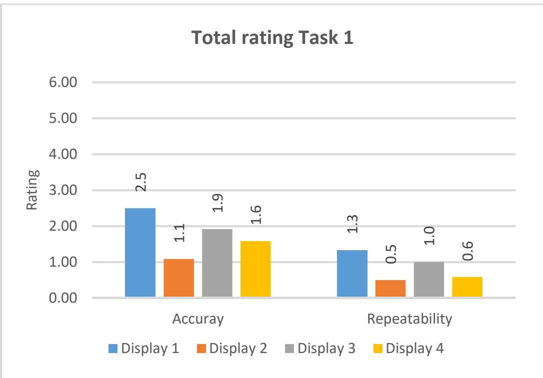
4.7.9.5 Participant ID 05

The participant with ID 05 is male and belongs to the age group 50–59 years. He wears glasses (farsightedness) and is not aware of any other limitations to his visual system. The use of digital devices and applications is also natural due to his profession. He has professional experience in digital media production with a focus on TV production, and streaming technologies. That said, he has no experience in working with digital color in the sense of color image editing.

Task 1	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	1.05	2.50	0.90	2.08	0.45	1.33
Display 2	0.38	1.08	0.45	1.08	0.23	0.50
Display 3	0.72	1.92	0.68	1.83	0.34	1.00
Display 4	0.52	1.58	0.47	1.42	0.24	0.58

Task 2	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	1.74	3.13	1.82	3.00	0.91	2.04
Display 2	1.38	2.79	1.54	2.88	0.77	1.96
Display 3	1.56	2.83	1.81	3.08	0.91	2.04
Display 4	1.22	2.50	1.34	2.71	0.67	1.79

Table 62. Total rating for Task 1 and Task 2 for each display used (participant ID 05).



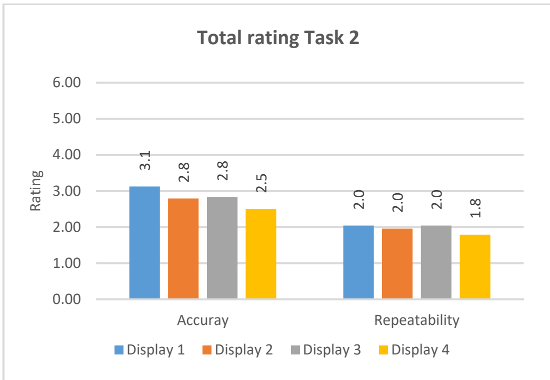


Figure 117. Visualization of total rating for Task 1 and Task 2 for each display used (participant ID 05).

The consideration of the overall rating for Task 1 shows clearer discrepancies. The poorest result is achieved by the color matches for Display 1, with overall ratings of 2.5 for accuracy (mean ΔE_{00} = 1.05) and 1.3 for repeatability (mean ΔE_{00} = 0.45). This means that the obtained results show good repeatability but low perceptible color differences. The same is true for displays 3 and 4, but these both show better individual values. Display 2 shows the best result, with overall ratings of 1.1 for accuracy (mean ΔE_{00} = 0.38) and 0.5 (mean ΔE_{00} = 0.23) for repeatability. In Task 2, the overall rating for all displays increases significantly; the results show low perceptible color differences to the target color, and repeatability also drops.

The representation of the color matches for Display 1 shows mostly mixed results. In the spectral value ranges green to blue, yellowish orange, and purplish pink, the colors are represented more bluish and reddish. In contrast, the color representation in the spectral ranges purplish blue and green to yellow is more greenish and yellowish. Except for three colors, the value for the luminance L* is increased. The saturation also increases for the most part. The less saturated colors are all represented with a higher saturation in the color matching. The color matches obtained show more or less perceptible color differences except for colors 6 and 11 with a rating of 1. It should be noted here that no color match receives a rating of 0. The best color match in Task 1 comes from color 6, with a color difference of ΔE_{00} = 0.33 (rating 1) and good repeatability (rating 1). A similar result is shown for color 11, with four color matches showing a rating of 2 and another four showing a rating of 2. The highest color difference (ΔE_{00} = 2.13; rating 4) is seen in color 18, but the color match for color 1 also receives a rating of 4. Both are less saturated colors. A clear difference is seen here when looking at the rating: while the results for color 1 hardly differ (rating 0), a clearer gap is observed between the results for color 3 (rating 3).

	Display 1 MCD → CC		Display 2 MCD → CC		Display 3 MCD → CC		Display 4 MCD → CC	
Task 1	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
1	2.11	4	0.62	2	0.83	2	0.28	1
2	0.77	2	0.39	1	0.50	2	0.76	2
3	2.13	4	0.56	2	0.55	2	0.73	2
4	1.12	3	0.20	1	0.53	2	0.20	1
5	1.43	3	0.15	0	0.54	2	0.64	2
6	0.33	1	0.21	1	0.53	2	0.45	1
8	0.63	2	0.49	1	0.53	2	0.27	1
11	0.49	1	0.84	2	0.84	2	0.57	2
12	0.77	2	0.13	0	0.40	1	0.52	2
16	0.54	2	0.26	1	0.44	1	0.50	2
17	1.18	3	0.53	2	0.24	1	0.41	1
18	1.15	3	0.18	0	2.75	4	0.94	2
Mean	1.05	2.50	0.38	1.08	0.72	1.92	0.52	1.58

Table 63. Overview of mean color differences and ratings obtained in Task 1 to evaluate the accuracy for each single color with the test displays used (participant ID 05).

The results for Display 2 show a more yellowish representation for the colors in the spectral ranges purplish blue and yellowish green to yellow. The colors in the spectral range blue green to yellowish green are represented more bluish and greenish. In the spectral range purplish blue to purplish pink, the representation of the color matches is more reddish. The value for the luminance L* increases especially in the more saturated colors, as does the saturation. The best match to the target color in Task 1 comes from color 12, with a color difference of $\Delta E_{00} = 0.13$ (rating 0) and very good repeatability (rating 0). Colors 5 and 18 show almost identical results. Five color matches show a rating of 1. The highest color difference ($\Delta E_{00} = 0.84$; rating 2) is seen in color 11. Colors 1, 3, and 17 show a color difference that is perceptible to experienced observers.

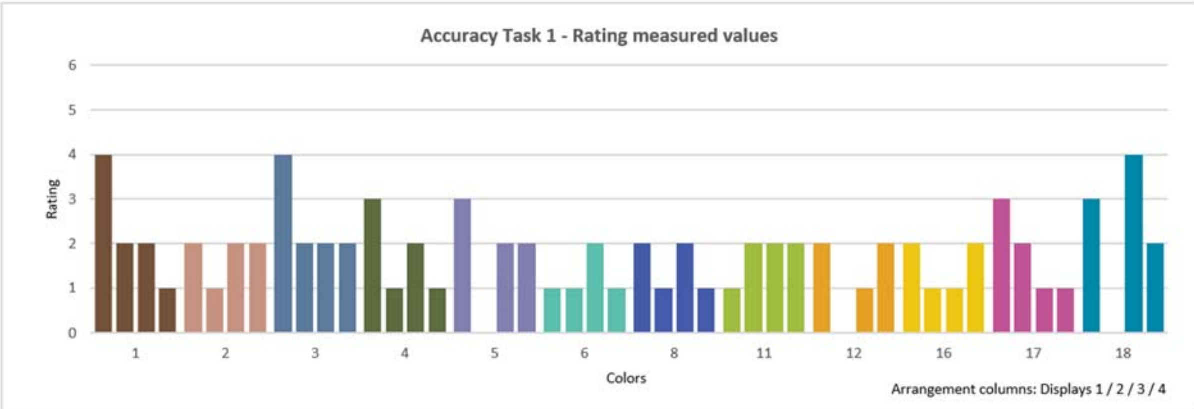


Figure 118. Visualization of ratings achieved by participant ID 05 in tasks for accuracy for all displays.

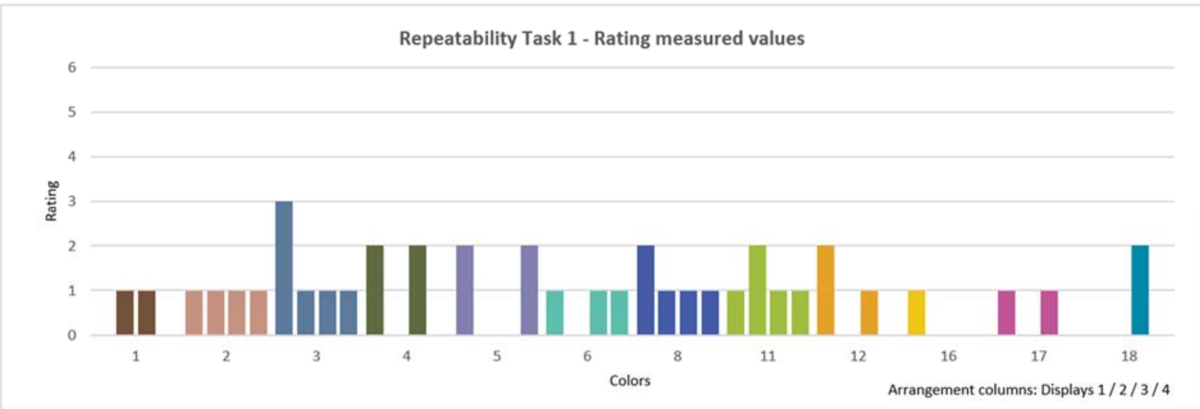


Figure 119. Visualization of ratings achieved by participant ID 05 in tasks for repeatability for all displays.

For Display 3, all color matches show a higher value for the luminance L*. It can also be seen that the majority of the color matches are represented more bluish. In addition, the representation is more reddish, except for the spectral ranges purplish pink and yellowish orange to yellow. A higher value for saturation is only found in four colors. Except for the more saturated colors 12, 16, and 17 (rating 1) in the spectral ranges yellow to yellowish orange and purplish pink, more or less strongly perceptible color differences are found. No color match achieves the rating 0. The best match of the color match to the target color in Task 1 comes from color 17, with a color difference of ΔE_{00} = 0.24 (rating 1) and good repeatability (rating 1). Eight color matches show a rating of 2. The highest color difference (ΔE_{00} = 2.75; rating 4) is seen in color 18. It is noticeable here that all the less saturated colors show a color difference that is perceptible to experienced observers.

The results for Display 4 show a more bluish representation of the color matches for all colors. Except for the colors near the primary red, the colors are also represented more reddish. For the majority of the colors, a higher value for the luminance L* can be seen by comparison. In turn, the colors are also represented with a lower saturation, with the exception of the spectral range purplish blue. No color match achieves the rating 0. The best match to the target color in Task 1 comes from color 4, with a color difference of ΔE_{00} = 0.20 (rating 1) and very good repeatability (rating 0). Similar results are shown for colors 1, 6, 8, and 17. The highest color difference (ΔE_{00} = 0.94; rating 4) is seen in color 18, with very good repeatability (rating 0). The color differences determined here are reasonably close to each other, and only color 18 falls off slightly.

Considering the achieved ratings for the accuracy of the individual colors from display to display, a certain level of stability can be seen for colors 2, 6, 8, 11, 12, and 16. Colors 1, 3, 4, 5, and 17 show a somewhat strongly increased rating in comparison to Display 1. The results in color 18 are particularly noticeable, ranging from a rating of 0 to 4. The evaluation of repeatability reveals quite different results in some cases. Color 3 shows the highest rating of 3 for Display 1, whereas displays 2 to 4 receive a rating of 1. Colors 4, 5, and 18 show significant differences: from rating 2 to rating 0. Colors 1, 2, 6, 16, and 17 show good to very good results. Only color 2 shows an identical rating for all displays.

4.7.9.6 Participant ID 06

The participant with ID 06 is female and belongs to the age group 20–29 years. No limitations of the visual system are known, and she is an experienced and proficient user of digital devices and applications. Study-related experience in digital media production is available. The participant’s artistic focus is 2D/3D graphic animation, which is why she has a high level of experience in working with digital color.

Both displays show almost identical results. Display 1 shows overall ratings of 1.5 for accuracy (mean ΔE_{00} = 0.63) and 1.1 for repeatability (mean ΔE_{00} = 0.42) in Task 1, meaning that the color matches obtained show color differences that are perceptible to experienced observers with good repeatability. This is also true for Display 2, with overall ratings of 1.6 for accuracy (mean ΔE_{00} = 0.54) and 1.1 for repeatability (mean ΔE_{00} = 0.36). For Task 2, the overall rating increases for both displays.

Task 1	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	0.63	1.50	0.83	1.83	0.42	1.08
Display 2						
Display 3	0.54	1.58	0.72	1.92	0.36	1.08
Display 4						

Task 2	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	1.23	2.50	1.59	2.83	0.79	1.88
Display 2						
Display 3	1.15	2.63	1.51	2.96	0.76	1.92
Display 4						

Table 64. Total rating for Task 1 and Task 2 for each display used (participant ID 06).

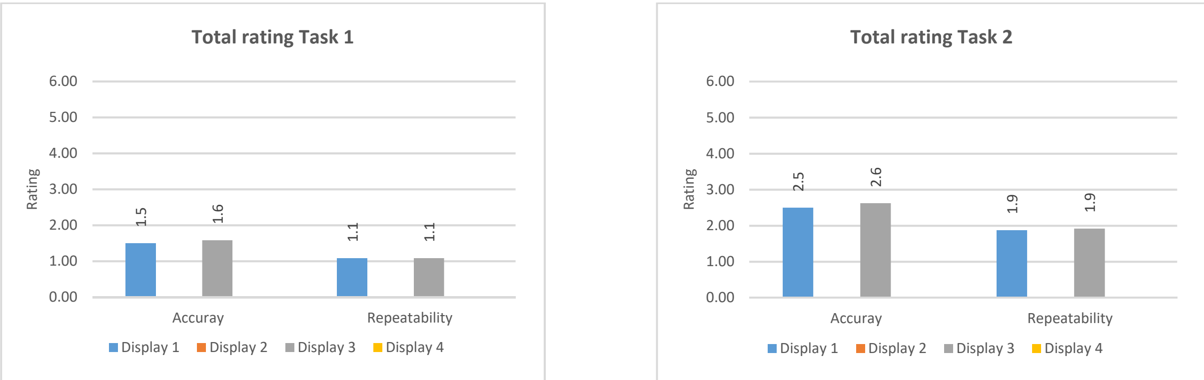


Figure 120. Visualization of total rating for Task 1 and Task 2 for each display used (participant ID 06).

The results for Display 1 show that the colors in the spectral range blue green to yellowish green are represented more greenish and yellowish and therefore more saturated. Only colors 3, 16, and 17 have a higher blue color value. In total, with the exception of color 16, all colors show a higher saturation. The value for the luminance L* increases especially in the less saturated colors. The best color match in Task 1 comes from color 1, with a color difference of ΔE_{00} = 0.06 (rating 0) and very good repeatability (rating 0). Six other color matches receive a rating of 1 for almost imperceptible color differences. It should be noted here that the lowest color differences are found in the less saturated colors 1–5. Three color matches receive a rating of 2 for a color difference that is perceptible to experienced observers. The highest color difference (ΔE_{00} = 1.13) is seen in color 8 but also in color 5; both these colors are found in the spectral range purplish blue.

The results for Display 3 show that the less saturated colors as well as the more saturated colors in the spectral range blue green to yellowish orange are represented more bluish. The color matches also tend, with a few exceptions, to have a lower red color value annex and are thus represented more greenish. Additionally, except for color 1, a higher value for the luminance L* can be seen in all color matches. The saturation, on the other hand, decreases in most cases. Color 1 shows the best match of the color difference to the target color, with a color difference of $\Delta E_{00} = 0.26$ (rating 1) and good repeatability (rating 1). Four other color matches also receive a rating of 1 for almost imperceptible color differences. The remaining colors show a rating of 2 for color differences that are perceptible to experienced observers. The highest color difference ($\Delta E_{00} = 0.86$) can be seen in color 4. No clear trend can be observed here, although higher color differences can be seen, especially in the spectral range blue green to purplish pink.

Display 1

	MCD → CC	
Task 1	ΔE_{00}	Rating
1	0.06	0
2	0.48	1
3	0.34	1
4	0.38	1
5	1.00	3
6	0.47	1
8	1.19	3
11	0.49	1
12	0.86	2
16	0.49	1
17	0.79	2
18	0.99	2
Mean	0.63	1.50

Display 2

	MCD → CC	
Task 1	ΔE_{00}	Rating
1		
2		
3		
4		
5		
6		
8		
11		
12		
16		
17		
18		
Mean		

Display 3

	MCD → CC	
Task 1	ΔE_{00}	Rating
1	0.47	1
2	0.50	2
3	0.62	2
4	0.86	2
5	0.43	1
6	0.43	1
8	0.51	2
11	0.26	1
12	0.51	2
16	0.37	1
17	0.77	2
18	0.77	2
Mean	0.54	1.58

Display 4

	MCD → CC	
Task 1	ΔE_{00}	Rating
1		
2		
3		
4		
5		
6		
8		
11		
12		
16		
17		
18		
Mean		

Table 65. Overview of mean color differences and ratings obtained in Task 1 to evaluate the accuracy for each single color with the test displays used (participant ID 06).

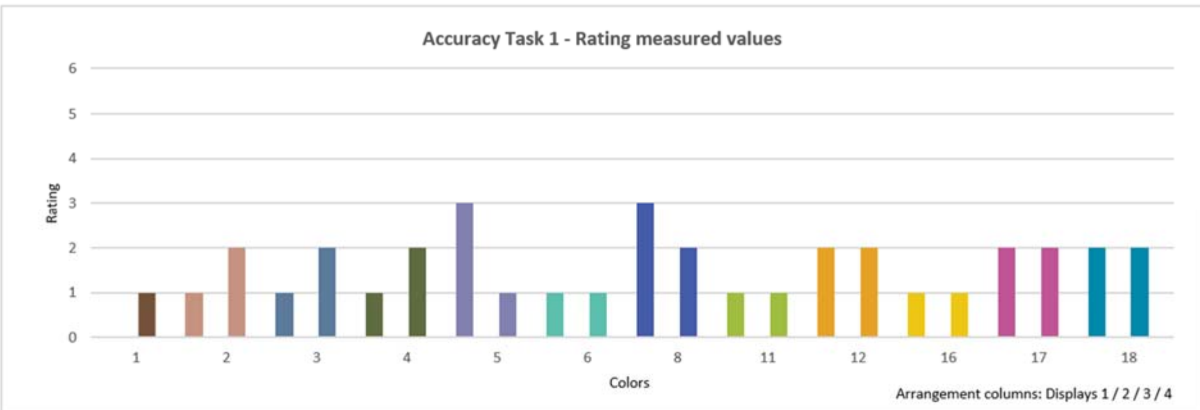


Figure 121. Visualization of ratings achieved by participant ID 06 in tasks for accuracy for all displays.

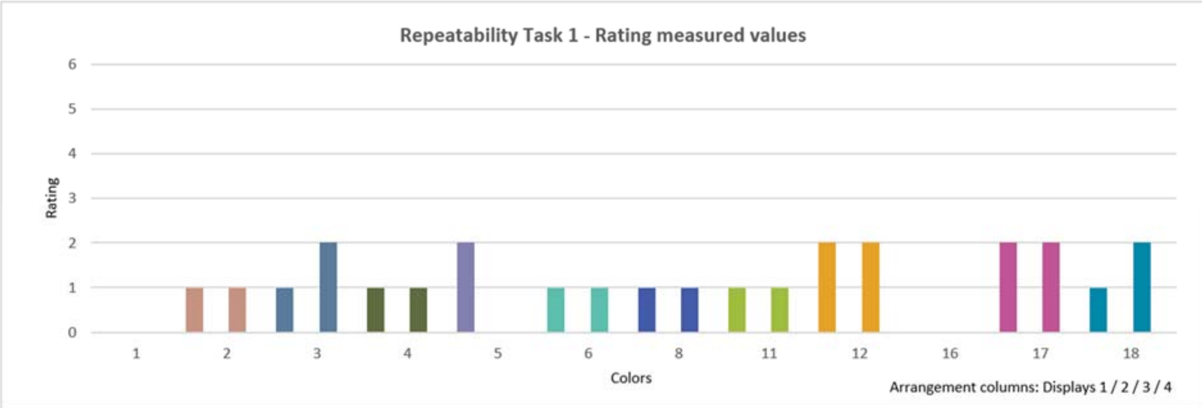


Figure 122. Visualization of ratings achieved by participant ID 06 in tasks for repeatability for all displays.

The comparison of the ratings for the accuracy of displays 1 and 3 for colors 6, 11, 12, 16, 17, and 18 shows identical results. The highest ratings for both displays can be seen in colors 5 and 8. The difference in the ratings in color 5 is striking. Colors 1 and 16 show the best rating (0) for repeatability, whereas colors 12 and 17 show the highest rating of 2. Except for colors 3, 5, and 18, the ratings for both displays are identical.

4.7.9.7 Participant ID 07

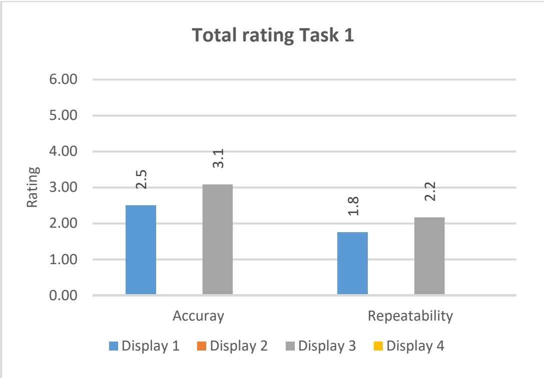
The participant with ID 07 is male and belongs to the age group 60–69 years. He wears glasses (nearsightedness); no other limitations of the visual system are known. The use of digital devices and applications is also standard for him in his professional environment. He has professional experience in digital media production with a focus on audio and film production but no experience in working with digital color in the sense of color image editing.

Task 1	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	1.05	2.50	1.45	2.58	0.72	1.75
Display 2						
Display 3	1.69	3.08	1.97	3.17	0.99	2.17
Display 4						

Task 2	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	2.31	3.54	3.41	4.08	1.69	2.96
Display 2						
Display 3	2.67	3.96	3.33	4.21	1.67	3.13
Display 4						

Table 66. Total rating for Task 1 and Task 2 for each display used (participant ID 07).

Display 1 indicates overall ratings of 2.5 for accuracy (mean ΔE_{00} = 1.05) and 1.8 for repeatability (mean ΔE_{00} = 0.72) in Task 1. By contrast, Display 3 indicates overall ratings of 3.1 for accuracy (mean ΔE_{00} = 1.69) and 2.2 for repeatability (mean ΔE_{00} = 0.99). The color matches show low perceptible color differences with poorer repeatability. Task 2 again shows higher ratings.



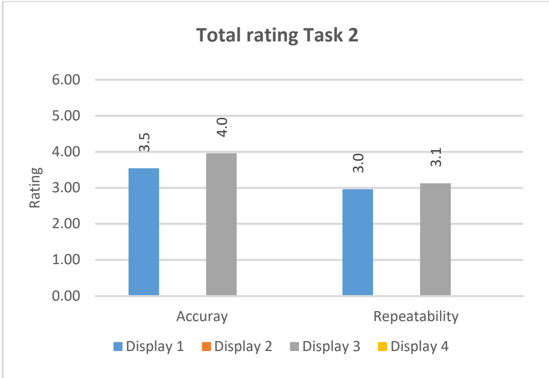


Figure 123. Visualization of total rating for Task 1 and Task 2 for each display used (participant ID 07).

Display 1

	MCD → CC	
Task 1	ΔE_{00}	Rating
1	0.72	2
2	1.91	3
3	1.03	3
4	0.84	2
5	1.51	3
6	0.68	2
8	1.33	3
11	0.54	2
12	1.13	3
16	1.00	3
17	1.50	3
18	0.45	1
Mean	1.05	2.50

Display 2

	MCD → CC	
Task 1	ΔE_{00}	Rating
1		
2		
3		
4		
5		
6		
8		
11		
12		
16		
17		
18		
Mean		

Display 3

	MCD → CC	
Task 1	ΔE_{00}	Rating
1	2.33	4
2	2.08	4
3	0.74	2
4	0.87	2
5	2.05	4
6	2.40	4
8	1.71	3
11	1.14	3
12	1.46	3
16	0.48	1
17	1.74	3
18	3.27	4
Mean	1.69	3.08

Display 4

	MCD → CC	
Task 1	ΔE_{00}	Rating
1		
2		
3		
4		
5		
6		
8		
11		
12		
16		
17		
18		
Mean		

Table 67. Overview of mean color differences and ratings obtained in Task 1 to evaluate the accuracy for each single color with the test displays used (participant ID 07).

The results for Display 1 in Task 1 show that, except for color 4, all color matches are represented more reddish. The colors in the spectral range blue green to purplish pink are also represented more bluish. In turn, except for colors 3, 4, and 8, a higher saturation can also be observed. The values for luminance L* are lower in the more saturated colors. The overall rating of 2.5 already indicates more or less perceptible differences for most of the color matches. Color 18 shows the closest match to the target color, with a rating of 1 (mean $\Delta E_{00} = 0.45$). Four other colors receive a rating of 2, and seven colors receive a rating of 3. In the spectral range green blue to yellowish, the color differences that do not exceed the limit value $\Delta E_{00} = 1.00$ can be seen. The highest perceptible color difference ($\Delta E_{00} = 1.91$; rating 3) is shown for the least saturated color, color 2. Four colors with a rating of 3 receive the same rating for repeatability, which indicates higher differences between the obtained results. However, a separate overall consideration of MR1 and MR2 does not show any high differences; these are actually attributable to the single color concerned.

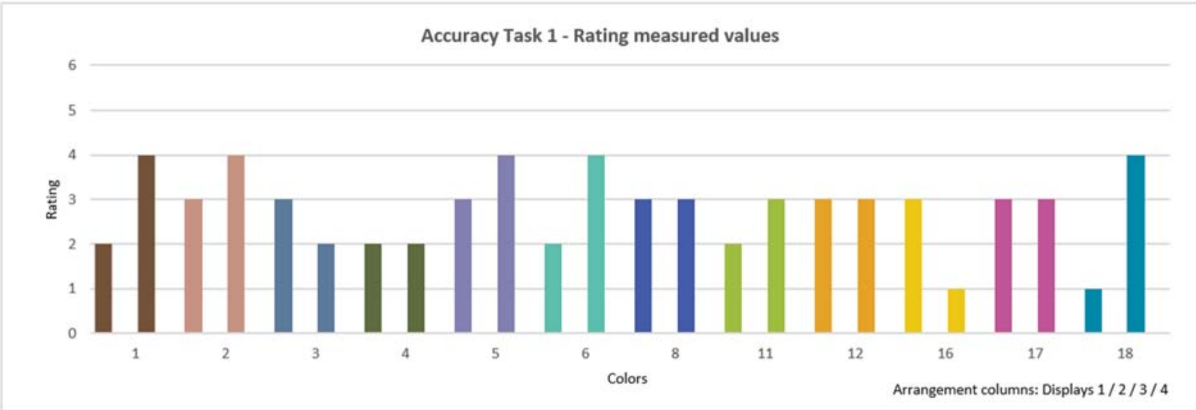


Figure 124. Visualization of ratings achieved by participant ID 07 in tasks for accuracy for all displays.

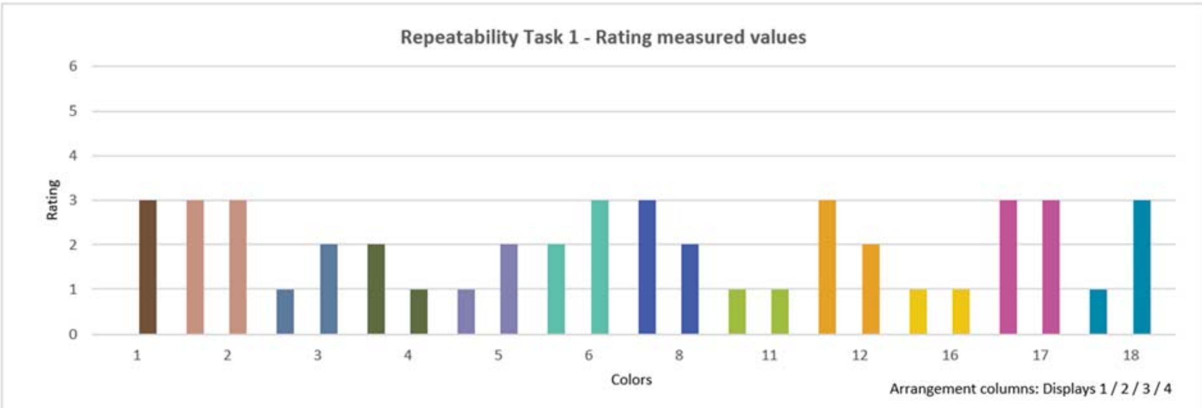


Figure 125. Visualization of ratings achieved by participant ID 07 in tasks for repeatability for all displays.

For Display 3, the color matches show a bluer representation, except for colors 3, 12, and 17. The colors in the spectral range from green to purplish pink are also represented more reddish. By contrast, the more saturated colors in the spectral ranges yellow to yellowish orange are represented more greenish. With a few exceptions, the saturation of the color matches is lower, while the L* value for luminance is higher. The color matching results obtained show an almost imperceptible color difference in only one color. Color 16 shows the most exact match to the target color, with a rating of 1 (mean $\Delta E_{00} = 0.48$). Two other colors receive a rating of 2, while four colors receive a rating of 3. Color 18 shows the highest perceptible color difference at ΔE_{00}

= 3.27 (rating 4). The less saturated colors 1, 2, 5, and 6 also show perceptible color differences (rating 4). All colors with a rating of 4 are represented more reddish and bluish.
The comparison of the accuracy ratings for displays 1 and 3 shows identical results for colors 4, 8, 12, and 17. However, clear differences are apparent in the other colors. Color 18 is particularly noticeable here, as is color 6. Likewise, the ratings for repeatability already show clear differences for color 1, with a rating of 0 or 3. A higher difference can otherwise only be seen in color 18, while identical results are shown for colors 2, 11, 16, and 17.

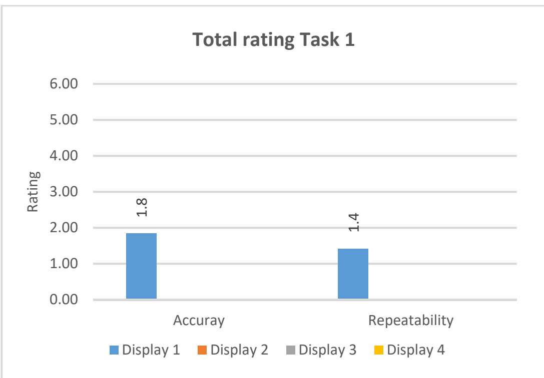
4.7.9.8 Participant ID 08

The participant with ID 08 is male and belongs to the age group 40–49 years. Limitations of the visual system are not known. He has professional experience in various areas of digital media production, with a focus on video and film production and event technology. An average level of experience in working with digital color and color image editing is available.
The overall ratings of 1.8 (mean ΔE_{00} = 0.68) for accuracy and 1.4 (mean ΔE_{00} = 0.49) for repeatability in Task 1 indicate that, on average, the color matches achieved show a color difference perceptible to experienced observers with good repeatability of the results. In Task 2, the rating for accuracy increases to 3.4 (mean ΔE_{00} = 1.96) and for repeatability to 2.1 (mean ΔE_{00} = 0.96).

Task 1	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	0.68	1.83	0.98	2.25	0.49	1.42
Display 2						
Display 3						
Display 4						

Task 2	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	1.96	3.38	1.98	3.08	0.99	2.17
Display 2						
Display 3						
Display 4						

Table 68. Total rating for Task 1 and Task 2 for each display used (participant ID 08).



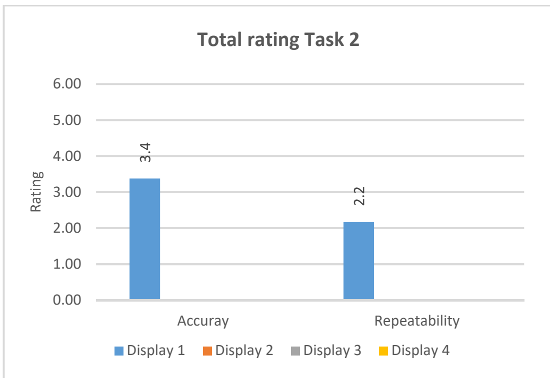


Figure 126. Visualization of total rating for Task 1 and Task 2 for each display used (participant ID 08).

The results obtained in Task 1 show that, except for color 16, all color matches are represented more reddish. The less saturated colors near the white point show a reduced blue color value and are represented more yellowish. This is also true for the saturated colors 8 and 11, which are closest to primary blue and primary green, respectively. The values for the luminance L* are increased, and the colors are represented as aturated. Exceptions are colors in the spectral ranges purplish blue to green.

Display 1

	MCD → CC	
Task 1	ΔE_{00}	Rating
1	0.37	1
2	0.60	2
3	0.41	1
4	0.08	0
5	1.11	3
6	0.31	1
8	0.86	2
11	0.78	2
12	1.23	3
16	1.11	3
17	0.60	2
18	0.74	2
Mean	0.68	1.83

Display 2

	MCD → CC	
Task 1	ΔE_{00}	Rating
1		
2		
3		
4		
5		
6		
8		
11		
12		
16		
17		
18		
Mean		

Display 3

	MCD → CC	
Task 1	ΔE_{00}	Rating
1		
2		
3		
4		
5		
6		
8		
11		
12		
16		
17		
18		
Mean		

Display 4

	MCD → CC	
Task 1	ΔE_{00}	Rating
1		
2		
3		
4		
5		
6		
8		
11		
12		
16		
17		
18		
Mean		

Table 69. Overview of mean color differences and ratings obtained in Task 1 to evaluate the accuracy for each single color with the test displays used (participant ID 08).

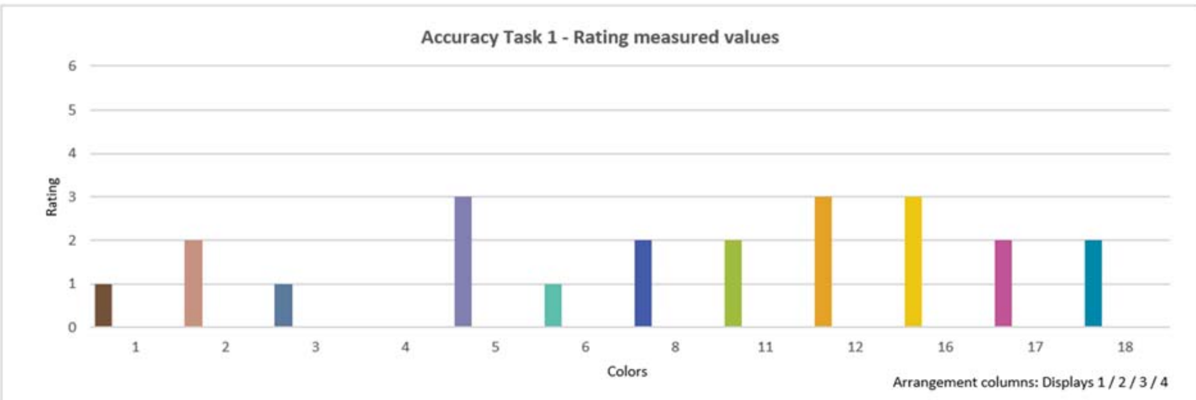


Figure 127. Visualization of ratings achieved by participant ID 08 in tasks for accuracy for all displays.

Eight color matches show a rating of 2 or 3. The best result, with the lowest color difference (ΔE_{00} = 0.08; rating 0) achieved for color 4. Three other colors show a rating of 1, and five colors are rated 2 for color differences that are not perceptible to experienced observers.

Essentially, it can be stated that the most accurate results here were obtained in the less saturated colors. The exception is color 5, which has a color difference of ΔE00 = 1.11 (rating 3). Colors 12 and 16 in the yellowish orange and yellow spectral range also receive a rating of 3. Color 12 shows the highest color difference (ΔE00 = 1.23) to the target color. The ratings for repeatability are clearly different here. If the results from MR1 and MR2 for color 3 are close together, a color difference is perceptible for color 16.

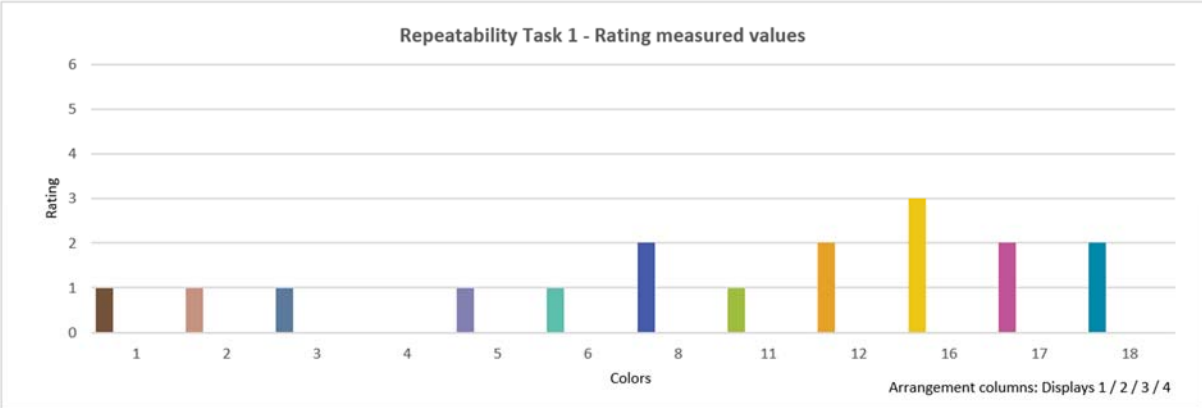


Figure 128. Visualization of ratings achieved by participant ID 08 in tasks for repeatability for all displays.

4.7.9.9 Participant ID 09

The participant with ID 09 is male and belongs to the age group 20–29 years. Limitations of the visual system are not known. The use of digital devices and applications is self-evident. Study-related experience in digital media production with an emphasis on audio technology is available. Accumulated experience of working with digital color or color image editing is not present to any notable degree.

Task 1	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	0.63	1.67	0.84	2.00	0.42	1.08
Display 2						
Display 3	0.54	1.42	0.62	1.58	0.31	1.00
Display 4						

Task 2	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	2.07	3.17	3.00	3.71	1.49	2.50
Display 2						
Display 3	1.47	2.92	1.95	3.21	0.97	2.21
Display 4						

Table 70. Total rating for Task 1 and Task 2 for each display used (participant ID 09).

Display 1 receives overall ratings of 1.7 for accuracy (mean ΔE00 = 0.63) and 1.1 for repeatability (mean ΔE00 = 0.42) in Task 1. The color matches show color differences that are perceptible to experienced observers. Display 2 shows overall ratings of 1.4 for accuracy (mean ΔE00 = 0.54) and 1.0 for repeatability (mean ΔE00 = 0.31) in Task 1. Thus, color differences that occur are almost imperceptible. Both displays show significantly higher ratings for accuracy and repeatability for Task 2.

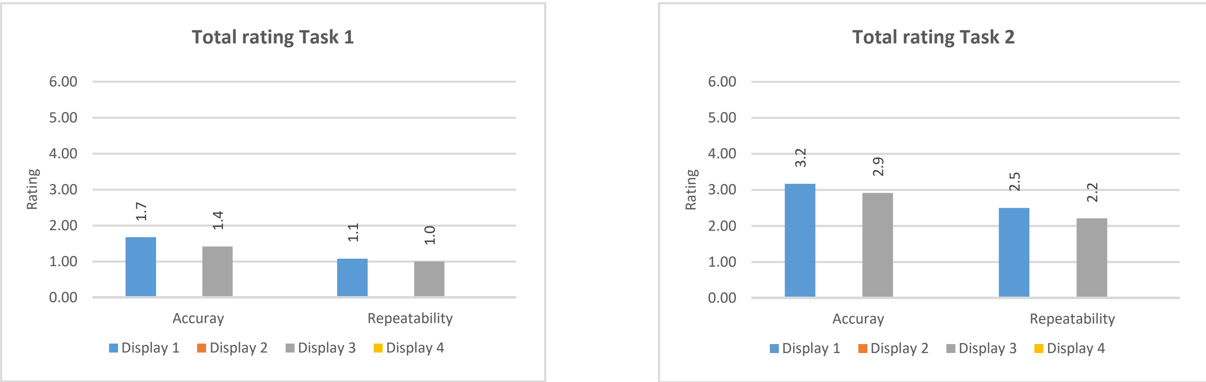


Figure 129. Visualization of total rating for Task 1 and Task 2 for each display used (participant ID 09).

Display 1

	MCD → CC	
Task 1	ΔE_{00}	Rating
1	0.02	0
2	0.41	1
3	0.70	2
4	0.44	1
5	0.51	2
6	0.29	1
8	0.76	2
11	0.71	2
12	0.59	2
16	1.34	3
17	0.97	2
18	0.83	2
Mean	0.63	1.67

Display 2

	MCD → CC	
Task 1	ΔE_{00}	Rating
1		
2		
3		
4		
5		
6		
8		
11		
12		
16		
17		
18		
Mean		

Display 3

	MCD → CC	
Task 1	ΔE_{00}	Rating
1	0.26	1
2	0.16	0
3	0.94	2
4	0.44	1
5	0.42	1
6	0.56	2
8	0.52	2
11	0.43	1
12	0.39	1
16	0.60	2
17	0.44	1
18	1.33	3
Mean	0.54	1.42

Display 4

	MCD → CC	
Task 1	ΔE_{00}	Rating
1		
2		
3		
4		
5		
6		
8		
11		
12		
16		
17		
18		
Mean		

Table 71. Overview of mean color differences and ratings obtained in Task 1 to evaluate the accuracy for each single color with the test displays used (participant ID 09).

The color matching in Task 1 shows a higher luminance L* for Display 1, except for the colors in the spectral range yellowish green to yellowish orange. A more reddish representation of the colors can be seen, especially in the spectral range blue green to purplish pink. In addition, the colors in the spectral range purplish blue to yellowish green show a reduced blue color value, resulting in a more yellowish representation. By contrast, the more saturated colors in the spectral ranges yellow to yellowish orange and purplish pink are represented more bluish. As a result, the saturation mostly increases in the already higher saturated colors, except colors 8 and

17. The best match to the target color in Task 1 is shown by color 1, with a color difference of ΔE_{00} = 0.02 (rating 0) and very good repeatability (rating 0). Three other color matches are rated 1 for almost imperceptible color differences, while seven receive a rating of 2 for color differences that are not perceptible to experienced observers. The highest color difference (ΔE_{00} = 1.34) can be seen in color 16. It should be noted that more or less strong perceptible color differences are visible in the more saturated colors, while the less saturated colors show better results.

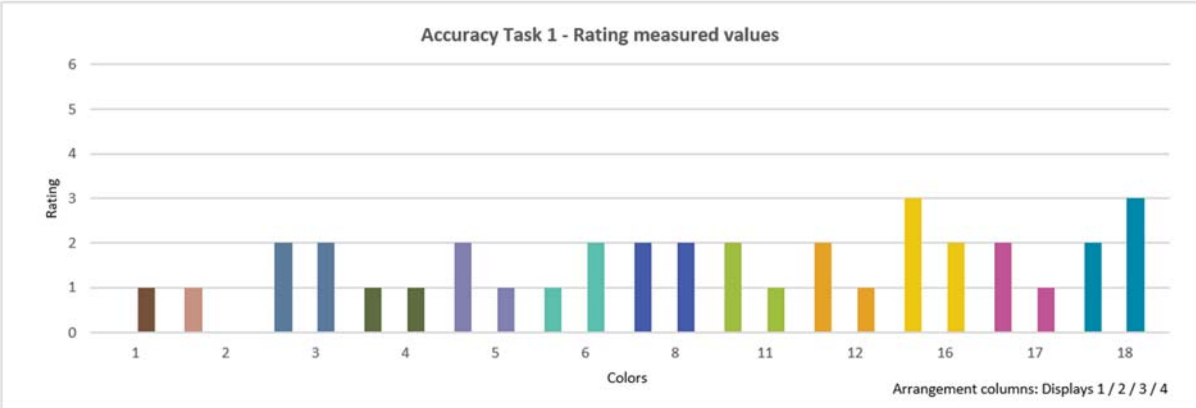


Figure 130. Visualization of ratings achieved by participant ID 09 in tasks for accuracy for all displays.

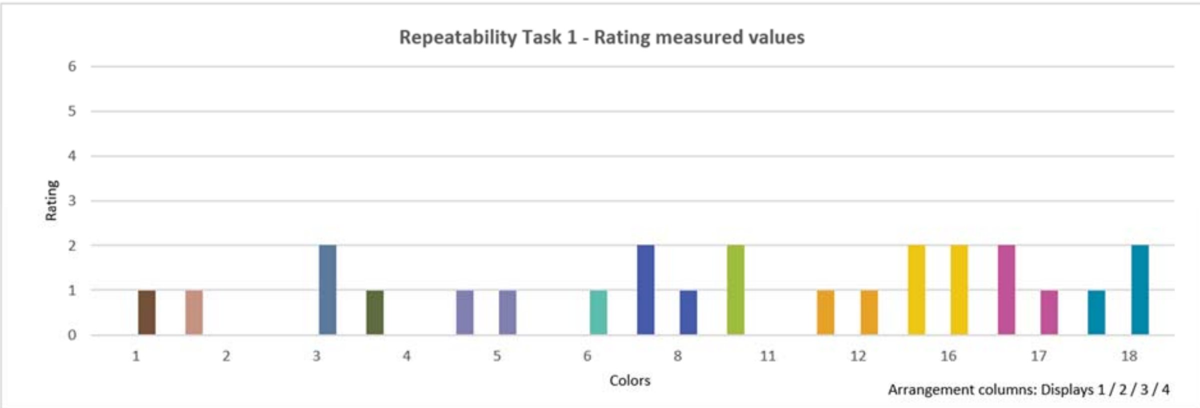


Figure 131. Visualization of ratings achieved by participant ID 09 in tasks for repeatability for all displays.

The results obtained for Display 3 are more mixed. All colors show a higher luminance L*. In the spectral range green to purplish pink, the achieved color matches are represented more reddish and bluish. For colors 5, 8, and 17, this also means an increase in saturation. The saturated colors in the spectral range yellow to yellow orange are also represented more bluish.

However, the red color value is reduced here, which leads to a greenish and also less saturated representation. Color 2 shows the best color matching result, with the lowest color difference of $\Delta E_{00} = 0.16$ (rating 0). Six colors indicate a rating of 1 and four colors indicate a rating of 2 (color difference perceptible to experienced observers). Color 18 has the highest perceptible color difference at $\Delta E_{00} = 1.33$ (rating 3). It is evident here that especially the color matches in the spectral range purplish blue to green show stronger differences to the target color. With the exception of color 3, these are represented more reddish and bluish.
The ratings obtained here are quite evenly distributed. Colors 1, 2, and 4 show the lowest color differences, while the highest rating (3) for accuracy is shown by colors 16 and 18. Identical ratings for both displays are shown by colors 3, 4, and 8; the same applies to repeatability. No conspicuous features are observed. Color 17 shows the highest rating for both displays.

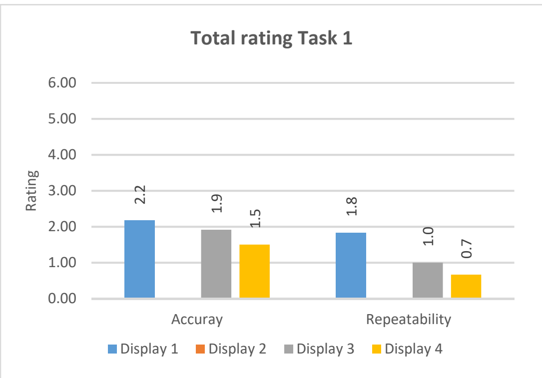
4.7.9.10 Participant ID 10

The participant with ID 10 is female and belongs to the age group 30–39 years. Limitations of the visual system are not known. The use of digital devices and applications in private and in a professional environment is reported. A small amount of study-related experience in digital media production is present, but this does not extend to working with digital color or color image editing.

Task 1	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	1.06	2.17	1.51	2.75	0.76	1.83
Display 2						
Display 3	0.72	1.92	0.92	1.83	0.46	1.00
Display 4	0.51	1.50	0.48	1.42	0.24	0.67

Task 2	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	2.52	3.50	2.99	3.67	1.49	2.50
Display 2						
Display 3	3.21	3.54	4.70	3.92	2.38	3.00
Display 4	1.26	2.63	1.63	2.83	0.82	1.88

Table 72. Total rating for Task 1 and Task 2 for each display used (participant ID 10).



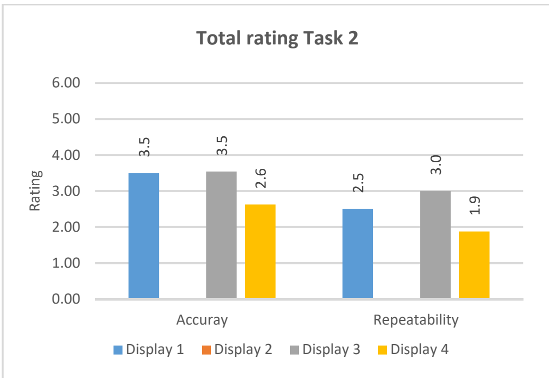


Figure 132. Visualization of total rating for Task 1 and Task 2 for each display used (participant ID 10).

Display 1 has the highest overall ratings of 2.2 for accuracy (mean ΔE_{00} = 1.06) and 1.8 for repeatability (mean ΔE_{00} = 0.76) in Task 1. The values for displays 3 and 4 are somewhat lower. However, the color matches achieved show a mean color difference that is perceptible to experienced observers. In Task 2, the accuracy rating for Display 1 increases to 3.5 (mean ΔE_{00} = 2.52) and for repeatability to 2.5 (mean ΔE_{00} = 1.49). Displays 3 and 4 also show increased overall ratings.

Display 1

	MCD → CC	
Task 1	ΔE_{00}	Rating
1	0.30	1
2	0.58	2
3	0.41	1
4	0.38	1
5	2.90	4
6	0.41	1
8	2.82	4
11	0.44	1
12	1.02	3
16	1.32	3
17	1.45	3
18	0.65	2
Mean	1.06	2.17

Display 2

	MCD → CC	
Task 1	ΔE_{00}	Rating
1		
2		
3		
4		
5		
6		
8		
11		
12		
16		
17		
18		
Mean		

Display 3

	MCD → CC	
Task 1	ΔE_{00}	Rating
1	0.22	1
2	0.45	1
3	0.60	2
4	0.19	0
5	2.08	4
6	0.60	2
8	1.08	3
11	0.25	1
12	0.24	1
16	0.50	2
17	1.39	3
18	1.05	3
Mean	0.72	1.92

Display 4

	MCD → CC	
Task 1	ΔE_{00}	Rating
1	0.84	2
2	0.78	2
3	0.58	2
4	0.22	1
5	0.80	2
6	0.57	2
8	0.50	2
11	0.14	0
12	0.32	1
16	0.46	1
17	0.56	2
18	0.39	1
Mean	0.51	1.50

Table 73. Overview of mean color differences and ratings obtained in Task 1 to evaluate the accuracy for each single color with the test displays used (participant ID 10).

The color matches for Display 1 are represented almost greenish in the spectral range purplish blue to yellow but more reddish in the colors near primary red. In this spectral range, the colors also show an increase in the blue color value. On the other hand, the colors in the spectral value ranges purplish blue and green to yellowish green are represented more yellowish. This also leads to a higher saturation, especially with several more saturated colors. This mostly decreases with the less saturated colors. The best match to the target color in Task 1 is shown by color 1, with a color difference of ΔE_{00} = 0.30 (rating 1) and good repeatability (rating 1). In total, five color matches are rated 1; with one exception, these are less saturated colors. Two color matches show a rating of 2, and three others show a rating of 3. The highest color difference (ΔE_{00} = 2.90; rating 4) can be seen in color 5. Color 8 also shows a similarly high perceptible color difference (rating 4). Both colors are in the spectral value range purplish blue. However, the evaluation of the repeatability is very different, with a tendency for the color matches (except color 5) to show a higher color difference to the target color with increasing saturation.

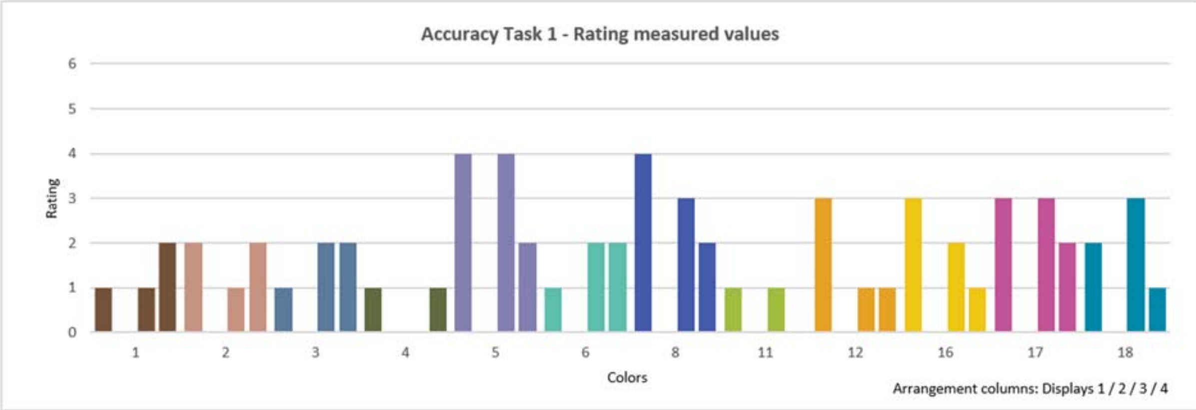


Figure 133. Visualization of ratings achieved by participant ID 10 in tasks for accuracy for all displays.

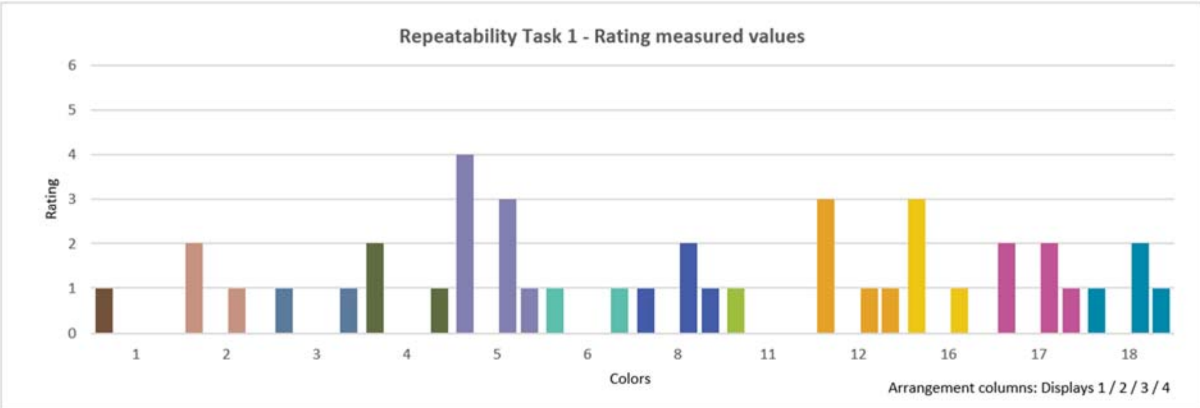


Figure 134. Visualization of ratings achieved by participant ID 10 in tasks for repeatability for all displays.

Display 3 tends to represent a more bluish color. The more saturated colors in the spectral value ranges yellowish green to yellowish orange and purplish pink are also represented more greenish, while the colors in the spectral range purplish blue to green are mostly represented more reddish. With the exception of color 8, all colors show a higher value for the luminance L*. The saturation, on the other hand, almost decreases. The best match to the target color in Task 1 is shown by color 4, with a color difference of ΔE_{00} = 0.19 (rating 0) and very good repeatability (rating 0). Four further color matches are rated as 1. Three color matches show a rating of 2, and another three show a rating of 3. The highest color difference (ΔE_{00} = 2.08) is seen in color 5 (rating 4), with a rating of 3 for repeatability. With the exception of color 16, all colors with more or less perceptible color differences to the target color are in the spectral range green blue to purplish pink. Again, except for color 5, these differences become higher with increasing saturation.

The color matches for Display 4 also show the tendency toward a more bluish representation. In addition, with the exception of the more saturated colors in the spectral range yellowish green to yellowish orange, the color matches are mostly represented more reddish. The more saturated colors in particular show a higher value for the luminance L*. The saturation mostly tends to decrease. Color 11 has the best match to the target color, with a color difference of $\Delta E_{00} = 0.14$ (rating 0) and very good repeatability (rating 0). Four other color matches receive a rating of 1; the remaining colors show color differences that are only perceptible to experienced observers. The highest color difference ($\Delta E_{00} = 2.84$) is seen in color 1 (rating 2). Except for color 4, the comparatively highest color differences are visible in the less saturated colors. The two most saturated colors (8 and 17) also receive a rating of 2 but only exceed the limit value $\Delta E_{00} = 0.5$ at most once. All the other more saturated colors have almost no perceptible color differences. The accuracy ratings are particularly high for color 5. Notably, all the more highly saturated colors also have higher color differences from the target color. By contrast, the best results are shown for colors 4 and 11, and the ratings for repeatability are similar. Typically, the colors with a higher color difference to the target color also show less repeatability. The best results come from colors 1, 3, 4, 6, and 11. Colors 5 and 8 have the highest rating (4) for Display 1.

4.7.9.11 Participant ID 11

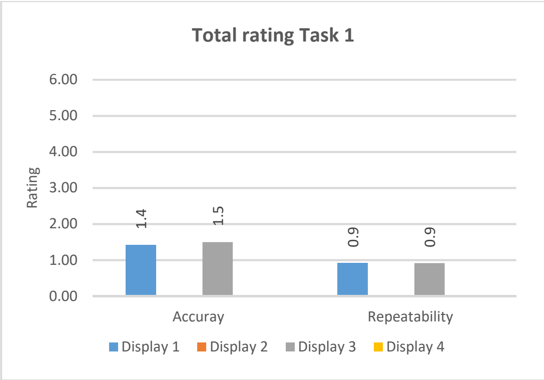
The participant with ID 11 is male and belongs to the age group 20–29 years. Limitations of the visual system are not known. The use of digital devices and applications is self-evident. Study-related experience in digital media production is present to a limited degree. However, this does not include working with digital color or color image editing.

Task 1	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	0.58	1.42	0.68	1.67	0.34	0.92
Display 2						
Display 3	0.53	1.50	0.58	1.58	0.29	0.92
Display 4						

Task 2	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	1.28	2.58	1.30	2.46	0.65	1.58
Display 2						
Display 3	1.40	2.79	1.67	2.96	0.83	2.04
Display 4						

Table 74. Total rating for Task 1 and Task 2 for each display used (participant ID 11).

Both displays indicate an almost identical overall rating for accuracy and repeatability. Display 1 shows the minimally better result for Task 1, with overall ratings of 1.4 for accuracy (mean $\Delta E_{00} = 0.58$) and 0.9 for repeatability (mean $\Delta E_{00} = 0.34$). The achieved match to the target colors shows almost imperceptible color differences with very good repeatability. In Task 2, the ratings for accuracy and repeatability increase for both displays, with Display 1 still showing slightly better results.



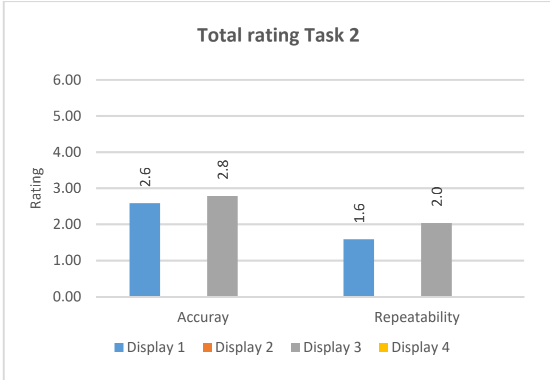


Figure 135. Visualization of total rating of Task 1 and Task 2 for each display used (participant ID 11).

Display 1

Task 1	MCD → CC ΔE_{00}	MCD → CC Rating
1	0.02	0
2	0.45	1
3	0.48	1
4	0.09	0
5	0.62	2
6	0.49	1
8	0.84	2
11	0.37	1
12	0.23	1
16	2.24	4
17	0.60	2
18	0.58	2
Mean	0.58	1.42

Display 2

Task 1	MCD → CC ΔE_{00}	MCD → CC Rating
1		
2		
3		
4		
5		
6		
8		
11		
12		
16		
17		
18		
Mean		

Display 3

Task 1	MCD → CC ΔE_{00}	MCD → CC Rating
1	0.64	2
2	0.69	2
3	0.55	2
4	0.18	0
5	0.50	2
6	0.81	2
8	0.91	2
11	0.38	1
12	0.49	1
16	0.25	1
17	0.44	1
18	0.58	2
Mean	0.53	1.50

Display 4

Task 1	MCD → CC ΔE_{00}	MCD → CC Rating
1		
2		
3		
4		
5		
6		
8		
11		
12		
16		
17		
18		
Mean		

Table 75. Overview of mean color differences and ratings obtained in Task 1 to evaluate the accuracy for each single color with the test displays used (participant ID 11).

An examination of the color matches for Display 1 shows a more reddish and yellowish representation of the colors in the spectral range green to yellowish green in Task 1. A greenish representation of the color matches can be seen, especially in the more saturated colors of the spectral range blue green to purplish blue and yellow to yellowish orange. It can also be seen that, with a few exceptions, the value for the luminance L* increases. An increase in saturation is seen for several of the more saturated colors. The best match of the color difference to the target color in Task 1 comes from color 1 with a color difference of $\Delta E_{00} = 0.02$ (rating 0) and very good repeatability (rating 0). The result for color 4 is similarly good. Five other color matches receive a rating of 1 (almost no perceptible color differences). It should be noted that the smallest color differences are mainly found in the less saturated colors. Four color matches receive a rating of 2 (color difference perceptible to experienced observers). These are found in the spectral range blue green to purplish pink. The largest color difference ($\Delta E_{00} = 2.24$) can be seen in color 16 and is surprisingly high as a perceptible color difference by comparison.

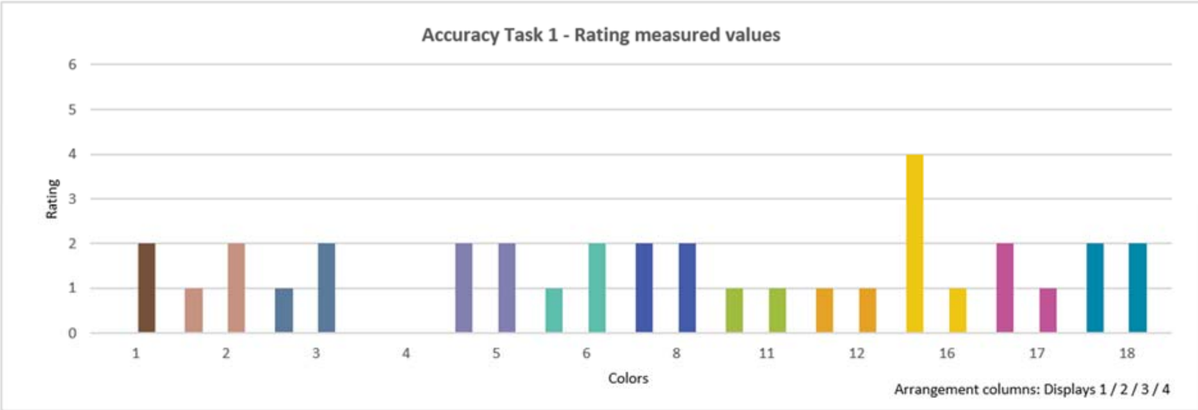


Figure 136. Visualization of ratings achieved by participant ID 11 in tasks for accuracy for all displays.

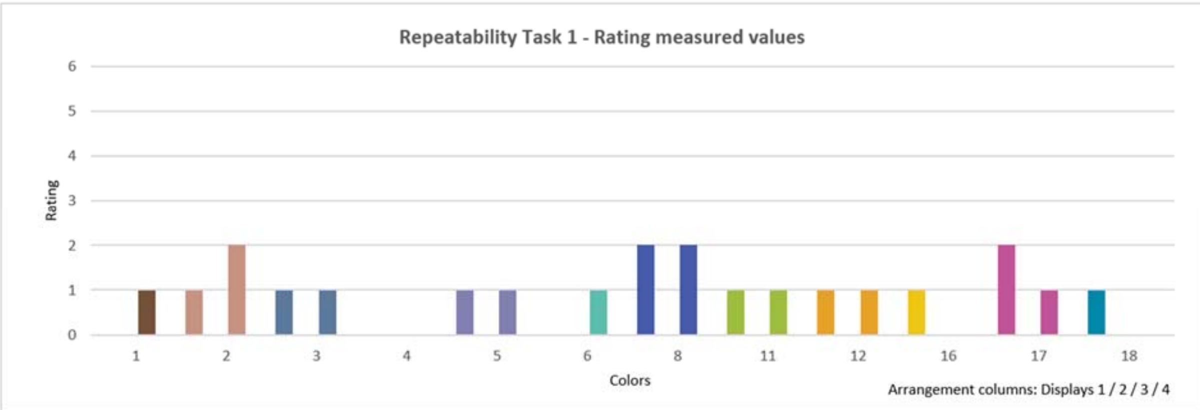


Figure 137. Visualization of ratings achieved by participant ID 11 in tasks for repeatability for all displays.

The color matches for Display 3 show that the colors in the spectral range blue green to purplish pink are represented more yellowish and also, with the exception of color 18, more greenish. In the spectral range green to orange, the color matches show a more bluish representation. The value for the luminance L* is higher in all colors, while the saturation decreases (except color 16). Color 4 has the best match to the target color in Task 1, with a color difference of $\Delta E_{00} = 0.18$ (rating 0) and good repeatability (rating 1). Four other more saturated color matches also receive a rating of 1 (almost imperceptible color differences to the target color). The remaining colors are rated 2 (color difference perceptible to experienced observers). With the exception of color 4, this includes all the less saturated colors. However, the highest color difference (ΔE_{00} = 0.91) is seen in color 8, the color with the strongest saturation. All colors in the spectral range blue green to purplish blue show a rating of 2.

The ratings for accuracy show stable results. The lowest color differences to the target color are found in colors 4, 11, and 12, which show an identical rating for both displays, as do colors 5, 8, and 18. The highest rating of 4 for color 16 is remarkable and does not fit into the overall display. The ratings for repeatability also show stable results. The most saturated color (8) has the highest rating of 2 for both displays.

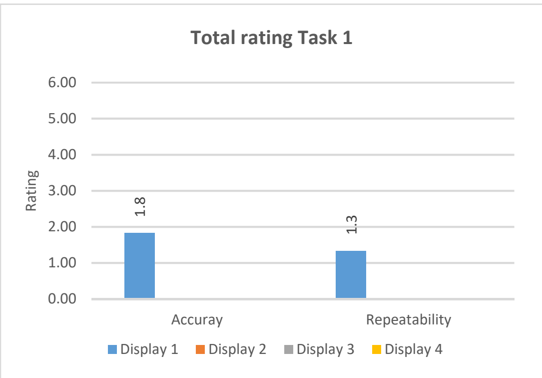
4.7.9.12 Participant ID 12

The participant with ID 12 is male and belongs to the age group 30–39 years. Limitations of the visual system of vision are not known. Working with digital devices and applications is a matter of course, especially at work. The experience with digital color and applications in the area of color grading and color image editing is correspondingly high due to the level of professional activity.

Task 1	Accuray		MR1 → MR 2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	0.67	1.83	0.92	2.33	0.46	1.33
Display 2						
Display 3						
Display 4						

Task 2	Accuray		MR1 → MR 2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	1.23	2.54	1.71	2.83	0.85	1.96
Display 2						
Display 3						
Display 4						

Table 76. Total rating for Task 1 and Task 2 for each display used (participant ID 12).



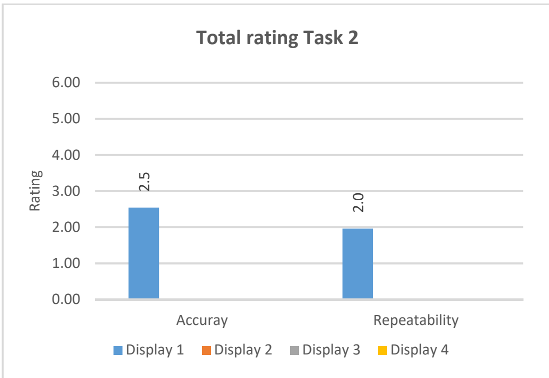


Figure 138. Visualization of total rating for Task 1 and Task 2 for each display used (participant ID 12).

In Task 1, the overall ratings of 1.8 for accuracy (mean ΔE_{00} = 0.67) and 1.3 for repeatability (mean ΔE_{00} = 0.46) indicate that, on average, the color matches achieved show a color difference that is perceptible to experienced observers, with good repeatability of the results. In

Task 2, the rating for accuracy increases to 2.5 (mean ΔE_{00} = 1.23) and for repeatability to 2.0 (mean ΔE_{00} = 0.85).

Display 1

	MCD → CC	
Task 1	ΔE_{00}	Rating
1	0.32	1
2	0.38	1
3	0.65	2
4	0.69	2
5	0.38	1
6	0.63	2
8	1.24	3
11	0.24	1
12	0.87	2
16	0.57	2
17	1.17	3
18	0.84	2
Mean	0.67	1.83

Display 2

	MCD → CC	
Task 1	ΔE_{00}	Rating
1		
2		
3		
4		
5		
6		
8		
11		
12		
16		
17		
18		
Mean		

Display 3

	MCD → CC	
Task 1	ΔE_{00}	Rating
1		
2		
3		
4		
5		
6		
8		
11		
12		
16		
17		
18		
Mean		

Display 4

	MCD → CC	
Task 1	ΔE_{00}	Rating
1		
2		
3		
4		
5		
6		
8		
11		
12		
16		
17		
18		
Mean		

Table 77. Overview of mean color differences and ratings obtained in Task 1 to evaluate the accuracy for each single color with the test displays used (participant ID 12).

The results obtained in Task 1 show a more mixed result. The colors in the spectral ranges purplish blue to purplish pink as well as yellowish orange show a more reddish representation. In addition, with the exception of colors 11 and 12, a more bluish representation can be observed. The luminance L* increases only in the spectral ranges blue green to yellow green. An increase in saturation can be seen above all for the colors that are already more saturated.

Eight color matches earn a rating of 2 or 3. The best result, with the smallest color difference of ΔE_{00} = 0.24 (rating 1), is obtained for color 11. Three other less saturated colors show a rating of 1, while six colors show a rating of 2 for a color difference perceptible to experienced observers. The two most saturated colors, 8 and 17, have a rating of 3. Color 8, as the most saturated color, shows the highest color difference (ΔE_{00} = 1.24) from the target color. High differences are also evident in repeatability. The results for color 8 show an imperceptible difference (rating 0), while the results for color 17 show a difference perceptible to experienced observers. It can be noted that the highest color differences from the target color are in the saturated colors in the spectral ranges blue green to purplish pink as well as yellowish orange, which are represented in a higher saturation.

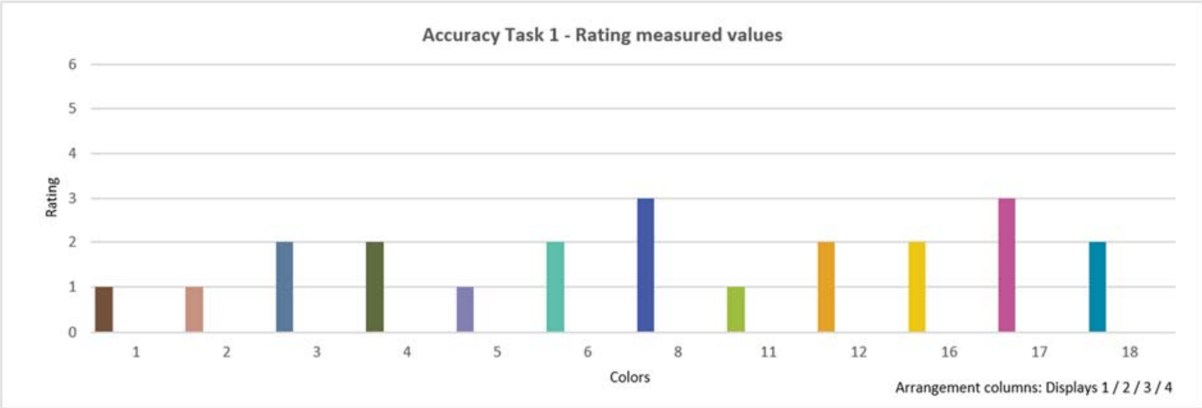


Figure 139. Visualization of ratings achieved by participant ID 12 in tasks for accuracy for all displays.

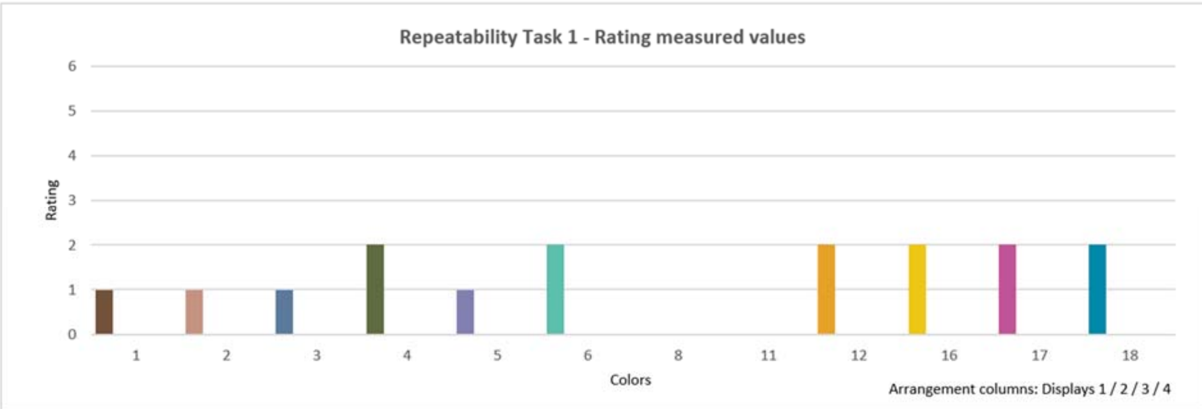


Figure 140. Visualization of ratings achieved by participant ID 12 in tasks for repeatability for all displays.

4.7.9.13 Participant ID 15

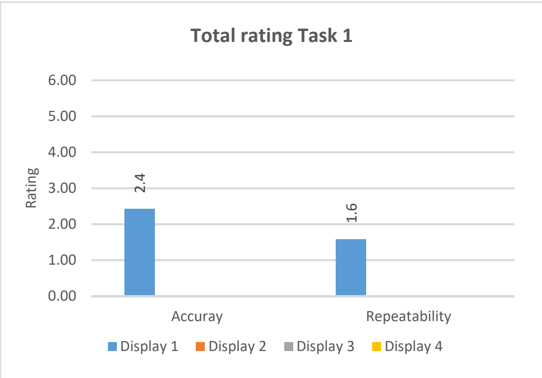
The participant with ID 15 is male and belongs to the age group 30–39 years. Limitations of the visual system are not known. He uses digital devices and applications both privately and professionally. However, experience in the field of digital media production and, in particular, color image editing is non-existent.

Task 1	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	1.03	2.42	1.34	2.42	0.67	1.58
Display 2						
Display 3						
Display 4						

Task 2	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	2.25	3.29	2.40	3.33	1.19	2.38
Display 2						
Display 3						
Display 4						

Table 78. Total rating for Task 1 and Task 2 for each display used (participant ID 15).

The overall ratings of 2.4 for accuracy (mean ΔE_{00} = 1.03) and 1.6 for repeatability (mean ΔE_{00} = 0.67) in Task 1 mean that the achieved color matches have, on average, a color difference perceptible to experienced observers, with poorer repeatability of the results. In Task 2, the rating for accuracy increases to 3.3 (mean ΔE_{00} = 2.25) and for repeatability to 2.4 (mean ΔE_{00} = 1.19).



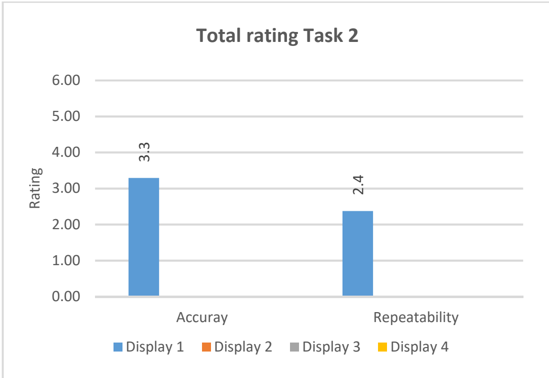


Figure 141. Visualization of total rating for Task 1 and Task 2 for each display used (participant ID 15).

Display 1

		MCD → CC	
Task 1		ΔE_{00}	Rating
	1	0.42	1
	2	0.71	2
	3	1.52	3
	4	1.07	3
	5	1.35	3
	6	0.54	2
	8	1.90	3
	11	0.59	2
	12	1.24	3
	16	1.30	3
	17	0.94	2
	18	0.83	2
Mean		1.03	2.42

Display 2

		MCD → CC	
Task 1		ΔE_{00}	Rating
	1		
	2		
	3		
	4		
	5		
	6		
	8		
	11		
	12		
	16		
	17		
	18		
Mean			

Display 3

		MCD → CC	
Task 1		ΔE_{00}	Rating
	1		
	2		
	3		
	4		
	5		
	6		
	8		
	11		
	12		
	16		
	17		
	18		
Mean			

Display 4

		MCD → CC	
Task 1		ΔE_{00}	Rating
	1		
	2		
	3		
	4		
	5		
	6		
	8		
	11		
	12		
	16		
	17		
	18		
Mean			

Table 79. Overview of mean color differences and ratings obtained in Task 1 to evaluate the accuracy for each single color with the test displays used (participant ID 15).

The color matches obtained by the participant in Task 1 show a reduced red color value in the more saturated colors and are mostly represented more greenish. By contrast, the six less saturated colors closer to the white point have a more reddish representation. At the same time, the blue color value is usually reduced here; this mostly leads to a higher saturation being registered. The more saturated colors, on the other hand, are usually represented more bluish. Exceptions are the colors 8 and 11 close to the display primaries blue and green, respectively.

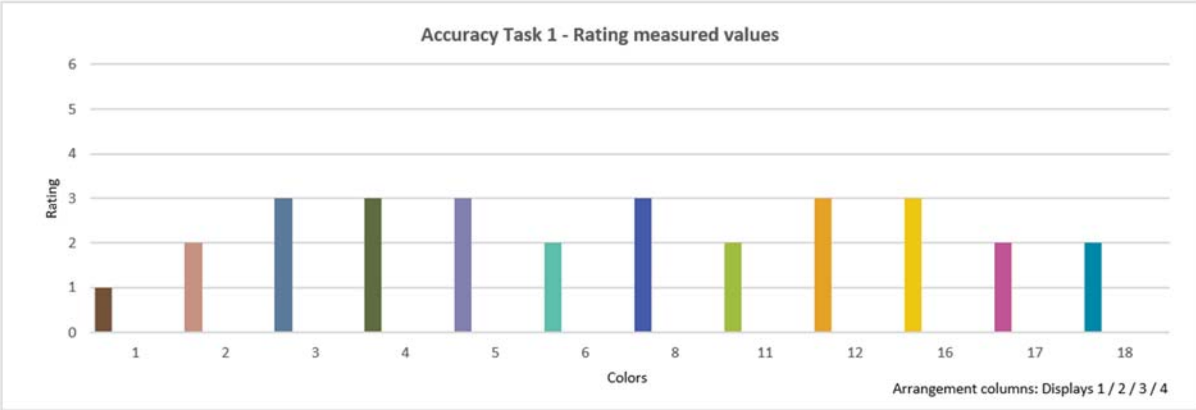


Figure 142. Visualization of ratings achieved by participant ID 15 in tasks for accuracy for all displays.

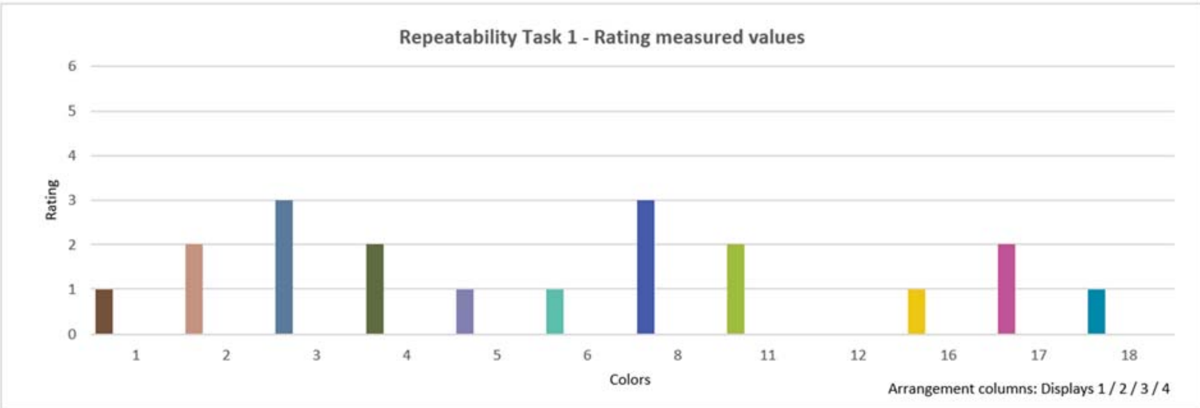


Figure 143. Visualization of ratings achieved by participant ID 15 in tasks for repeatability for all displays.

The overall rating of 2.4 already indicates that more or less perceptible differences can be found for most color matches. Color 1 shows the most exact match to the target color, with a rating of 1 (mean $\Delta E_{00} = 0.42$). Five other colors show a rating of 2, and six colors show a rating of 3. The highest perceptible color difference ($\Delta E_{00} = 1.90$; rating 3) is shown by the most saturated color (8). In the spectral range green blue to purplish blue, the highest color differences are seen, followed by the spectral range yellow orange and yellow. Also noticeable is the rating of 3 for repeatability in colors 3 and 8, which show the highest color differences from the target color. Looking at MR1 and MR2 individually reveals a better overall result for MR2, but while a much better result is achieved for color 3, the result for color 8 is significantly poorer.

4.7.9.14 Participant ID 16

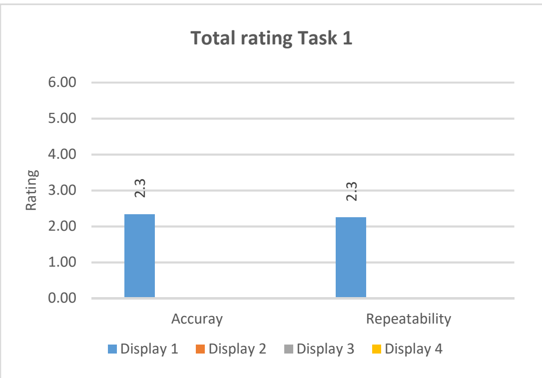
The participant with ID 16 is male and belongs to the age group 40–49 years. He wears glasses (myopia), and no other limitations of the visual system are known. The use of digital devices and applications is a matter of course, both privately and professionally. Professional experience in the field of media production is available. The handling of digital color and color image editing is limited to the pastime of photography.

In Task 1, the participant achieves overall ratings of 2.3 for accuracy (mean $\Delta E_{00} = 1.20$) and 2.3 for repeatability (mean $\Delta E_{00} = 1.03$). The color matches show a difference from the target colors that is perceptible to experienced observers, with less repeatability of the results. In Task 2, the rating for accuracy increases to 3.2 (mean $\Delta E_{00} = 1.88$), whereas the rating for repeatability improves to 1.9 (mean $\Delta E_{00} = 1.07$).

Task 1	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	1.20	2.33	2.07	3.25	1.03	2.25
Display 2						
Display 3						
Display 4						

Task 2	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	1.88	3.13	2.14	2.96	1.07	1.92
Display 2						
Display 3						
Display 4						

Table 80. Total rating for Task 1 and Task 2 for each display used (participant ID 16).



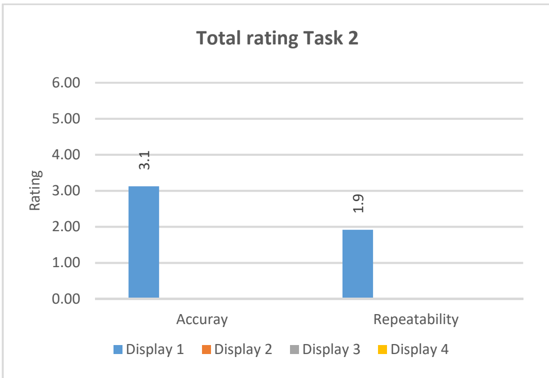


Figure 144. Visualization of total rating of Task 1 and Task 2 for each display used (participant ID 16).

The results obtained in Task 1 show a mixed result. For the most part, the color matches show higher luminance L* and higher saturation. The more saturated colors in the spectral range blue green to yellowish orange are represented more reddish with a higher saturation. By contrast, the two colors with the highest saturation (8 and 17) show a reduced red color value and are therefore also represented with a lower saturation. It is also noticeable that the less saturated colors show a reduced blue color value and are represented more yellowish.

	Display 1		Display 2		Display 3		Display 4	
	MCD → CC		MCD → CC		MCD → CC		MCD → CC	
Task 1	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
1	0.38	1						
2	0.70	2						
3	1.74	3						
4	0.73	2						
5	0.41	1						
6	0.72	2						
8	1.83	3						
11	0.38	1						
12	3.35	4						
16	1.58	3						
17	1.16	3						
18	1.44	3						
Mean	1.20	2.33						

Table 81. Overview of mean color differences and ratings obtained in Task 1 to evaluate the accuracy for each single color with the test displays used (participant ID 16).

The overall rating of 2.3 already suggests that more or less perceptible differences can be found for most color matches. Only three colors receive a rating of 1 for almost imperceptible differences. The less saturated colors 2, 4, and 6 show differences that are perceptible to experienced observers. The highest color differences are mainly found in the most saturated colors. Colors 3, 8, 16, 17, and 18 show small perceptible color differences (rating 3). Repeatability also shows a rating of 3. However, the results from MR1 and MR2 differ more clearly from each other. Color 12 shows the highest perceptible color difference: $\Delta E_{00} = 3.35$ (rating 4). The individual examination of MR1 and MR2 shows a better overall result for MR1, but the quality of the individual results varies strongly between the two runs.

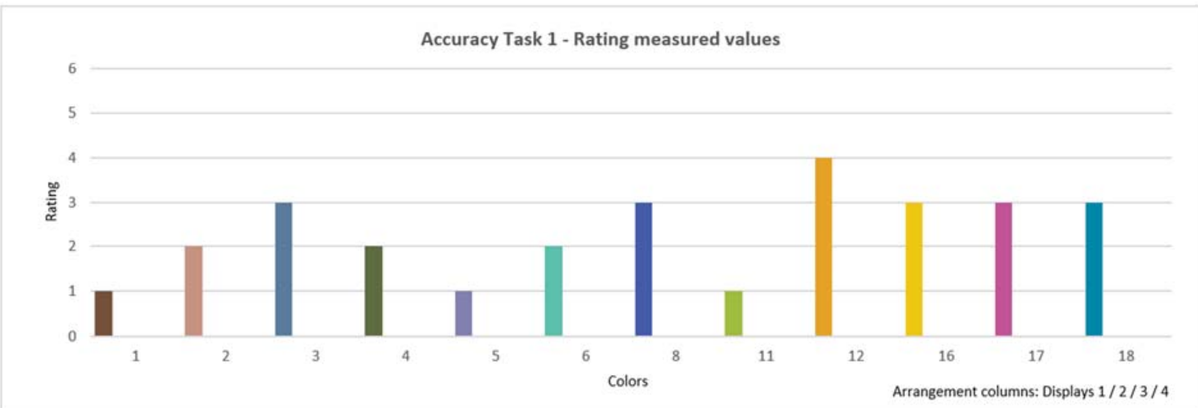


Figure 145. Visualization of ratings achieved by participant ID 16 in tasks for accuracy for all displays.

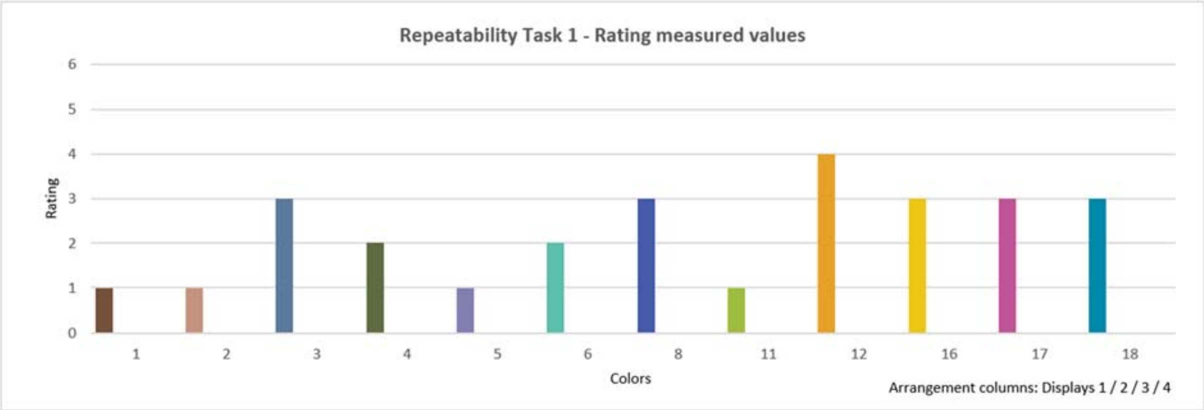


Figure 146. Visualization of ratings achieved by participant ID 16 in tasks for repeatability for all displays.

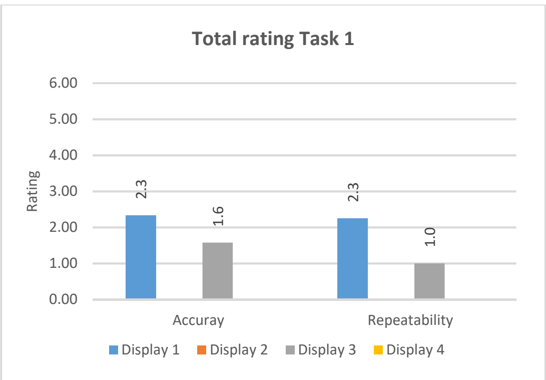
4.7.9.15 Participant ID 17

The participant with ID 17 is male and belongs to the age group 50–59 years. He is a wearer of glasses (farsightedness), and no other limitations of the visual system are known. The use of digital devices is reported in both private and professional environments. Experience in the field of digital media production has already been gained. However, this relates almost exclusively to the use and handling of various digital recording devices.

Task 1	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	1.20	2.33	2.07	3.25	1.03	2.25
Display 2						
Display 3	0.49	1.58	0.71	1.83	0.36	1.00
Display 4						

Task 2	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	1.88	3.13	2.14	2.96	1.07	1.92
Display 2						
Display 3	0.83	2.13	1.03	2.17	0.51	1.33
Display 4						

Table 82. Total rating for Task 1 and Task 2 for each display used (participant ID 17).



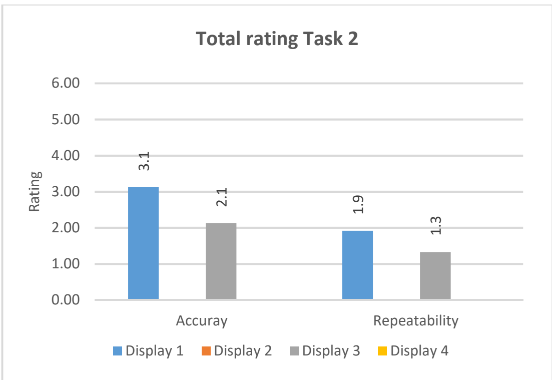


Figure 147. Visualization of total rating for Task 1 and Task 2 for each display used (participant ID 17).

Display 1 shows a significantly poorer result compared to Display 3. The overall ratings of 2.3 for accuracy (mean $\Delta E_{00} = 1.20$) and 2.3 for repeatability (mean $\Delta E_{00} = 1.03$) in Task 1 mean that the achieved color matches show, on average, a color difference that is perceptible to experienced observers. The repeatability is less good. This is contrasted with an overall rating of 1.6 for accuracy (mean $\Delta E_{00} = 0.49$) with better repeatability for Display 3. In Task 2, the overall rating for both displays increases significantly. Again, Display 3 shows the better result, with overall ratings of 2.1 (mean $\Delta E_{00} = 0.83$) for accuracy and 1.3 (mean $\Delta E_{00} = 0.51$) for repeatability.

	Display 1		Display 2		Display 3		Display 4	
	MCD → CC		MCD → CC		MCD → CC		MCD → CC	
Task 1	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
1	0.38	1			0.54	2		
2	0.70	2			0.36	1		
3	1.74	3			0.64	2		
4	0.73	2			0.27	1		
5	0.41	1			0.48	1		
6	0.72	2			0.54	2		
8	1.83	3			0.64	2		
11	0.38	1			0.20	1		
12	3.35	4			0.56	2		
16	1.58	3			0.36	1		
17	1.16	3			1.04	3		
18	1.44	3			0.31	1		
Mean	1.20	2.33			0.49	1.58		

Table 83. Overview of mean color differences and ratings obtained in Task 1 to evaluate the accuracy for each single color with the test displays used (participant ID 17).

The color matches obtained in Task 1 show a more bluish representation, with the exception of colors 11 and 12. Colors 5, 8, and 17 in the purplish blue to purplish pink spectral range and colors 1 and 12 in the orange to yellowish orange spectral range also show a higher red color value, while the other colors tend to be greenish. As a result, the more saturated colors in particular are represented with an even higher saturation. Only three colors have a rating of 1 for almost imperceptible color differences from the target color. The closest match to the target color is shown by color 1, with a color difference $\Delta E_{00} = 0.38$. Three other colors receive a rating of 2; five colors receive a rating of 3. The highest perceptible color difference ($\Delta E_{00} = 3.35$; rating 4) is shown for color 12. The highest differences from the target color are found in the spectral ranges yellowish orange and orange as well as in the spectral range green blue to purplish pink. Except for color 3, this mainly affects the more saturated colors. The poor repeatability rating in these colors is noticeable. The individual analysis of MR1 and MR2 shows a clearly better overall result for MR2. Only colors 8 and 13 show a poorer result here.

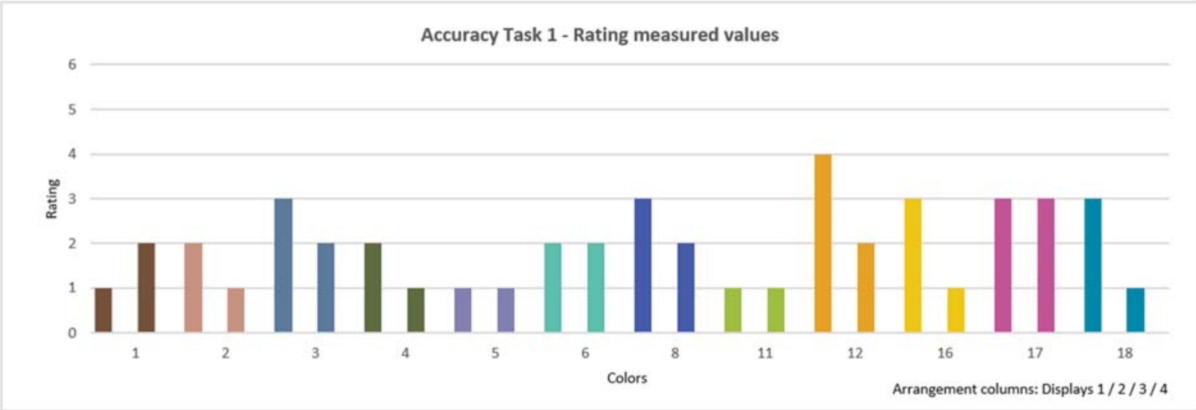


Figure 148. Visualization of ratings achieved by participant ID 17 in tasks for accuracy for all displays.

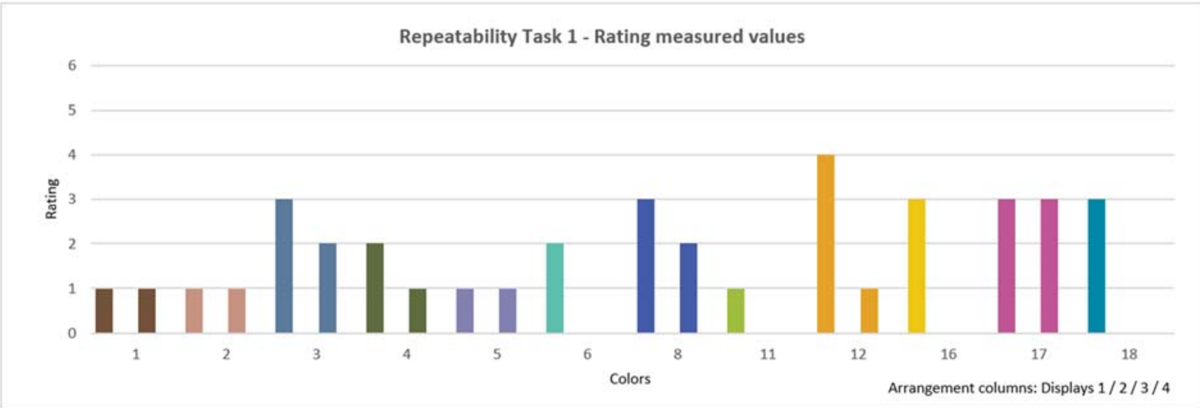


Figure 149. Visualization of ratings achieved by participant ID 17 in tasks for repeatability for all displays.

The color matches obtained by the participant for Display 3 show that the colors in the spectral ranges yellowish green to orange and purplish pink have a lower color value red and are therefore represented more greenish. In contrast, the colors in the spectral range green to purplish blue are represented more reddish. The saturated colors in the spectral range yellowish orange to yellow and various less saturated colors have a more bluish representation. The luminance L* increases up to color 12, but the saturation is mostly lower. The evaluation of the accuracy of the color matches achieved shows a rating of 1 for six colors. The most accurate color match comes from color 11 (mean $\Delta E_{00} = 0.20$). Repeatability is excellent. Five colors show a perceptible difference to trained observers (rating 2). The largest color difference (ΔE_{00}

= 1.04; rating 3) is seen in color 17, followed by color 8. Thus, the two most saturated colors show the largest color differences from the target color. The rating of 3 for the repeatability of color 17 indicates a greater color difference between the two results obtained.
Comparison of the ratings obtained for accuracy shows mixed results. Colors 5 and 11 have the lowest color differences from the target color and show an identical rating for both displays, as do colors 6 and 18. The highest rating of 4 for color 12 is noteworthy. It can be seen that the more saturated colors mostly have higher color differences from the target color. The ratings for repeatability show higher differences; the results for Display 2 show significantly better repeatability in comparison. Analogous to the accuracy, the more saturated colors also show a higher rating here.

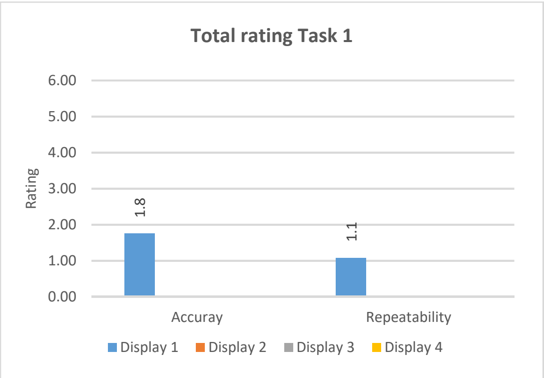
4.7.9.16 Participant ID 18

The participant with ID 18 is male and belongs to the age group 40–49 years. He is a wearer of glasses (myopia), and no other limitations of the visual system are known. The use of digital devices and applications is self-evident. Experience in digital media production is limited to web and app development. The use of digital color and color image editing programs is limited to a pastime level.

Task 1	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	0.64	1.75	0.85	2.08	0.43	1.08
Display 2						
Display 3						
Display 4						

Task 2	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	1.59	2.88	2.23	3.04	1.11	2.08
Display 2						
Display 3						
Display 4						

Table 84. Total rating for Task 1 and Task 2 for each display used (participant ID 18).



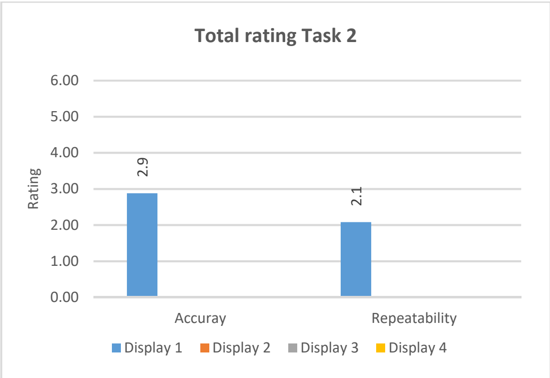


Figure 150. Visualization of total rating for Task 1 and Task 2 for each display used (participant ID 18).

In Task 1, the overall ratings of 1.8 for accuracy (mean ΔE_{00} = 0.64) and 1.1 for repeatability with a mean color difference (mean ΔE_{00} = 0.43) imply that the achieved color matches have color differences that are perceptible to experienced observers, with a good repeatability of the results. In Task 2, the rating for accuracy increases to 2.9 (mean ΔE_{00} = 1.59) and for repeatability to 2.1 (mean ΔE_{00} = 1.11).

The color matches obtained by the participant in Task 1 mostly show a higher red color value compared to the target color. In addition, except for color 11, all colors are represented more bluish. The luminance L* decreases as a result, with a few exceptions. A higher saturation can be seen, especially in the already more saturated colors.

Display 1

Task 1	MCD → CC	
	ΔE_{00}	Rating
1	0.30	1
2	0.27	1
3	0.56	2
4	0.58	2
5	0.41	1
6	0.74	2
8	1.18	3
11	0.27	1
12	0.94	2
16	0.43	1
17	1.19	3
18	0.85	2
Mean	0.64	1.75

Display 2

Task 1	MCD → CC	
	ΔE_{00}	Rating
1		
2		
3		
4		
5		
6		
8		
11		
12		
16		
17		
18		
Mean		

Display 3

Task 1	MCD → CC	
	ΔE_{00}	Rating
1		
2		
3		
4		
5		
6		
8		
11		
12		
16		
17		
18		
Mean		

Display 4

Task 1	MCD → CC	
	ΔE_{00}	Rating
1		
2		
3		
4		
5		
6		
8		
11		
12		
16		
17		
18		
Mean		

Table 85. Overview of mean color differences and ratings obtained in Task 1 to evaluate the accuracy for each single color with the test displays used (participant ID 18).

First, it should be noted that no color match achieved a rating of 0. Four colors achieved a rating of 1. The closest match to the target color is shown by color 11 (mean ΔE_{00} = 0.27). Repeatability is good. Six colors show a perceptible difference to experienced observers (rating 2), while a small perceptible difference from the target color (rating 3) is shown by the two most saturated colors 8 (mean ΔE_{00} = 1.18) and 17 (mean ΔE_{00} = 1.19). Both are represented more reddish and bluish, resulting in an even higher saturation of the color representation. However, a clear difference can be seen in the repeatability. The two results for color 8 hardly differ, a small perceptible color difference (ΔE_{00} = 1.83) is shown between the results for color 17. The same is also true for colors 4, 6, 12, and 18, which results in a rating of 2 for repeatability for all these colors. If the results MR1 and MR2 are considered separately, MR2 clearly shows a better overall result.

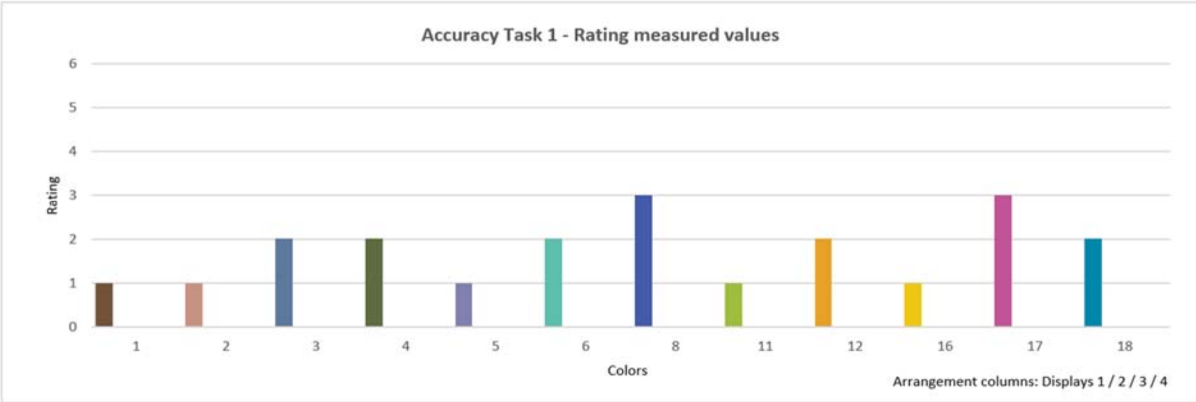


Figure 151. Visualization of ratings achieved by participant ID 18 in tasks for accuracy for all displays.

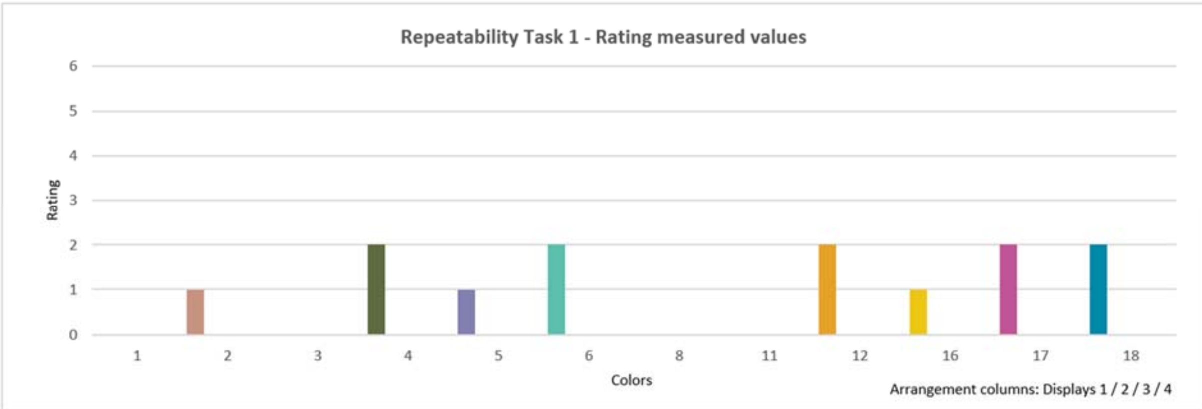


Figure 152. Visualization of ratings achieved by participant ID 18 in tasks for repeatability for all displays.

4.7.9.17 Participant ID 20

The participant with ID 20 is female and belongs to the age group 60–69 years. She wears glasses (nearsightedness). She is an experienced and savvy user of digital devices and applications. She has a high level of experience in various areas of digital media production. Working with digital color and color image editing applications comes naturally to her.

The overall ratings of 1.3 for accuracy (mean $\Delta E_{00} = 0.48$) and 1.1 for repeatability (mean $\Delta E_{00} = 0.31$) in Task 1 represent a very good result. The color differences detected are almost imperceptible. In Task 2, the rating for accuracy increases to 2.3 (mean $\Delta E_{00} = 1.01$) and for repeatability to 1.6 (mean $\Delta E_{00} = 0.60$).

Task 1	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	0.48	1.33	0.63	1.67	0.31	1.08
Display 2						
Display 3						
Display 4						

Task 2	Accuray		MR1 → MR2		Repeatability	
Measured values	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
Display 1	1.01	2.29	1.21	2.63	0.60	1.67
Display 2						
Display 3						
Display 4						

Table 86. Total rating for Task 1 and Task 2 for each display used (participant ID 20).

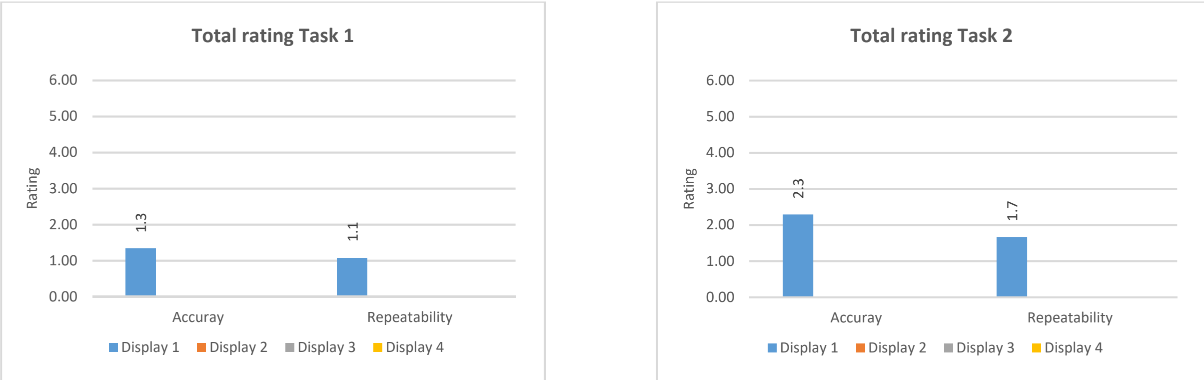


Figure 153. Visualization of total rating for Task 1 and Task 2 for each display used (participant ID 20).

Display 1

Task 1	MCD → CC ΔE_{00}	MCD → CC Rating
1	0.02	0
2	0.75	2
3	0.45	1
4	0.39	1
5	0.91	2
6	0.72	2
8	0.38	1
11	0.28	1
12	0.59	2
16	0.25	1
17	0.61	2
18	0.36	1
Mean	0.48	1.33

Display 2

Task 1	MCD → CC ΔE_{00}	MCD → CC Rating
1		
2		
3		
4		
5		
6		
8		
11		
12		
16		
17		
18		
Mean		

Display 3

Task 1	MCD → CC ΔE_{00}	MCD → CC Rating
1		
2		
3		
4		
5		
6		
8		
11		
12		
16		
17		
18		
Mean		

Display 4

Task 1	MCD → CC ΔE_{00}	MCD → CC Rating
1		
2		
3		
4		
5		
6		
8		
11		
12		
16		
17		
18		
Mean		

Table 87. Overview of mean color differences and ratings obtained in Task 1 to evaluate the accuracy for each single color with the test displays used (participant ID 20).

An examination of the color matches obtained shows mostly a reduced red color value compared to the target color and thus a greenish representation. In the spectral range blue to blue-green, on the other hand, a more reddish representation can be seen. The blue color value proportion decreases, especially in the less saturated colors near the white point. The colors are mostly represented more yellowish, which also leads to an increase in both luminance L* and saturation. The colors with a higher saturation are mostly displayed bluer. Exceptions are colors 8 and 11, which are closest to primary blue and primary green, respectively.

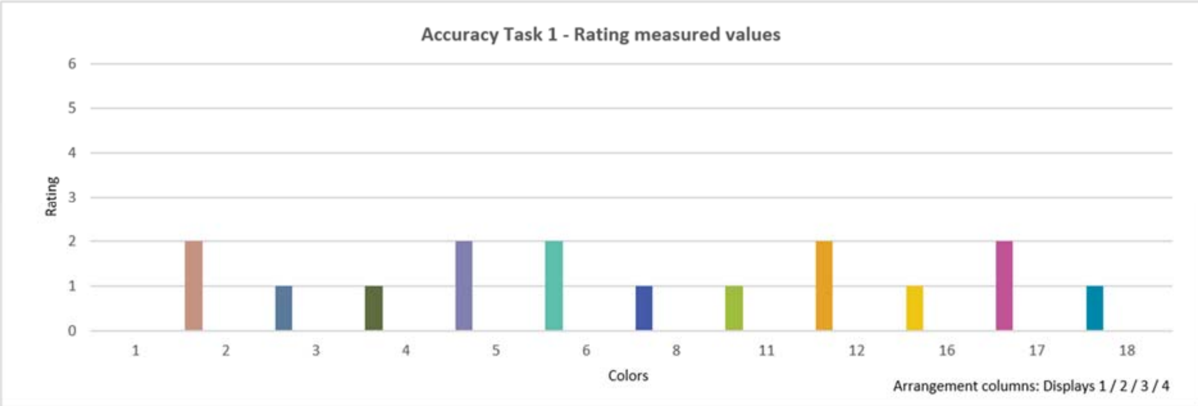


Figure 154. Visualization of ratings achieved by participant ID 20 in tasks for accuracy for all displays.

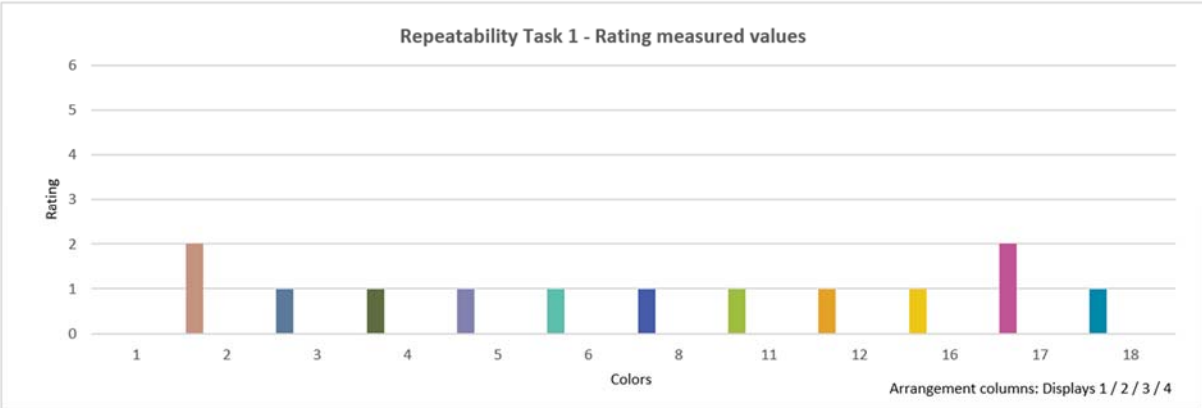


Figure 155. Visualization of ratings achieved by participant ID 20 in tasks for repeatability for all displays.

Color 1 (rating 0) has the best match to the target color with very good repeatability (rating 0). Six other color matches receive a rating of 1 for almost imperceptible color differences. The remaining five color matches performed receive a rating of 2 (color difference perceptible to experienced observers). The highest color difference ($\Delta E_{00} = 0.91$) is seen in color 5, followed by colors 2 and 6. Here, the blue color value is reduced and the saturation thus increases. The saturated colors 12 and 17 are represented more reddish and bluish. The color difference to the target color is no longer quite so high here, but it still exceeds the limit value $\Delta E_{00} = 0.5$. It is noticeable that the results from MR1 and MR2 for colors 2 and 12 show small perceptible color differences, which is reflected in a rating of 2 for repeatability.

5 Conclusion

In modern digital media production, displays are the most important interfaces between digital information and human perception. For this reason, the quality and accuracy of color representation is of great importance. Color representation is strongly influenced by the technical specifications and performance of the various display technologies available. By using color management, these differences can be taken into account in media production, making it possible to ensure a high degree of consistency in the color representation of identical digital content on different displays.

The results of this study show that the native representable color gamuts of the large number of available displays can differ greatly. To achieve the goal of high color consistency that is independent of the output device, standard color spaces have been defined based on the technical possibilities of the displays currently on the market. Moreover, the needs of users and the applications they use have also been considered in the standardization process. With the assistance of a color management system, the native color gamut of the display used is adapted to the specifications of these standard color spaces. In the course of technical development, the image capture technologies, displays, standards, and the digital content have evolved together over time, and the demands and expectations of the various areas of media production are reflected in these defined standard color spaces. Therefore, on the one hand, they are a reflection of the performance of the current technologies used; on the other hand, they also represent expectation and thus also become drivers of consistent further development. This is particularly true in the area of display technologies.

The sRGB standard color space remains the most commonly used, not least due to its implementation in the Windows operating system. Today, it is broadly covered by the multitude of different displays and is therefore mainly used in the production of online content. AdobeRGB, on the other hand, was developed as a standard for print media production and is used primarily in professional image editing programs. Representing this color gamut still poses a challenge, but more and more displays on the market are achieving almost complete coverage. In the field of video and film production, however, the requirements are increasing. Here, the technical advancement of display technologies toward large wide gamut displays and 4K UHD television is particularly noticeable. However, the current standard color space DCI-P3 is only considered an intermediate step in coverage. With the BT.2020/Rec.2020 standard, the next generation of standard color spaces has already been defined. This clearly shows how high the expectations are for future displays, which at the same time also entails a great leap of faith in technical development. Conversely, this constant further development also brings challenges. Due to the ever higher quantity of representable colors and the constantly improving quality of reproduction, the individual perception of the user plays an increasingly important role and must be taken into account. This is dependent on a variety of physiological and psychological influences and can vary greatly from user to user.

The quality of color representation of a display has a significant influence on the individual color perception of an observer. With the help of the presented research, the relationship between individual visual color perception and the real reproduced colorimetric values of the used displays is analyzed. In the selection of displays, the focus was deliberately placed on quantum dot (QD)-enhanced LCDs. These devices produce highly saturated primary colors and wide color gamuts with excellent color reproducibility. The colorimetric studies were performed in three discrete sequential steps. Step 1 is a comparison of the performance of four current measuring devices that are widely used in the media industry in particular. On the basis of the data obtained, a decision was made as to which measuring device would be used for the calibration and profiling of the test displays employed as part of the planned investigations. This is an essential component of experimental methods in image processing and is therefore of crucial importance to the study overall.

The four selected measuring devices are all-in-one devices designed for simple functionality and operation. The open-source software DisplayCal was used to perform the measurement processes, as the available user programs of the respective manufacturers do not allow a qualitative comparison of the measurement results. Likewise, the measurement geometries used are distinctive, which may also apply to the transformations used for profile generation. DisplayCal, on the other hand, offers comprehensive options for specifically adapting the calibration and profiling process to individual requirements. The use of all measuring devices with the same user software as well as importable device-related manufacturer information allows the best possible comparison of the results obtained.

The performance comparison was carried out with Display 1 as a reference. For the measurements to be performed, this display was set to a defined reproducible state using a display profile created using the chosen display calibration device. A test form with 30 test patches was used to obtain the data required for the analysis. In 10 successive measurement processes, the spectral values of the colors included in the test form are recorded, and then the color difference (ΔE^*_{00}) from the defined nominal values is calculated. These data form the basis of the performance analysis of the displays under study. The analysis led to the decision to use display calibration device 1 as the measuring device of choice for the further course of the examinations.

The measurements carried out showed the best results for the defined criteria of accuracy and repeatability. The analysis was initially conducted on the basis of the single colors and then moved on to an overall evaluation. It is also clear from the results that the accuracy of the measurement result is strongly related to the spectral composition of the color being measured. For this reason, the analysis was also specifically divided into different color groups: primary and secondary colors as well as tertiary colors. In the area of the tertiary colors, a clear increase in the color differences determined can be seen. Overall, it can be stated that measuring device 1 achieves the best results overall with excellent repeatability. The results of measuring device 2 are similarly good. Measuring device 3 shows unacceptable results in two colors, which then also impacts on the overall evaluation. Measurement device 4 achieves the poorest results overall, which is also reflected in the significantly poorer repeatability of the results.

In step 2, a performance benchmarking of the four selected test displays was conducted. Various measurements were taken with the aim of verifying the performance and also the stability of the color representation of the available displays and to establish comparability. The planned measurements were taken over a defined period and repeated several times. They show very high differences when looking at the defined key performance indicators. It quickly becomes clear how different the representation properties of displays can be and how device-specific the color representation is in reality.

The maximum white luminance already shows high differences. Display 4 achieves the highest luminance with 469 cd/m². This is accompanied by the maximum measured black luminance of 0.4750 cd/m². Both parameters are recognizably directly related. Display 3 shows the lowest value for the maximum representable luminance with 239 cd/m². The measured black luminance of 0.1052 cd/m² is also the lowest value. As expected, the power consumption is higher for the two displays with a diagonal of 32" than for the displays with a diagonal of 27". Both displays with a screen diagonal of 27" deliver the better results here. This also has a direct effect on the determined luminance efficiency. Display 4 shows the best value with 12.69 cd/W, while displays 1 and 3 with a higher screen diagonal drop significantly. Display 2 shows the highest native color gamut, expressed in a coverage of 99.3% (vol. 167.6%) of the AdobeRGB color space. Display 1 shows a higher coverage of 99.5% (vol 164.1%) of AdobeRGB, but the overall volume is still slightly lower. Based on these values, it was decided to calibrate and profile these two displays for the subsequent color matching experiments based on the

AdobeRGB color space. The color gamut of Display 3 is already significantly smaller, while Display 4 offers by far the smallest native color gamut. This led to the decision to calibrate and profile these displays based on the sRGB standard color space for the color matching experiments.

The measurements highlight the lack of uniformity and homogeneity in these four displays. Display 4 shows the best values here, with a mean deviation of the brightness distribution of 8.20%. This also applies to the mean chromaticity difference of ΔC^*_{00} = 1.40. The results for the other displays exceed the assumed perception threshold for brightness variations of 10%, which must be evaluated as unsatisfactory. The highest mean deviation for the brightness distribution of 12.11 % can be seen in Display 3, as is the highest mean chromaticity difference of ΔC^*_{00} = 3.79. The brightness of all displays drops toward the edges and especially toward the corners of the displays. However, different degrees and tendencies are noticeable from display to display. Nonetheless, it should be noted here that the performance of the color matching experiments is unaffected. The structure of Task 1 ensures that the test patches are represented in the center of the display and thus in the area of highest luminance. Task 2, with its higher basic structure by area, is also not perceptibly influenced.

To check the stability of the color representation, control measurements were taken with a defined test form within three defined time slots over a specified period of five days. With each measurement performed, the measured values for white point, color temperature, white luminance, and black luminance were recorded on the one hand, and the spectral values of 30 defined test colors were measured on the other. All displays show a good stability of the performance values, with expected fluctuations. For the analysis, an overall view of the results was first performed before they were evaluated at the level of test days and finally time slots.

Display 1 and Display 2 were calibrated and profiled on the basis of the AdobeRGB color space for the measurements. Both show very stable values in the observation. The recorded luminance is 159.8 cd/m² and 159.9 cd/m² on average, respectively, for a target luminance of 160 cd/m². The color temperature values as a benchmark for measuring the white point are, on average, 6,430 K for Display 1 and 6,513 K for Display 2. It can be determined for Display 1 that the values increase in line with runtime. The highest average values were recorded in time slot 3. Display 2 shows the highest values in time slot 1, which drop somewhat in slot 2 and then increase again in slot 3. It should be noted that the fluctuations here are miniscule. For example, the difference in color temperature between slots 1 and 2 is only 5 K for Display 2.

Display 3 and Display 4 were calibrated and profiled on the basis of the sRGB color gamut, with a target luminance of 80 cd/m². The achieved values also show good stability here. The 30 measurements performed show a mean white luminance of 79.8 cd/m² and a mean color temperature of 6,481 K for Display 3. For Display 4, the mean white luminance is 81.2 cd/m², and the mean color temperature is 6,401 K. A closer look at the results for Display 3 shows that the performance decreases with increasing runtime (i.e., the mean values for luminance and color temperature mostly decrease). Display 4, on the other hand, shows an increase in mean luminance from time slot 1 to time slot 3, whereas mean color temperature decreases.

To provide a higher data basis for evaluating the stability of the color representation, the values of all 30 test colors were analyzed from two randomly selected measurements per day of the measurement cycle. For this purpose, the color difference determined between the nominal values and measured values was used. The evaluation was carried out on two levels. First, the results of all 30 test colors of one measurement run were converted into an overall evaluation, then the results from all measurements were used to evaluate the single colors. Display 1 shows an overall color difference of $\Delta E_{00} = 0.18$ on average. This value is confirmed by the average color difference $\Delta E_{00} = 0.18$ in the analysis of the single colors. In total, the color representation of the nominal spectral values is excellent. However, it should also be noted that several tertiary colors have significantly higher color differences by comparison. For three colors, this means a color difference that is perceptible to experienced observers. Display 2 shows a mean color difference of $\Delta E_{00} = 0.13$. This result is very good. For Display 3, the mean color difference is $\Delta E_{00} = 0.18$. Here, too, as in Display 1, slightly higher color differences are seen in the tertiary color range in the implementation of the nominal values. However, this is only visible for one color in a color difference that is perceptible to experienced observers. Display 4 consistently shows an excellent result in the conversion of the nominal values, with a mean color difference of $\Delta E_{00} = 0.12$.

From this, it can be stated that all four displays show a high stability in the representation performance. The conversion of the nominal spectral values is also very good in the repeat test. This statement is also confirmed by the further measurements to determine the spectral values of the 24 target colors for the evaluation of the color matching experiments. However, the results also show that a distinction must be made between chromatic and achromatic colors, which are mostly more difficult for the displays to convert. Whereas Display 1 shows a mean color difference of $\Delta E_{00} = 0.56$ from the nominal values across all colors, if only the chromatic colors are considered, the mean color difference is reduced to $\Delta E_{00} = 0.43$; by comparison, the mean color difference of the achromatic colors is $\Delta E_{00} = 0.95$. Display 2 yields a better result. The determined color differences of the measured values from the nominal default are, on average, $\Delta E_{00} = 0.34$. However, it can also be noted here that the measured color differences in the achromatic colors are somewhat higher by comparison. Display 3 shows a mean color difference of ΔE_{00} = 0.30. Here, too, there is a tendency, albeit less pronounced, for the achromatic colors to show slightly higher differences from the nominal default. Display 4 gives the best result. Comparing the nominal values with the mean spectral measured values results in a mean color difference of ΔE_{00} = 0.24, while the difference between chromatic and achromatic colors is not as pronounced. Overall, it should be noted that in terms of the stability of color representation, the repeatability is very good.

Due to the ongoing pandemic, the realization of the planned experiments was only possible in a limited capacity and after approval by the management of the University of Applied Sciences Offenburg (study site). Based on a developed hygiene and safety concept, the necessary approval was granted at the beginning of September 2020. Unfortunately, the resulting time slot was very limited due to the renewed lockdown in Germany, so that the desired number of participants could not be reached. Due to this uncertainty, it was then decided to finish this elaboration with the existing results. However, the experiments will be continued as soon as the pandemic situation allows. The laboratory, which has been redesigned to carry out the planned research, will be integrated into the media technology teaching environment at Offenburg University as part of the concept of research-oriented education.

The goal of obtaining as many data sets as possible—on the basis of which an analysis of the individual color perception of the participants could be performed and the influence of the display used could be assessed—could not be achieved in this way. Unfortunately, only the results from 17 participants could be included in the evaluation. At its fullest extent (i.e., a double execution of the presented experiments on each of the used displays), the implementation could only be realized by four participants. Therefore, within the framework of this thesis, it is sensible to refrain from attempting to classify the participants into possible observer groups, as the data basis is simply not high enough for such an implementation. Nevertheless, it can already be stated that the participants represent a broad cross-section of society. All age groups from 20 to 69 years are represented. Unfortunately, female participants are still somewhat underrepresented, with five in total. Media professionals are just as well represented as completely inexperienced users.

The research environment for conducting the experiments was newly created. Important factors in the choice of the location included the presence of air conditioning and, most crucially, the ability to darken the room. This made it possible to keep the given measurement condition uniform over the full period of the research. The technology used was chosen very consciously, with attention to common processes in the media industry. The safety and hygiene concept was

approved by the university management and implemented accordingly. All participants were positive about this, and no concerns were expressed.
From an organizational point of view, the time required to complete the experiments was a significant challenge. Taking into account various aspects, from the hygiene measures to be carried out to the performance of planned control measurements, time slots of 90 min were planned per participant for each performance of the tests. This time frame was well chosen and was not exceeded by any participant. Evidently, this meant that the participants' time commitment was very high. Nonetheless, 50 participants were recruited in the run-up to the studies. However, the development of the health crisis meant that the planning could unfortunately only be realized within a limited framework. On a positive note, the technical implementation of the tasks received excellent feedback from all participants. This evaluation ensured the organization, procedure, and usability of the application were put to the test, thereby delivering the best possible performance in the tests themselves.
The application, programmed in "unity", presents colored test patches based on the colorimetric patches of the X-Rite ColorChecker Classic target. The investigations are carried out with two different test geometries, which differ fundamentally. In Task 1, the models and definitions of Hunt and Fairchild are considered for the structure and representation of the single colors. Only one color field (stimulus) is displayed for processing. The specifications for the proximal field, background, surround, and adapting field are implemented. The structure of Task 2 deviates clearly from this. The size of the color fields is significantly reduced, and 24 different color fields are displayed simultaneously. The final interviews showed that the participants rated the actual task to be performed as clearly and comprehensibly defined. The design of the programmed application and its usability were also rated very positively throughout.
The set task is quite demanding and also exhausting, which was confirmed by all participants. However, the workload was acceptable, although it was noted in isolated cases that the ability to concentrate was felt to have diminished slightly toward the end. No signs of fatigue were observed, which was attributed to the 15-minute break between Task 1 and Task 2. Routine in the sense of an already conscious approach to the adjustment of the individual color channels was not observed. Possible systematic errors could not be detected. It can be stated that the first participation is mostly seen as a kind of approach to the task set. This is expressed in a mostly higher expenditure of time and in the overall evaluation in somewhat poorer results. However, this statement does not apply at the level of the single colors, where a thoroughly mixed picture emerges.

The evaluation of the obtained results is anonymized. The analysis is conducted as standard in a reference system with a fixed observer (CIE L*a*b* 1976). The aim of the analysis is to record the accuracy or deviation of the visual matching with the specified target values. Intra-variability (i.e., the ability of an observer to repeatedly perform the identical task) is also considered here. In the next step, the inter-variability of the results of all participants is considered. The analysis is based on the determined nominal color values and the measured spectral values. The given target colors were measured several times, and mean values were formed for each color. This is to compensate for any minor fluctuations in the color representation of the display. The color difference ΔE_{00} is determined and used to evaluate the results. The basis for the interpretation and evaluation of the results is a rating scale revised for this analysis, which is based on the principle of the interpretation proposed by the CIE but also encompasses further interpretations currently used in the media industry.

To analyze and evaluate the individual color perception of the participants, initially only the results from Task 1 on all displays were used. Here, the design of the experiment corresponds to the scientifically defined and typical procedure for obtaining individual perceived spectral values. The data show very clearly how individual the perception of colors is. The data collected and the ratings made can be found in compressed form in Annex 4.4. The evaluations not only differ interpersonally but also intra-personally, especially when comparing the results obtained by the participants for different displays; higher differences can sometimes be seen. It is notable here that the color representation of the displays is very heavily device-dependent and is significantly influenced by the native color gamut and the specially created display profiles.

If all results for all participants are combined, the overall accuracy of the results receives a rating of 1.7. This means that in the majority of the results, color differences are present between the achieved color matches and the defined target colors that are perceptible to experienced observers. This is a good result, because only colors 17 and 18 minimally exceed the limit value $\Delta E_{00} = 1.00$ on average. Colors 1, 4, and 14 receive a rating of 1 for almost imperceptible color differences. It also becomes clear that the less saturated colors (1–6) show better results than the more saturated colors (8–18). The exception here is color 11 near the display primary green. It can be seen that the less and more saturated colors in the spectral range green to yellowish green show some of the best results. By comparison, the less and more saturated colors in the spectral range blue green to purplish pink show poorer results. These results are also confirmed by the repeatability rating. The overall assessment of the repeatability of the results yields a rating of 1.2. This means that the majority of the results show almost imperceptible color differences in the achieved color matches to the defined target colors. The limit value ΔE_{00} =

1.00 is never exceeded on the mean. The tendency for the color matches of the less saturated colors to show better results is confirmed, as is the evaluation of the different spectral ranges. When considering the saturated colors, it can be seen that colors 12 and 16 have good repeatability in the spectral range yellow to yellow orange, while saturated colors 8, 17, and 18 receive a rating of 2.

The color matches in Task 2 show significantly poorer results. However, this is predictable. The structure of Task 2 clearly influences this, whereby the size of the color patches is significantly reduced and 24 different color patches are displayed simultaneously. This multitude of different stimuli influences the perception of the participants and clearly complicates the task to be performed. The achromatic colors contained in the task are particularly problematic. The measurements to determine the target values already show that the displays used in the achromatic colors 19–24 usually have somewhat higher color differences than the chromatic colors and that the color representation varies strongly in some cases. For the chromatic colors (1–18), it can thus be stated that all displays convert the nominal color values very well and stably. The overall accuracy of the results for all 24 colors shows a mean rating of 2.8. The repeatability shows a mean rating of 2.1.

Separating achromatic and chromatic colors highlights the aforementioned problems. The mean ratings of the chromatic colors are 2.6 for accuracy and 1.9 for repeatability. By contrast, the achromatic colors show a mean rating of 3.3 for accuracy, while the rating of 2.6 for repeatability is also significantly less good. This shows that especially in the achromatic colors, the influence of surrounding colored stimuli is more noticeable. The examination of the results confirms the basic tendencies in the quality of the results in the different spectral ranges or the less and more saturated colors found in Task 1, despite the higher color differences found. A further study of how the arrangement of the different color patches affects the individual results is planned; its application has already been programmed but cannot yet be carried out for the reasons mentioned.

Considering the results achieved in Task 1 on the level of the individual displays, the impression of device-dependency is clear. The overall view of the results achieved by the participants per display shows perceptible differences in the quality of the results. Display 1 receives a mean rating of 1.9 in the overall evaluation of all participants for accuracy, which is the highest rating achieved. Display 3 shows a mean rating of 1.8, followed by Display 4 with a mean rating of 1.4. The best mean rating of 1.3 is achieved by Display 2. Thus, displays 1 and 3 mostly show color differences perceptible to experienced observers, while the color matches achieved by displays 2 and 4 show almost no perceptible color differences from the target color.

The evaluation of the repeatability of the results represents a similar picture. The mean rating of 1.6 for Display 1 is again the highest value. Display 3 follows again with a mean rating of 1.1, followed by Display 2 with a mean rating of 0.9. The best repeatability rating is given to Display 4, with a mean rating of 0.8. Once again, displays 2 and 4 show the best and, in this case, excellent values. However, it must be remembered here that unfortunately not every participant was able to perform the task set for every display, which is why a different number of results are included in the overall evaluation depending on the display. In response, the results of the participants with IDs 01, 03, 04, and 05—for whom the results of all four displays are available—were specifically combined. Accordingly, the statements derived from the overall assessment are confirmed.

The native color gamuts of the four displays differ significantly in some cases, which is represented accordingly in the representation of the defined target colors. Display 1 represents the chromatic colors with the highest saturation of all displays, with a few exceptions, and thus also uses the highest number of representable colors. By comparison, the native gamut of Display 2 has a significantly more saturated primary color blue and a somewhat extended representable color range. Higher differences in the representable gamut can also be seen in the comparison with Display 3, which turns out to be smaller due to the display primaries green and blue. Display 4 has the smallest representable color gamut, and except for color 1, all nominal values and also the measured spectral values of the chromatic colors are the least saturated. The neutral colors (colors 19–24) are represented slightly differently from display to display depending on the white point of the profile.

Examining the averaged results of the four participants for the individual colors enables more detailed insight. The results for Display 1 show four color matches with a rating of 3 for small perceptible color differences. Only two colors receive a rating of 1. This is naturally expressed in a higher mean overall rating. Display 2 shows the best result, which is expressed in a rating of 1 for seven colors. A rating of 3 is only given to color 17. Both displays are profiled on the basis of the AdobeRGB color space and cover a higher color range than displays 3 and 4. The results for Display 3 show a rating of 1 three times and a rating of 2 nine times. The ratings for Display 4 are somewhat better. In the overall view of the single colors, it can be seen that in the less saturated colors, the color matches show a more accurate result than the more saturated colors. This statement can be applied to all displays. However, the example of Display 4 shows that the smaller the representable color gamut and thus the lower the saturation in the more saturated colors, the smoother the transition. The overall view of the single colors also shows that the less and more saturated colors in the spectral range green to yellowish green show some of the best results. This impression is very much determined by the fact that the majority of the results included in the overall analysis were achieved for Display 1, where this is very clearly visible. This statement can also be fully adopted for Display 3. The results for displays 2 and 4 confirm this statement for the less saturated spectral range, while in the more saturated range, color matching detected color differences that were not perceptible to experienced observers. Finally, the overall observation prompts the conclusion that the less and more saturated colors in the spectral range blue green to purplish pink represent a problem zone and mostly show inferior results by comparison. This statement is confirmed in the results of all four displays and is particularly clear for Display 1. Display 4 with the smallest representable color gamut shows the best results in terms of repeatability. In general, the higher this becomes, the greater the differences in the achieved color matches, with higher saturation of the target color.

Unfortunately, the number of tests performed does not yet allow any qualitative statements, but various observations can already be made. The QD-enhanced LCDs used show very stable and accurate color representation. However, the color matching experiments carried out by the participants also show that in the spectral ranges dominated by the display primary blue, the quality of the color representation declines somewhat. This is due to the fact that in the BLU, no QD extension is used for the blue spectral component, and therefore the emission spectrum of the blue BLU LEDs used determines the spectral representation. This turns out to be somewhat broader by comparison, because the properties of the QDs used for red and green to represent light with a narrow emission and excellent control of the wavelength do not come into play here. Across all color matches of the participants, the settings made for the blue color value draw the highest inaccuracies or deviations from the target value of the represented target colors. By contrast, the very precise spectral definition of the primaries red and green made possible by the use of QDs leads to excellent results with low deviations.

As expected, the high number of representable colors is also a challenge for the participants. The available results demonstrate that especially experienced users with knowledge of digital image processing master this significantly more adeptly, as shown in their consistently good results, irrespective of the display used. In the context of standardized media production in particular, this shows the importance of the color representation quality of the display technology used for the production of high-quality results. In this area, QD-enhanced LCDs offer significant added value compared to other display technologies. The importance of calibrating and profiling displays for standardized production is again emphasized by the results obtained. The device-dependent color representation and its influence on the color matching achieved underlines the importance of the quality of the display profiles used. In turn, this is

largely determined by the display calibration device. The performance comparison carried out with four industry-standard all-in-one devices shows device-dependent differences, but also good to very good results. Ultimately, the deliberate selection of such a device and its specific adjustment to the display used enables stable, reproducible, and accurate color representation.
Especially with the inexperienced participants, the increase in representable colors leads to a noticeable intra-variability of the results, which is very strongly determined by the device-dependent color representation of the displays. In sum, the tendencies already presented here are visible, but these are not comprehensively transferable to every participant. Nonetheless, the individuality of color perception is evident. In the context of future standardized media production and in line with the constant development of the technologies used, the discussion must also be held here on how to deal with this individuality. For example, this could be taken into account in a user-related profile for a defined display, which links the device-dependent color representation to the individual perception of the observer.

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Annexes

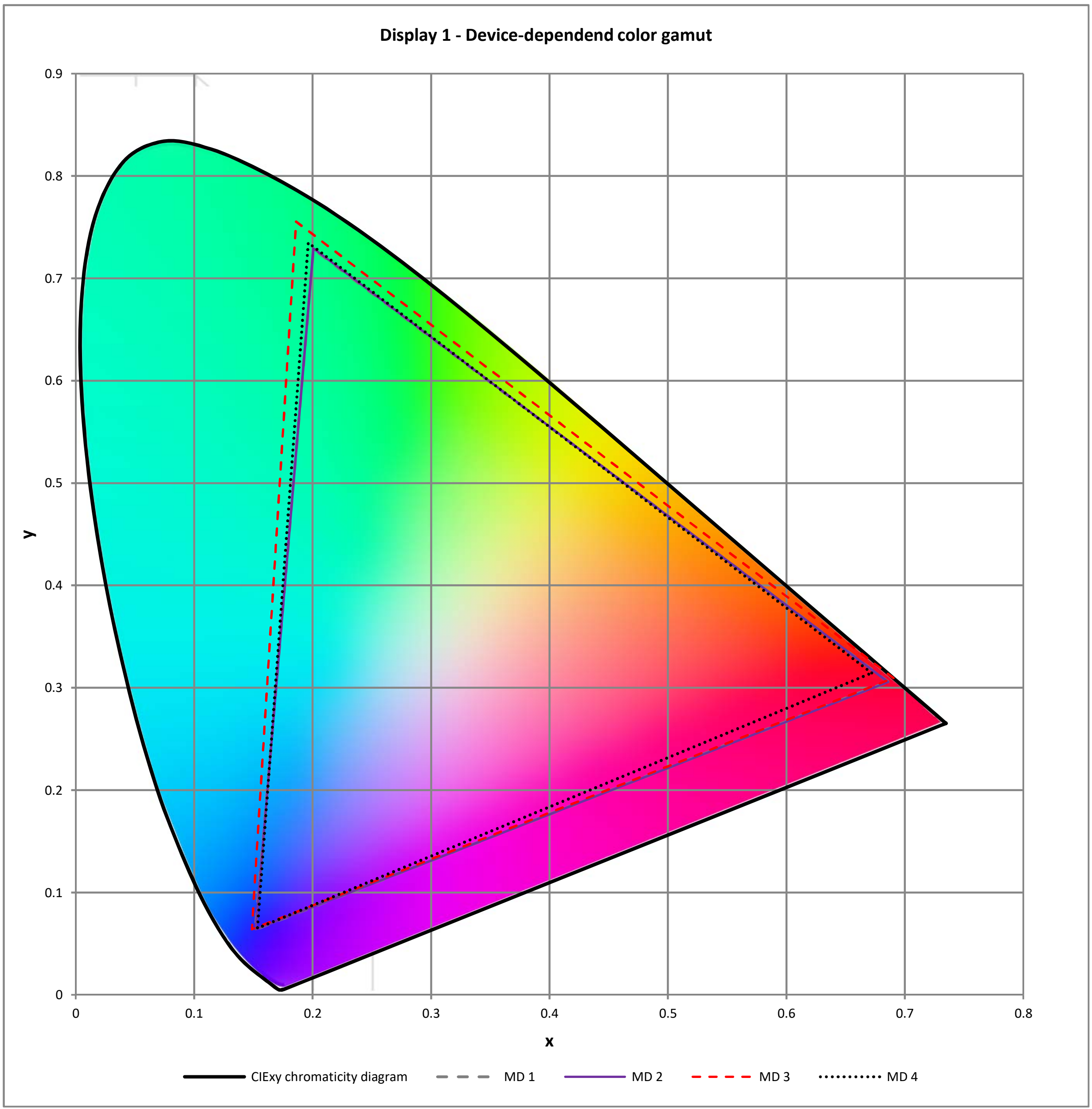
Annex 1 Device-dependent display gamuts

1| Device-dependent display gamuts

1.1 - Display 1: Measured display gamut with the available measuring devices

	RED					GREEN					BLUE				
	X	Y	Z	x	y	X	Y	Z	x	y	X	Y	Z	x	y
MD 1 *	56.85	25.37	0.69	0.6857	0.3060	18.25	68.31	6.45	0.2006	0.7286	19.75	8.32	102.15	0.1517	0.0639
MD 2 *	57.93	25.41	0.72	0.6858	0.3055	18.23	66.25	6.38	0.2006	0.7292	19.75	8.34	102.33	0.1518	0.0641
MD 3 *	59.23	26.56	0.00	0.6904	0.3096	16.00	64.96	5.04	0.1861	0.7554	19.65	8.47	104.04	0.1487	0.0641
MD 4 *	57.82	27.06	1.16	0.6720	0.3145	17.20	64.43	6.06	0.1962	0.7347	20.07	8.51	102.20	0.1534	0.0651

*** MD: Measurement device**



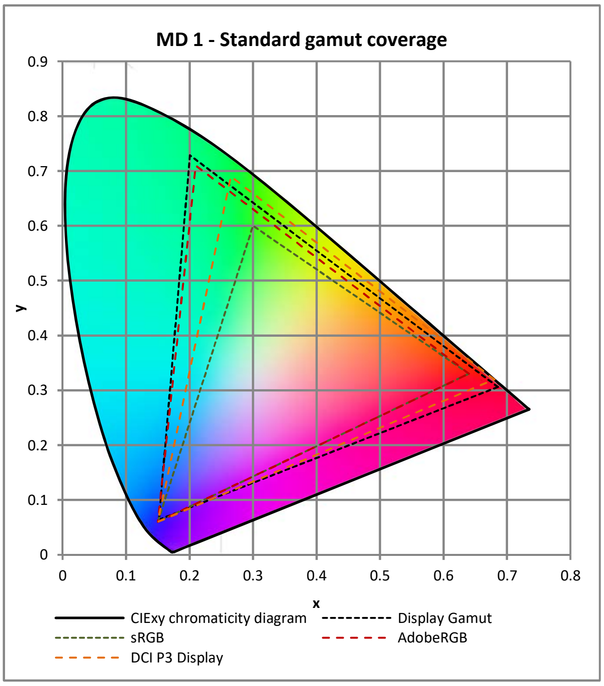
1| Device-dependent display gamuts

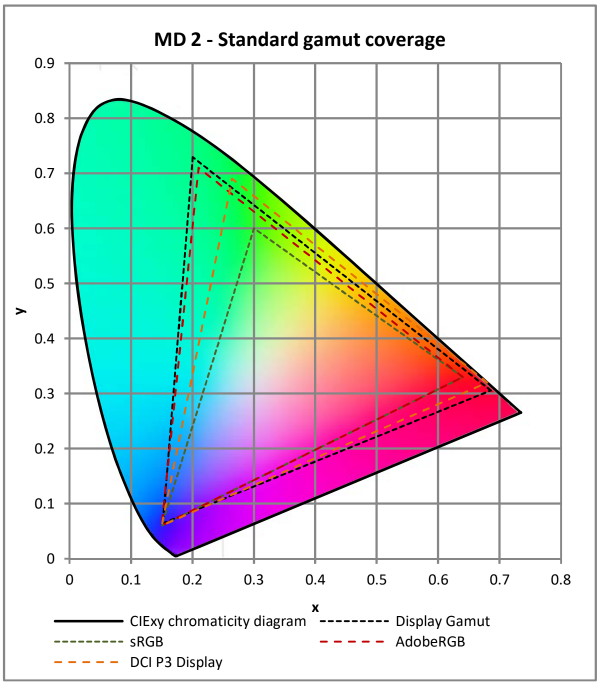
1.1 - Display 1: Resulting standard gamut coverage

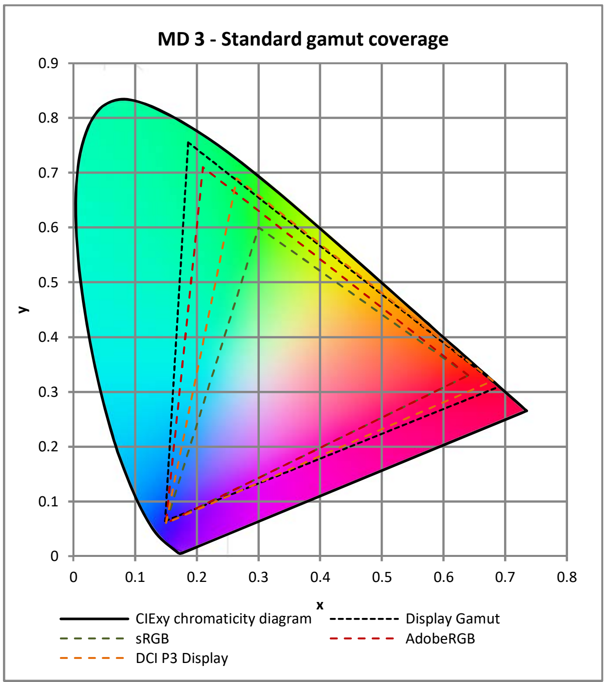
	sRGB		AdobeRGB		DCI-P3	
	Cov.*	Vol.**	Cov.*	Vol.**	Cov.*	Vol.**
MD 1	99.5%	164.2%	99.2%	113.1%	93.3%	116.3%
MD 2	99.5%	163.8%	99.2%	112.9%	93.2%	116.3%
MD 3	99.2%	179.5%	99.2%	123.7%	96.8%	127.1%
MD 4	99.3%	160.9%	99.0%	110.9%	91.8%	114.0%

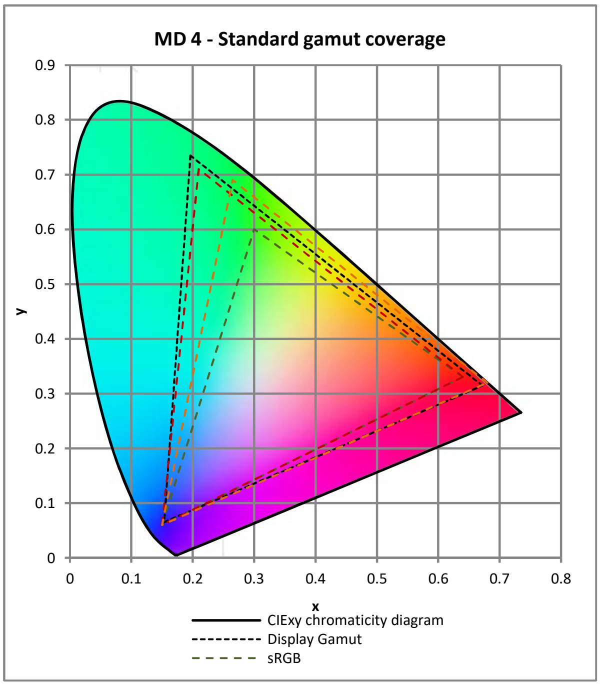
*Cov.: Standard gamut coverage

**Vol.: Amount of displayable colors compared to the standard color gamut







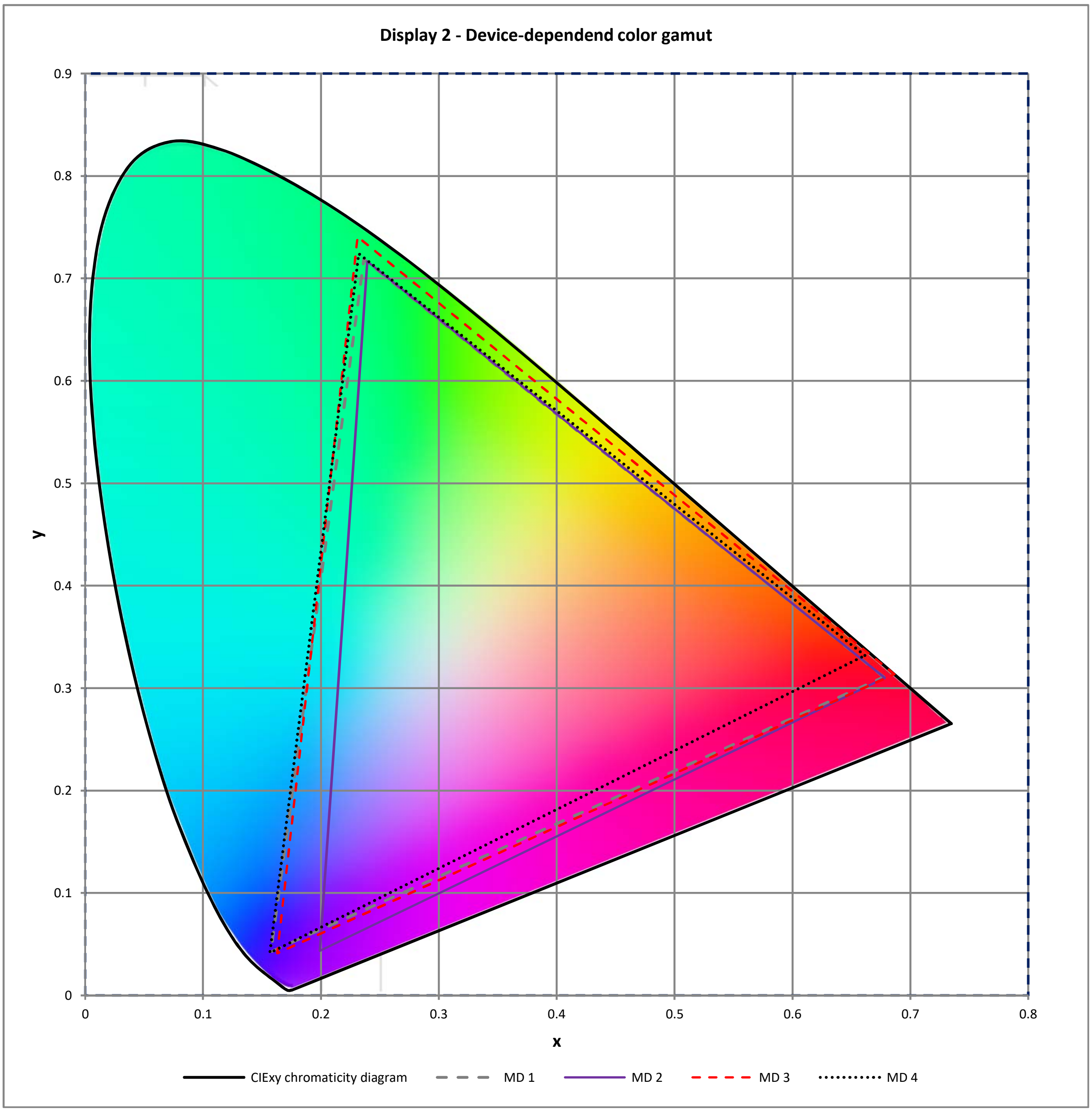


1| Device-dependent display gamuts

1.2 - Display 2: Measured display gamut with the available measuring devices

	RED					GREEN					BLUE				
	X	Y	Z	x	y	X	Y	Z	x	y	X	Y	Z	x	y
MD 1 *	51.53	23.57	0.88	0.6774	0.3109	23.34	70.93	4.44	0.2364	0.7186	20.35	5.50	103.28	0.1576	0.0426
MD 2 *	50.39	23.03	0.87	0.6783	0.3100	23.82	71.32	4.38	0.2394	0.7166	20.64	5.65	103.45	0.1991	0.0435
MD 3 *	51.19	23.40	0.00	0.6863	0.3137	22.20	71.11	2.71	0.2312	0.7406	21.73	5.49	106.06	0.1630	0.0412
MD 4 *	52.61	25.69	1.24	0.6614	0.3320	22.10	68.93	4.17	0.2321	0.7241	20.24	5.38	103.60	0.1567	0.0416

*** MD: Measurement device**



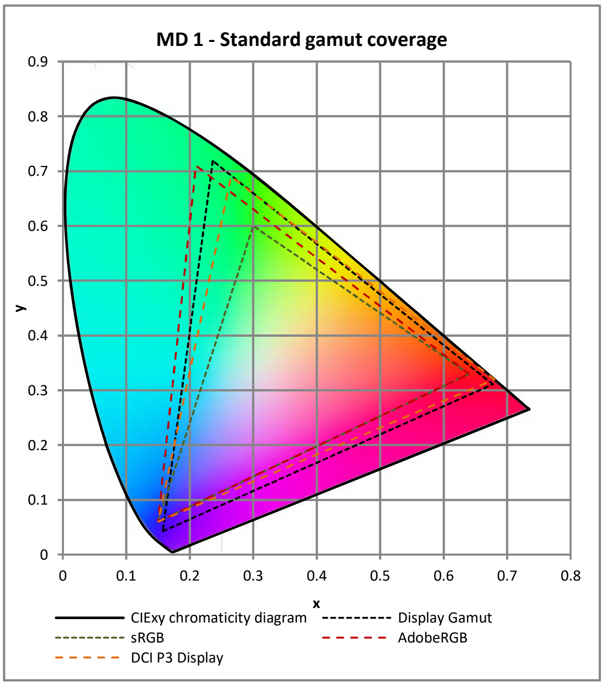
1| Device-dependent display gamuts

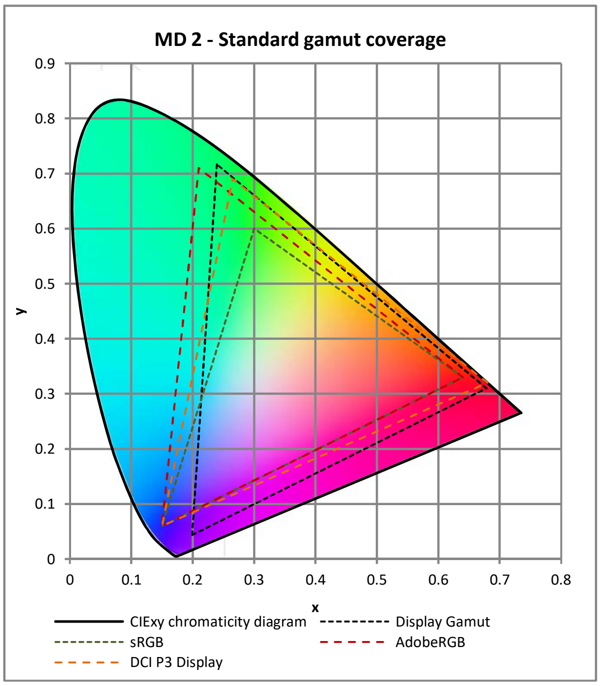
1.2 - Display 2: Resulting standard gamut coverage

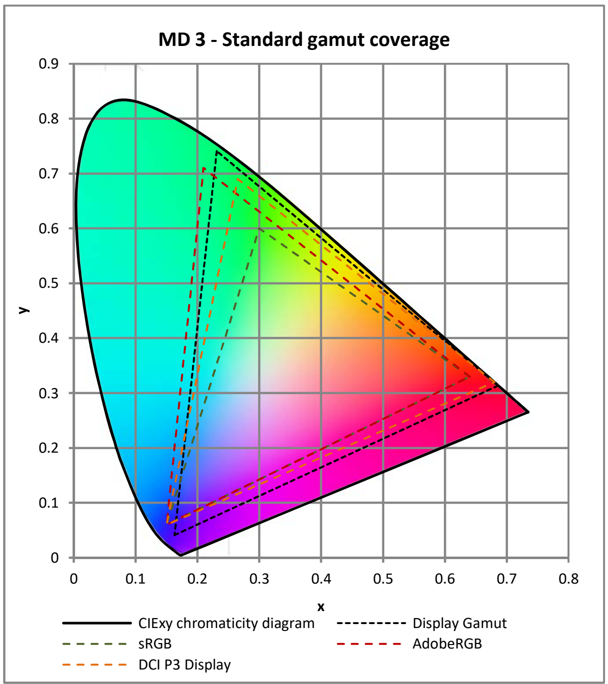
	sRGB		AdobeRGB		DCI-P3	
	Cov.*	Vol.**	Cov.*	Vol.**	Cov.*	Vol.**
MD 1	99.4%	168.5%	92.2%	116.1%	96.5%	119.4%
MD 2	99.2%	166.3%	90.7%	114.6%	96.3%	117.8%
MD 3	99.0%	181.5%	92.3%	125.1%	98.2%	128.6%
MD 4	99.3%	164.9%	93.2%	113.6%	95.2%	116.8%

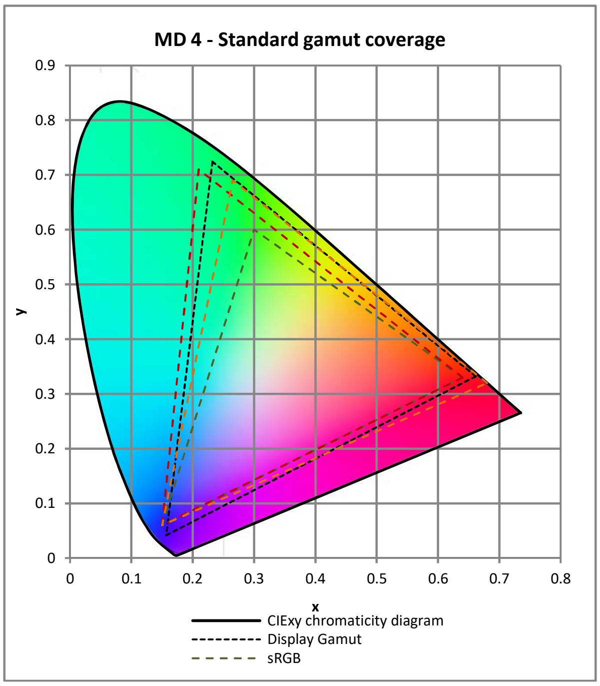
*Cov.: Standard gamut coverage

**Vol.: Amount of displayable colors compared to the standard color gamut







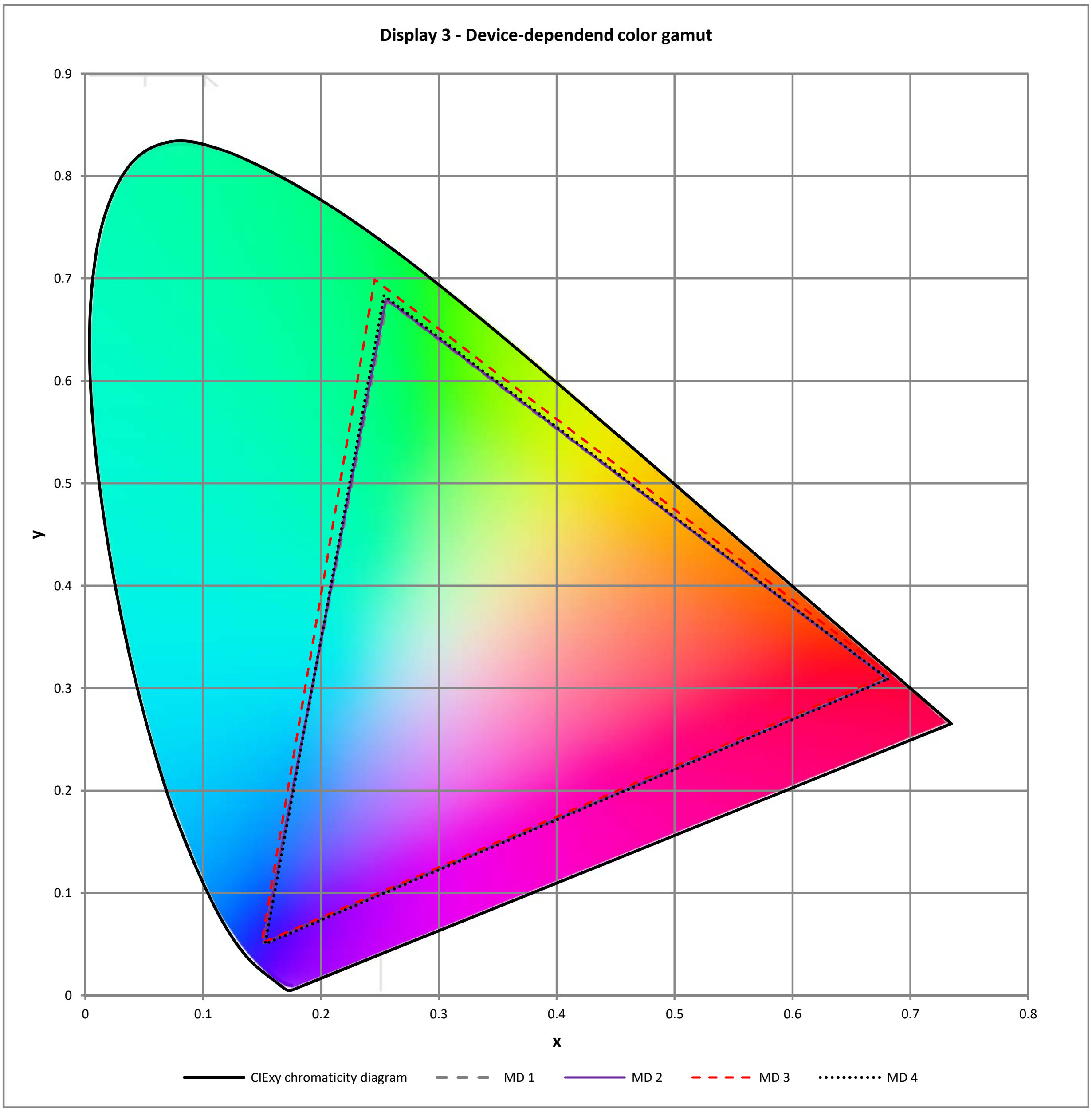


1| Device-dependent display gamuts

1.3 - Display 3: Measured display gamut with the available measuring devices

	RED					GREEN					BLUE				
	X	Y	Z	x	y	X	Y	Z	x	y	X	Y	Z	x	y
MD 1 *	48.82	22.19	9.74	0.6804	0.3093	26.94	71.36	6.91	0.2561	0.6782	19.15	6.44	101.20	0.1510	0.0508
MD 2 *	48.98	22.22	0.77	0.6805	0.3088	26.78	71.31	6.79	0.2553	0.6799	19.10	6.46	100.73	0.1512	0.0512
MD 3 *	52.62	23.71	0.31	0.6824	0.3135	24.51	69.74	5.55	0.2455	0.6988	19.16	6.45	102.16	0.1498	0.0512
MD 4 *	49.14	22.30	0.74	0.6808	0.3090	26.44	71.26	6.60	0.2535	0.6832	19.52	6.43	101.87	0.1527	0.0503

*** MD: Measurement device**



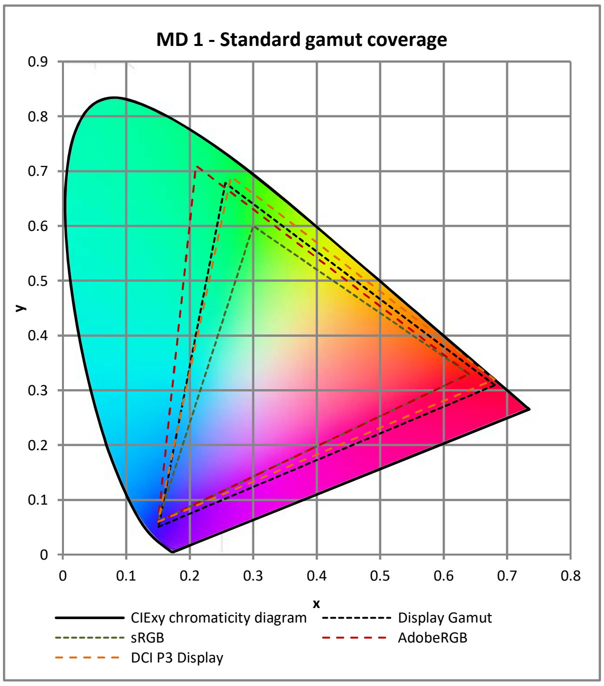
1| Device-dependent display gamuts

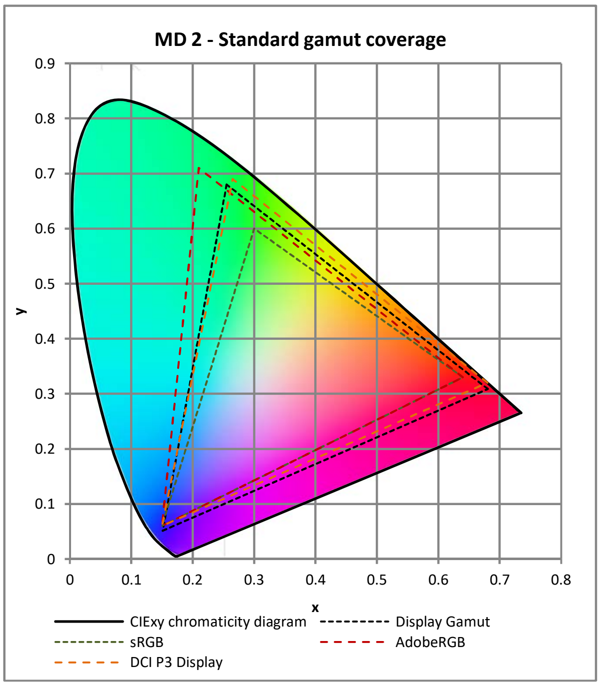
1.3 - Display 3: Resulting standard gamut coverage

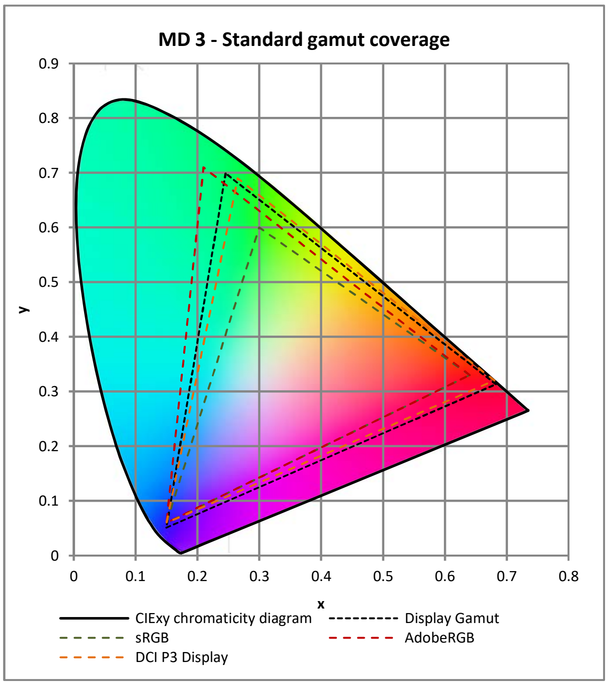
	sRGB		AdobeRGB		DCI-P3	
	Cov.*	Vol.**	Cov.*	Vol.**	Cov.*	Vol.**
MD 1	99.9%	143.9%	87.8%	99.2%	92.4%	102.0%
MD 2	99.9%	144.5%	88.1%	99.6%	92.5%	102.0%
MD 3	99.9%	154.4%	91.6%	106.4%	95.7%	109.4%
MD 4	99.8%	144.3%	87.7%	99.4%	92.3%	102.2%

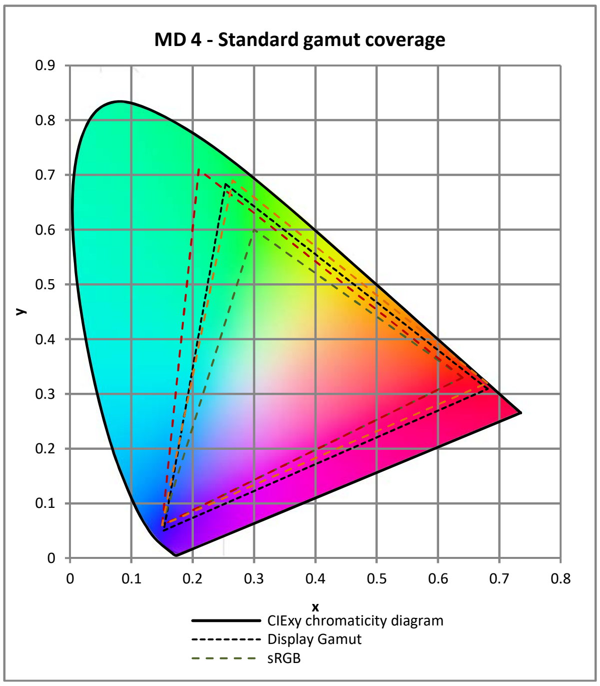
*Cov.: Standard gamut coverage

**Vol.: Amount of displayable colors compared to the standard color gamut







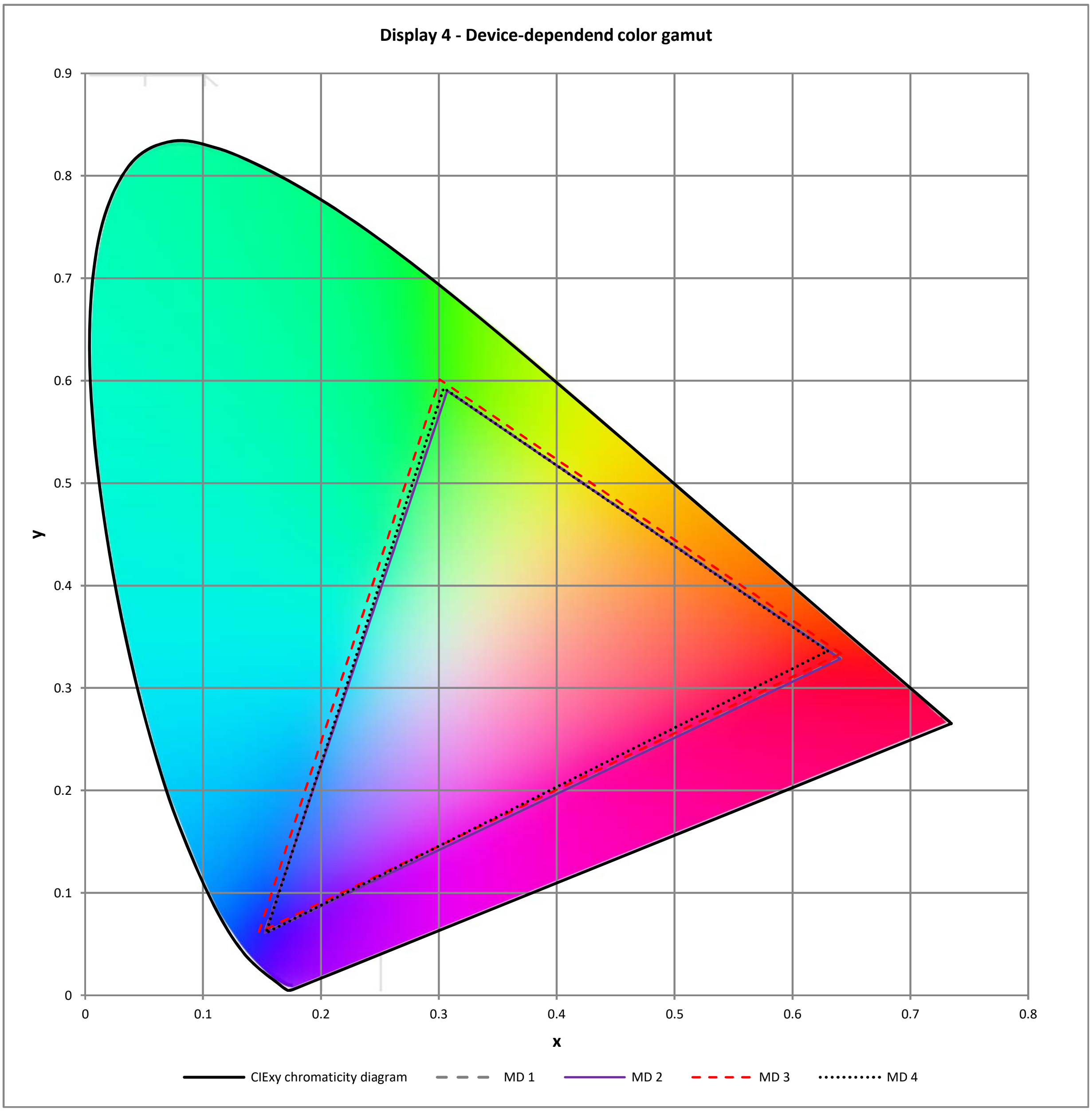


1| Device-dependent display gamuts

1.4 - Display 4: Measured display gamut with the available measuring devices

	RED					GREEN					BLUE				
	X	Y	Z	x	y	X	Y	Z	x	y	X	Y	Z	x	y
MD 1 *	39.06	20.03	1.84	0.6410	0.3288	37.80	72.70	12.66	0.3069	0.5903	18.15	7.27	93.71	0.1524	0.0610
MD 2 *	39.05	20.02	1.88	0.6406	0.3285	37.84	72.64	12.66	0.3073	0.5899	18.36	7.33	94.71	0.1525	0.0609
MD 3 *	41.60	21.65	1.65	0.6411	0.3335	35.51	71.00	11.59	0.3007	0.6012	17.66	7.36	94.98	0.1472	0.0613
MD 4 *	40.08	21.40	2.16	0.6298	0.3362	36.62	71.36	12.40	0.3042	0.5928	18.22	7.24	93.38	0.1533	0.0609

*** MD: Measurement device**



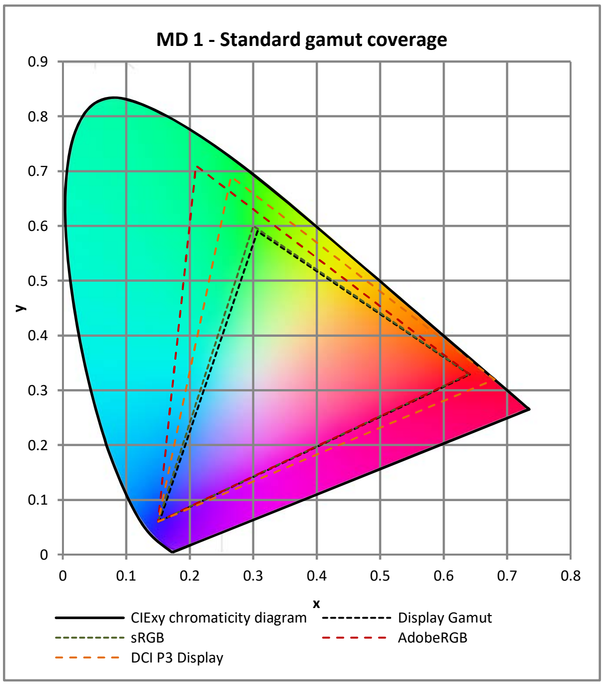
1| Device-dependent display gamuts

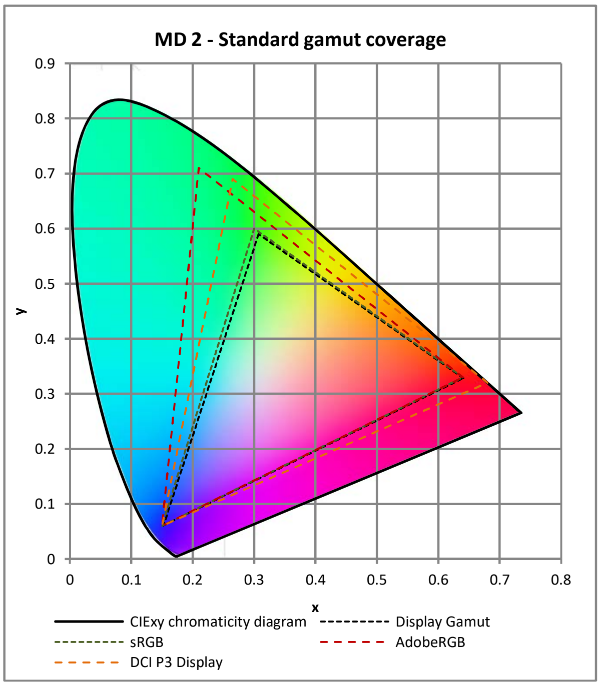
1.4 - Display 4: Resulting standard gamut coverage

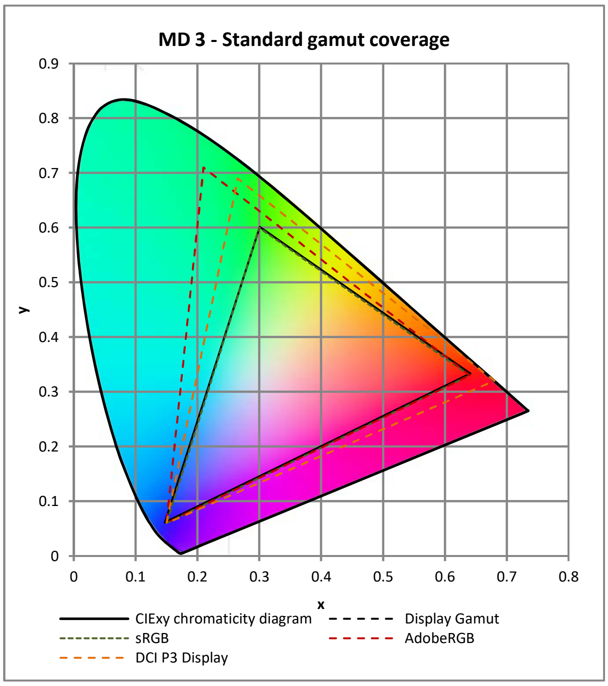
	sRGB		AdobeRGB		DCI-P3	
	Cov.*	Vol.**	Cov.*	Vol.**	Cov.*	Vol.**
MD 1	95.1%	95.2%	65.5%	65.6%	67.5%	67.5%
MD 2	95.0%	95.3%	65.5%	65.6%	67.5%	67.5%
MD 3	97.0%	100.4%	69.1%	127.1%	71.0%	71.1%
MD 4	93.3%	93.4%	64.3%	64.3%	66.1%	66.1%

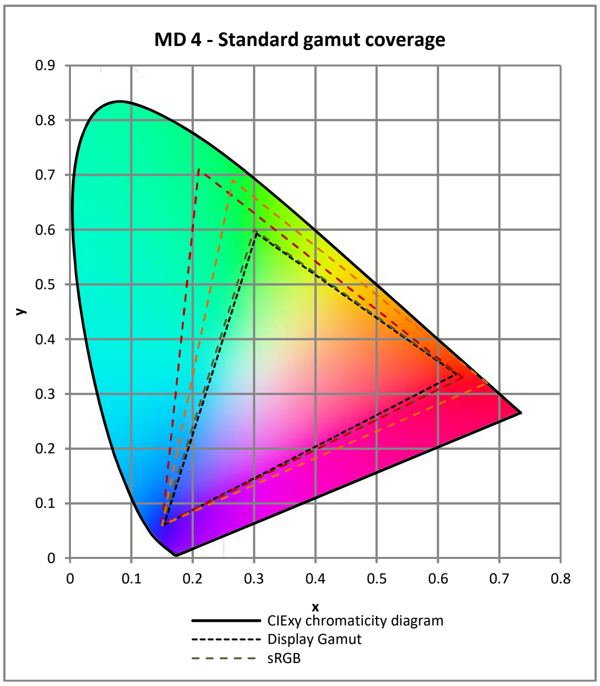
*Cov.: Standard gamut coverage

**Vol.: Amount of displayable colors compared to the standard color gamut







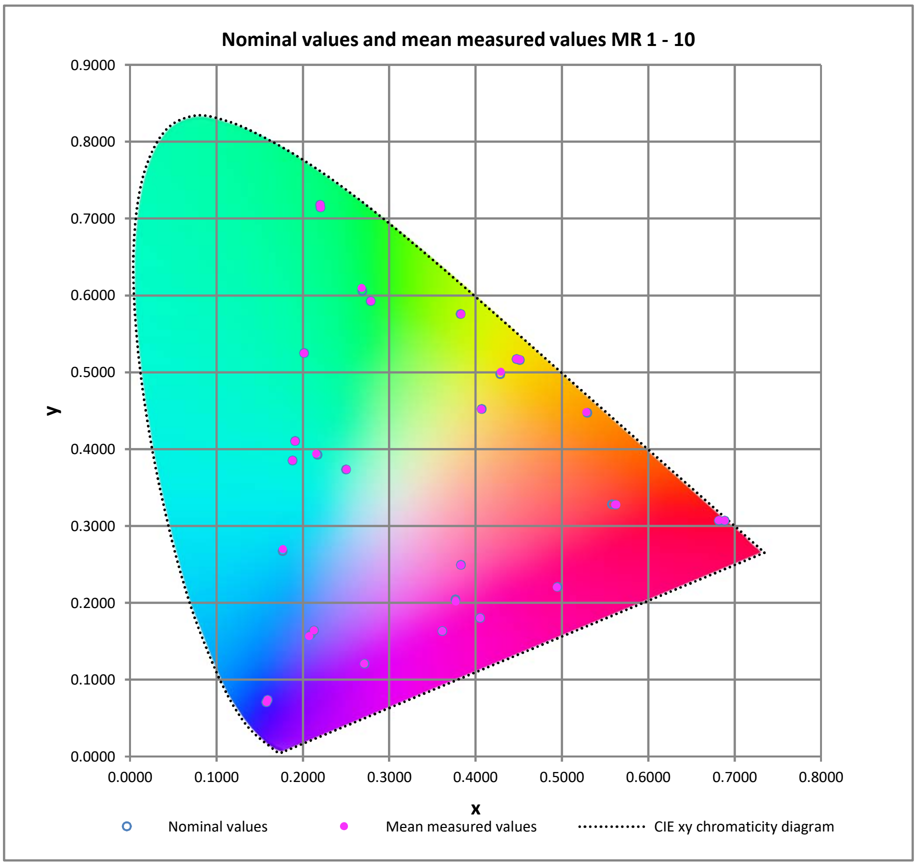


Annex 2 Display calibration device performance data

2| 1 Display calibration device performance data

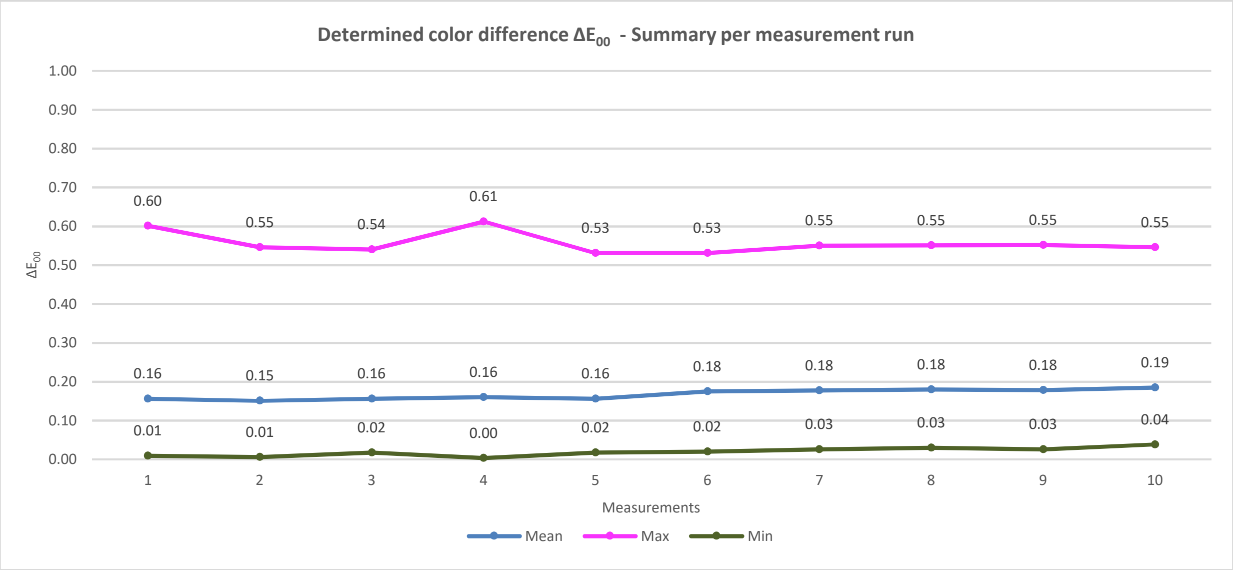
1.1 - Summary and visualization of the measured values

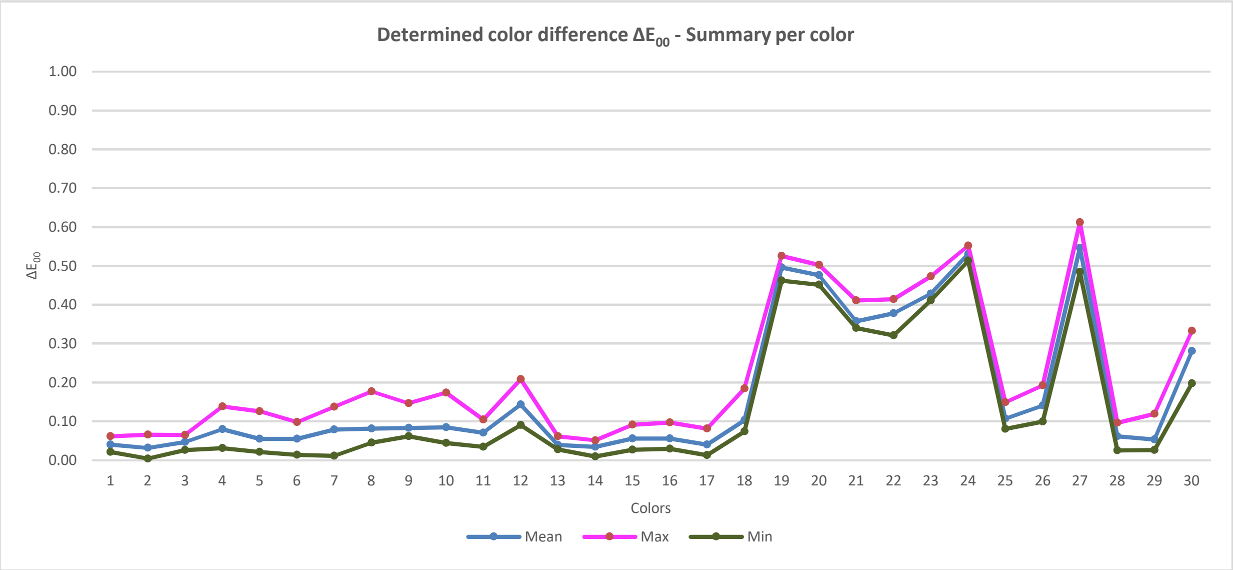
	Device Values			Nominal Values					Mean Measured Values MR1 - MR10					
Color	R	G	B	L*	a*	b*	x	y	L*	a*	b*	x	y	ΔE_{00}
1	128	0	0	30.73	64.64	48.49	0.6819	0.3069	30.69	64.56	48.44	0.6819	0.3069	0.04
2	255	0	0	58.82	104.87	93.98	0.6886	0.3069	58.80	104.85	93.94	0.6886	0.3069	0.02
3	255	128	128	68.38	77.12	37.49	0.5621	0.3274	68.41	77.05	37.50	0.5620	0.3276	0.03
4	0	128	0	55.46	-97.26	64.06	0.2206	0.7142	55.50	-97.18	64.13	0.2210	0.7140	0.05
5	0	255	0	84.76	-137.79	91.88	0.2203	0.7178	84.81	-137.66	91.95	0.2206	0.7175	0.05
6	128	255	128	88.01	-95.27	64.37	0.2789	0.5924	88.07	-95.26	64.41	0.2791	0.5923	0.04
7	0	0	128	16.63	43.55	-74.76	0.1594	0.0736	16.62	43.77	-74.88	0.1596	0.0734	0.08
8	0	0	255	31.70	66.67	-112.36	0.1581	0.0706	31.69	66.90	-112.44	0.1582	0.0705	0.08
9	128	128	255	52.23	30.77	-78.08	0.2131	0.1640	52.28	30.87	-78.09	0.2133	0.1640	0.07
10	0	128	128	52.42	-63.49	-6.60	0.1912	0.4103	52.46	-63.44	-6.68	0.1912	0.4100	0.06
11	0	255	255	88.57	-91.25	-18.75	0.1882	0.3848	88.62	-91.34	-18.71	0.1882	0.3849	0.05
12	170	255	255	92.32	-53.30	-12.88	0.2503	0.3734	92.43	-52.90	-12.79	0.2511	0.3734	0.14
13	128	0	128	29.70	63.13	-41.21	0.3619	0.1630	29.71	63.20	-41.28	0.3618	0.1629	0.02
14	255	0	255	64.65	113.43	-56.57	0.4056	0.1803	64.64	113.49	-56.63	0.4056	0.1802	0.02
15	255	170	255	78.06	68.31	-34.66	0.3833	0.2492	78.03	68.46	-34.78	0.3833	0.2489	0.05
16	128	128	0	59.79	-11.50	73.79	0.4478	0.5171	59.80	-11.49	73.78	0.4478	0.5170	0.01
17	255	255	0	96.92	-15.49	111.96	0.4514	0.5159	96.96	-15.54	112.01	0.4514	0.5160	0.03
18	255	255	170	98.03	-10.96	54.52	0.4073	0.4520	98.09	-11.03	54.29	0.4069	0.4517	0.10
19	170	85	85	50.38	59.69	28.73	0.5583	0.3280	50.39	60.85	29.93	0.5634	0.3277	0.50
20	85	170	85	69.25	-83.59	54.31	0.2692	0.6056	69.69	-84.84	55.51	0.2685	0.6092	0.47
21	85	85	170	37.77	25.27	-63.60	0.2098	0.1595	37.52	25.99	-64.86	0.2075	0.1562	0.35
22	85	170	170	66.79	-60.36	-9.17	0.2171	0.3926	67.06	-61.42	-9.08	0.2158	0.3937	0.37
23	170	85	170	49.37	68.10	-40.04	0.3768	0.2041	49.16	69.61	-40.85	0.3774	0.2014	0.43
24	170	170	85	72.91	-14.02	66.66	0.4287	0.4972	73.14	-14.54	68.64	0.4297	0.5003	0.53
25	255	0	170	61.82	109.31	-21.62	0.4951	0.2203	61.86	109.35	-21.94	0.4943	0.2200	0.10
26	170	255	0	91.74	-54.11	103.44	0.3828	0.5758	91.81	-53.76	103.57	0.3836	0.5752	0.14
27	0	170	255	67.78	-42.55	-52.16	0.1769	0.2672	68.20	-43.47	-51.56	0.1772	0.2695	0.54
28	0	255	170	86.51	-116.69	25.04	0.2016	0.5247	86.57	-116.64	25.05	0.2018	0.5245	0.04
29	170	0	255	45.97	87.19	-88.38	0.2717	0.1207	46.00	87.16	-88.45	0.2715	0.1207	0.04
30	255	170	0	81.67	29.87	101.25	0.5295	0.4471	81.83	29.39	101.36	0.5286	0.4479	0.28

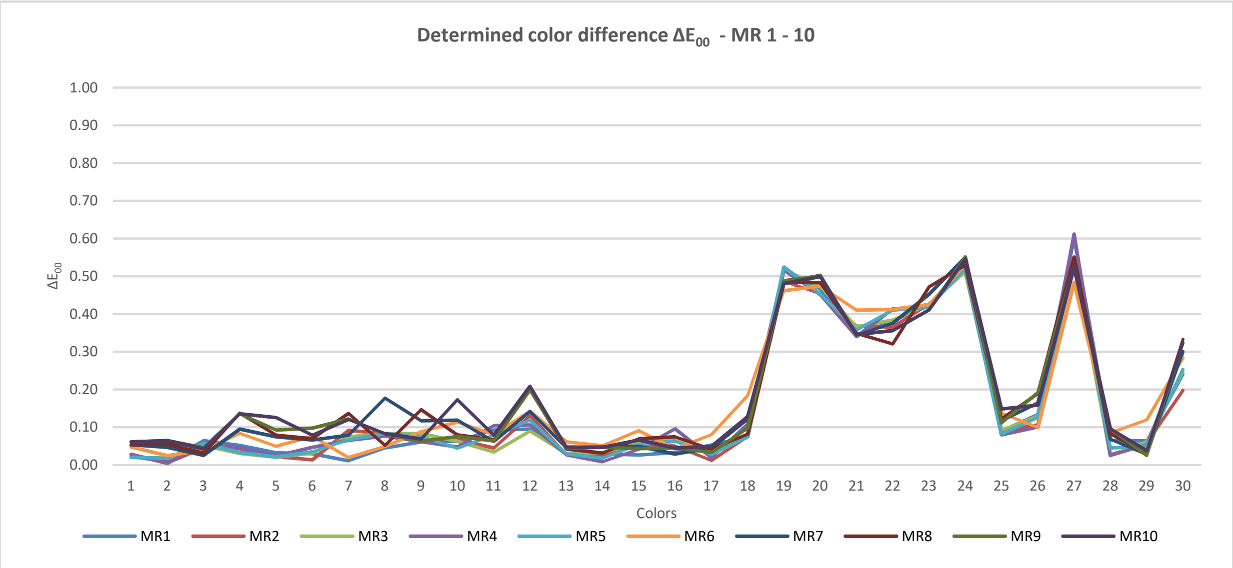


2| 1 Display calibration device performance data

1.1 - Summary and visualization of the measured values







2| 1 Display calibration device performance data

1.2 - Measured values

	Measured Values MR1						Measured Values MR2						Measured Values MR3					
Color	L*	a*	b*	x	y	ΔE_{00}	L*	a*	b*	x	y	ΔE_{00}	L*	a*	b*	x	y	ΔE_{00}
1	30.71	64.58	48.45	0.6819	0.3069	0.02	30.70	64.58	48.45	0.6819	0.3069	0.03	30.71	64.59	48.47	0.6819	0.3069	0.02
2	58.83	104.87	93.97	0.6886	0.3069	0.01	58.82	104.85	93.95	0.6886	0.3069	0.01	58.84	104.87	93.98	0.6886	0.3069	0.02
3	68.43	77.06	37.58	0.5621	0.3276	0.06	68.42	77.07	37.54	0.5620	0.3276	0.04	68.43	77.10	37.56	0.5621	0.3276	0.05
4	55.48	-97.51	64.09	0.2201	0.7147	0.05	55.47	-97.47	64.07	0.2201	0.7147	0.04	55.47	-97.41	64.08	0.2203	0.7145	0.03
5	84.80	-137.93	91.93	0.2201	0.7180	0.03	84.79	-137.86	91.9	0.2202	0.7179	0.02	84.79	-137.78	91.91	0.2204	0.7177	0.02
6	88.05	-95.35	64.42	0.2789	0.5925	0.03	88.03	-95.28	64.36	0.2789	0.5923	0.01	88.05	-95.37	64.40	0.2788	0.5924	0.03
7	16.62	43.52	-74.73	0.1594	0.0736	0.01	16.62	43.82	-74.92	0.1595	0.0733	0.09	16.62	43.78	-74.91	0.1595	0.0734	0.08
8	31.69	66.78	-112.37	0.1582	0.0705	0.05	31.69	66.92	-112.45	0.1582	0.0704	0.08	31.69	66.92	-112.45	0.1582	0.0704	0.08
9	52.27	30.85	-78.08	0.2133	0.1640	0.06	52.26	30.87	-78.09	0.2133	0.1640	0.06	52.27	30.90	-78.09	0.2133	0.1640	0.08
10	52.44	-63.60	-6.71	0.1908	0.4100	0.06	52.42	-63.56	-6.73	0.1908	0.4099	0.07	52.43	-63.52	-6.72	0.1909	0.4098	0.06
11	88.61	-91.61	-18.68	0.1879	0.3851	0.09	88.59	-91.47	-18.78	0.1879	0.3848	0.04	88.59	-91.41	-18.78	0.1880	0.3848	0.03
12	92.41	-53.04	-12.82	0.2508	0.3734	0.09	92.4	-52.89	-12.83	0.2510	0.3733	0.13	92.41	-53.06	-12.82	0.2508	0.3734	0.09
13	29.72	63.19	-41.18	0.3622	0.1631	0.03	29.71	63.23	-41.23	0.3621	0.1629	0.03	29.73	63.20	-41.21	0.3621	0.1630	0.03
14	64.67	113.50	-56.51	0.4058	0.1804	0.03	64.67	113.54	-56.61	0.4057	0.1802	0.02	64.68	113.56	-56.59	0.4057	0.1803	0.03
15	78.04	68.40	-34.70	0.3834	0.2490	0.03	78.04	68.51	-34.78	0.3833	0.2489	0.05	78.05	68.54	-34.77	0.3834	0.2489	0.06
16	59.78	-11.44	73.74	0.4478	0.5169	0.03	59.76	-11.42	73.72	0.4479	0.5169	0.05	59.77	-11.37	73.74	0.4480	0.5168	0.07
17	96.96	-15.60	112.05	0.4513	0.5161	0.05	96.94	-15.49	111.98	0.4514	0.5159	0.01	96.95	-15.43	111.99	0.4515	0.5158	0.03
18	98.08	-10.98	54.31	0.4070	0.4517	0.07	98.07	-10.95	54.28	0.4070	0.4516	0.08	98.09	-10.99	54.31	0.4070	0.4517	0.08
19	50.41	60.89	29.98	0.5636	0.3277	0.52	50.38	60.78	29.91	0.5633	0.3278	0.49	50.41	60.90	29.98	0.5636	0.3277	0.52
20	69.66	-85.04	55.48	0.2680	0.6096	0.47	69.65	-84.99	55.45	0.2681	0.6095	0.45	69.68	-84.94	55.51	0.2683	0.6094	0.47
21	37.51	25.91	-64.75	0.2076	0.1564	0.34	37.5	26.06	-64.89	0.2075	0.1561	0.37	37.50	26.08	-64.88	0.2075	0.1561	0.37
22	67.02	-61.55	-9.10	0.2155	0.3937	0.38	67.01	-61.51	-9.13	0.2155	0.3936	0.37	67.04	-61.49	-9.06	0.2157	0.3938	0.38
23	49.17	69.62	-40.80	0.3775	0.2015	0.42	49.16	69.62	-40.81	0.3775	0.2015	0.43	49.17	69.64	-40.80	0.3776	0.2015	0.43
24	73.12	-14.54	68.65	0.4297	0.5004	0.53	73.11	-14.51	68.61	0.4298	0.5003	0.51	73.12	-14.45	68.62	0.4299	0.5002	0.51
25	61.88	109.47	-21.88	0.4946	0.2200	0.09	61.89	109.3	-21.85	0.4944	0.2201	0.09	61.90	109.32	-21.83	0.4945	0.2202	0.09
26	91.80	-53.75	103.53	0.3836	0.5752	0.13	91.79	-53.83	103.52	0.3834	0.5753	0.11	91.80	-53.76	103.53	0.3835	0.5752	0.13
27	68.17	-43.75	-51.56	0.1768	0.2696	0.60	68.18	-43.53	-51.56	0.1771	0.2695	0.55	68.18	-43.50	-51.55	0.1772	0.2695	0.54
28	86.55	-117.06	25.13	0.2012	0.5252	0.07	86.54	-116.73	24.99	0.2015	0.5245	0.03	86.54	-116.66	24.99	0.2017	0.5245	0.02
29	46.02	87.06	-88.40	0.2715	0.1208	0.06	46.01	87.06	-88.41	0.2714	0.1208	0.06	46.02	87.07	-88.40	0.2715	0.1208	0.06
30	81.82	29.46	101.34	0.5287	0.4478	0.24	81.81	29.55	101.34	0.5289	0.4476	0.20	81.84	29.47	101.38	0.5287	0.4478	0.25

	Measured Values MR4						Measured Values MR5						Measured Values MR6					
Color	L*	a*	b*	x	y	ΔE_{00}	L*	a*	b*	x	y	ΔE_{00}	L*	a*	b*	x	y	ΔE_{00}
1	30.70	64.58	48.46	0.6819	0.3069	0.03	30.71	64.59	48.47	0.6819	0.3069	0.02	30.68	64.54	48.41	0.6819	0.3070	0.05
2	58.82	104.85	93.97	0.6886	0.3069	0.00	58.84	104.87	93.99	0.6886	0.3069	0.02	58.80	104.85	93.91	0.6886	0.3069	0.03
3	68.42	77.06	37.58	0.5621	0.3276	0.06	68.43	77.10	37.58	0.5621	0.3276	0.06	68.42	77.02	37.44	0.5618	0.3275	0.04
4	55.47	-97.49	64.09	0.2201	0.7147	0.05	55.47	-97.43	64.09	0.2203	0.7146	0.03	55.50	-96.92	64.09	0.2216	0.7133	0.08
5	84.79	-137.89	91.91	0.2202	0.7179	0.02	84.79	-137.81	91.93	0.2203	0.7178	0.02	84.83	-137.70	91.91	0.2206	0.7175	0.05
6	88.05	-95.48	64.43	0.2787	0.5927	0.05	88.05	-95.40	64.42	0.2788	0.5925	0.03	88.07	-95.54	64.32	0.2785	0.5925	0.08
7	16.62	43.74	-74.87	0.1595	0.0734	0.07	16.62	43.74	-74.86	0.1595	0.0734	0.07	16.65	43.58	-74.82	0.1594	0.0736	0.02
8	31.68	66.87	-112.40	0.1582	0.0705	0.08	31.68	66.88	-112.39	0.1582	0.0705	0.08	31.73	66.86	-112.54	0.1581	0.0705	0.05
9	52.26	30.83	-78.03	0.2134	0.1641	0.06	52.26	30.85	-78.02	0.2134	0.1641	0.08	52.31	30.84	-78.26	0.2130	0.1638	0.09
10	52.43	-63.60	-6.68	0.1908	0.4101	0.05	52.43	-63.56	-6.68	0.1909	0.4101	0.04	52.49	-63.40	-6.76	0.1912	0.4096	0.11
11	88.60	-91.69	-18.69	0.1878	0.3852	0.10	88.62	-91.49	-18.66	0.1881	0.3851	0.08	88.65	-91.56	-18.84	0.1878	0.3847	0.08
12	92.42	-53.07	-12.74	0.2509	0.3736	0.11	92.42	-53.01	-12.73	0.2510	0.3735	0.12	92.45	-53.00	-12.97	0.2507	0.3730	0.14
13	29.72	63.18	-41.18	0.3622	0.1631	0.03	29.72	63.20	-41.19	0.3622	0.1631	0.03	29.71	63.19	-41.39	0.3613	0.1627	0.06
14	64.65	113.48	-56.57	0.4057	0.1803	0.01	64.66	113.50	-56.55	0.4058	0.1803	0.02	64.66	113.50	-56.78	0.4052	0.1800	0.05
15	78.02	68.43	-34.73	0.3833	0.2490	0.04	78.04	68.52	-34.69	0.3836	0.2490	0.05	78.04	68.46	-34.93	0.3829	0.2487	0.09
16	59.79	-11.67	73.76	0.4473	0.5174	0.10	59.77	-11.39	73.79	0.4480	0.5169	0.06	59.81	-11.56	73.74	0.4476	0.5171	0.04
17	96.95	-15.51	111.99	0.4514	0.5159	0.02	96.95	-15.45	112.01	0.4515	0.5158	0.03	96.98	-15.65	111.96	0.4512	0.5161	0.08
18	98.08	-11.08	54.34	0.4069	0.4518	0.11	98.09	-11.01	54.36	0.4070	0.4518	0.07	98.11	-11.18	54.25	0.4066	0.4518	0.18
19	50.40	60.88	29.98	0.5636	0.3277	0.52	50.41	60.90	30.00	0.5636	0.3277	0.53	50.40	60.83	29.84	0.5632	0.3276	0.46
20	69.66	-84.78	55.50	0.2686	0.6092	0.45	69.67	-84.72	55.50	0.2687	0.6091	0.45	69.70	-84.93	55.42	0.2682	0.6091	0.47
21	37.50	25.89	-64.71	0.2076	0.1565	0.34	37.50	26.04	-64.83	0.2076	0.1562	0.36	37.52	25.93	-65.04	0.2069	0.1559	0.41
22	67.04	-61.58	-9.01	0.2156	0.3940	0.41	67.05	-61.54	-9.00	0.2157	0.3940	0.41	67.09	-61.59	-9.19	0.2154	0.3935	0.41
23	49.16	69.60	-40.75	0.3776	0.2016	0.42	49.17	69.62	-40.74	0.3777	0.2016	0.42	49.18	69.58	-40.97	0.3769	0.2013	0.43
24	73.11	-14.52	68.64	0.4298	0.5003	0.52	73.12	-14.47	68.65	0.4299	0.5003	0.52	73.15	-14.64	68.57	0.4294	0.5004	0.53
25	61.89	109.29	-21.80	0.4945	0.2202	0.08	61.90	109.31	-21.77	0.4946	0.2203	0.08	61.87	109.38	-22.08	0.4939	0.2198	0.14
26	91.79	-53.85	103.53	0.3834	0.5754	0.10	91.80	-53.78	103.54	0.3835	0.5753	0.13	91.84	-53.93	103.57	0.3833	0.5755	0.10
27	68.16	-43.77	-51.51	0.1768	0.2697	0.61	68.18	-43.47	-51.56	0.1772	0.2695	0.53	68.22	-43.35	-51.80	0.1771	0.2689	0.48
28	86.54	-116.78	25.04	0.2015	0.5247	0.02	86.56	-116.89	25.07	0.2014	0.5249	0.05	86.60	-116.85	24.89	0.2013	0.5242	0.09
29	46.01	87.04	-88.35	0.2716	0.1209	0.05	46.01	87.05	-88.34	0.2716	0.1209	0.05	46.01	87.06	-88.65	0.2708	0.1206	0.12
30	81.82	29.34	101.35	0.5285	0.4480	0.30	81.84	29.46	101.39	0.5287	0.4478	0.25	81.84	29.37	101.31	0.5285	0.4479	0.28

2| 1 Display calibration device performance data

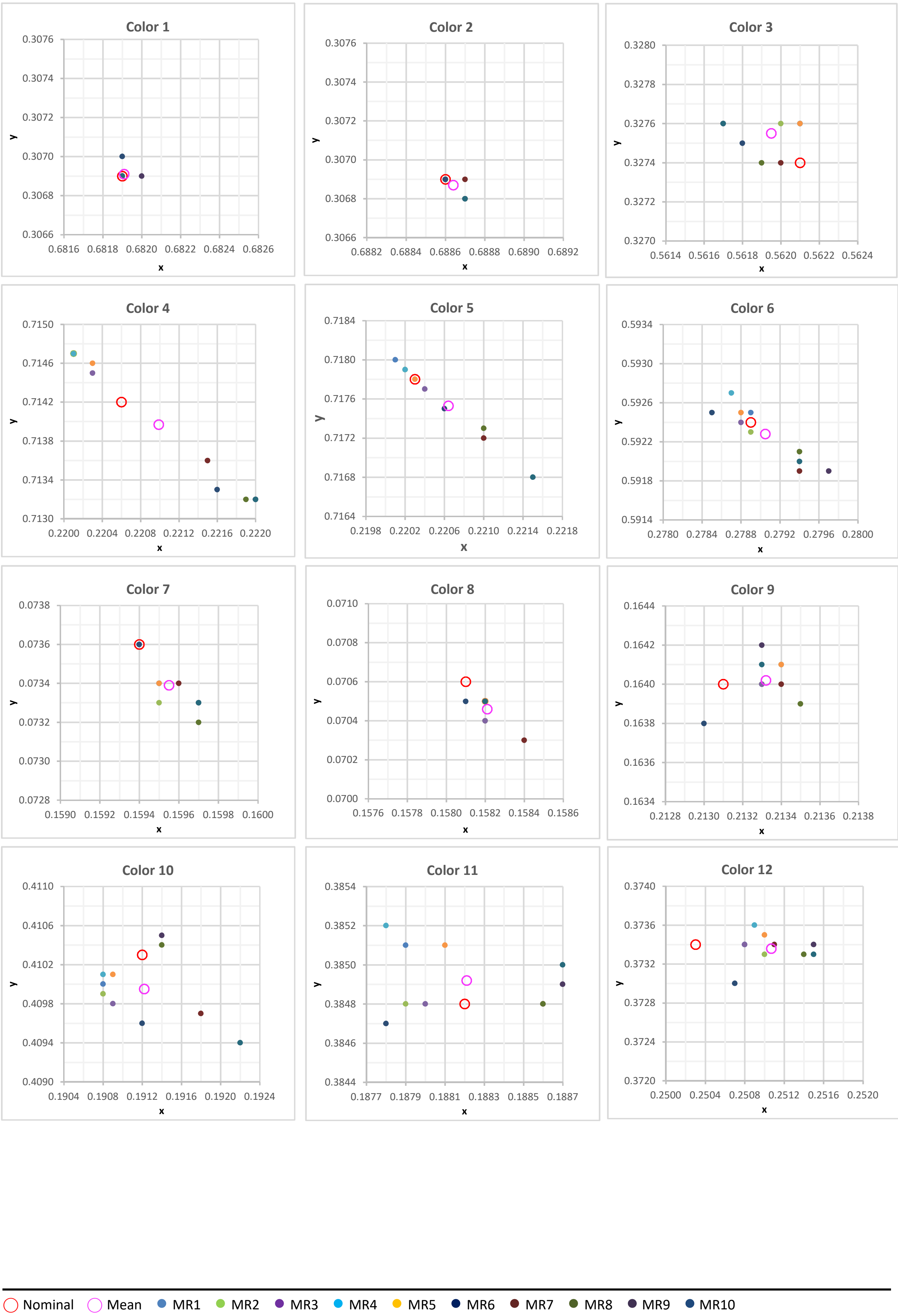
1.2 - Measured values

Color	Measured Values MR7						Measured Values MR8						Measured Values MR9					
Color	L*	a*	b*	x	y	ΔE_{00}	L*	a*	b*	x	y	ΔE_{00}	L*	a*	b*	x	y	ΔE_{00}
1	30.67	64.54	48.42	0.6819	0.3069	0.05	30.67	64.54	48.42	0.6819	0.3069	0.05	30.66	64.54	48.41	0.6820	0.3069	0.06
2	58.77	104.83	93.91	0.6887	0.3069	0.05	58.76	104.85	93.91	0.6887	0.3068	0.06	58.75	104.83	93.91	0.6887	0.3068	0.06
3	68.40	77.11	37.44	0.5620	0.3274	0.03	68.37	77.08	37.41	0.5619	0.3274	0.03	68.38	76.92	37.44	0.5617	0.3276	0.05
4	55.53	-97.01	64.16	0.2215	0.7136	0.10	55.55	-96.87	64.22	0.2219	0.7132	0.14	55.54	-96.84	64.21	0.2220	0.7132	0.14
5	84.82	-137.46	91.97	0.2210	0.7172	0.08	84.83	-137.49	92.00	0.2210	0.7173	0.08	84.84	-137.44	92.03	0.2211	0.7172	0.09
6	88.08	-95.06	64.40	0.2794	0.5919	0.07	88.09	-95.10	64.44	0.2794	0.5921	0.07	88.08	-94.93	64.46	0.2797	0.5919	0.10
7	16.63	43.78	-74.89	0.1596	0.0734	0.08	16.62	43.94	-74.97	0.1597	0.0732	0.14	16.62	43.89	-74.93	0.1597	0.0733	0.12
8	31.66	67.18	-112.52	0.1584	0.0703	0.18	31.70	66.81	-112.39	0.1582	0.0705	0.05	31.69	66.90	-112.42	0.1582	0.0705	0.08
9	52.30	30.96	-78.13	0.2134	0.1640	0.12	52.27	31.02	-78.10	0.2135	0.1639	0.15	52.29	30.75	-78.00	0.2133	0.1642	0.06
10	52.49	-63.17	-6.67	0.1918	0.4097	0.12	52.50	-63.49	-6.57	0.1914	0.4104	0.08	52.49	-63.48	-6.54	0.1914	0.4105	0.08
11	88.65	-91.07	-18.70	0.1886	0.3848	0.06	88.65	-91.04	-18.69	0.1886	0.3848	0.07	88.63	-91.03	-18.65	0.1887	0.3849	0.06
12	92.45	-52.92	-12.75	0.2511	0.3734	0.14	92.45	-52.68	-12.75	0.2514	0.3733	0.20	92.43	-52.68	-12.71	0.2515	0.3734	0.20
13	29.69	63.21	-41.35	0.3615	0.1627	0.05	29.69	63.21	-41.34	0.3616	0.1627	0.04	29.68	63.21	-41.34	0.3616	0.1627	0.04
14	64.61	113.56	-56.72	0.4054	0.1800	0.05	64.62	113.42	-56.64	0.4054	0.1802	0.03	64.60	113.44	-56.66	0.4054	0.1801	0.05
15	78.04	68.43	-34.80	0.3832	0.2489	0.05	78.02	68.52	-34.83	0.3833	0.2488	0.07	78.02	68.38	-34.76	0.3832	0.2490	0.04
16	59.81	-11.46	73.80	0.4478	0.5170	0.03	59.82	-11.63	73.82	0.4475	0.5173	0.07	59.83	-11.46	73.84	0.4479	0.5170	0.05
17	96.97	-15.57	112.03	0.4513	0.5160	0.05	96.96	-15.57	112.04	0.4513	0.5160	0.04	96.94	-15.56	112.05	0.4514	0.5160	0.03
18	98.10	-11.05	54.24	0.4068	0.4517	0.12	98.09	-11.01	54.33	0.4070	0.4517	0.08	98.07	-10.96	54.21	0.4069	0.4515	0.10
19	50.39	60.83	29.89	0.5633	0.3277	0.48	50.38	60.85	29.90	0.5634	0.3277	0.48	50.38	60.84	29.91	0.5634	0.3277	0.49
20	69.73	-84.90	55.54	0.2685	0.6093	0.50	69.72	-84.55	55.55	0.2692	0.6087	0.48	69.73	-84.77	55.58	0.2688	0.6091	0.50
21	37.56	25.91	-64.86	0.2074	0.1563	0.34	37.54	26.03	-64.89	0.2075	0.1562	0.35	37.53	26.01	-64.85	0.2075	0.1562	0.35
22	67.10	-61.34	-9.09	0.2160	0.3936	0.38	67.07	-61.18	-9.14	0.2161	0.3933	0.32	67.10	-61.21	-9.05	0.2163	0.3936	0.36
23	49.15	69.69	-40.92	0.3773	0.2012	0.45	49.14	69.76	-40.96	0.3773	0.2011	0.47	49.16	69.50	-40.86	0.3771	0.2015	0.41
24	73.16	-14.65	68.65	0.4295	0.5005	0.55	73.15	-14.46	68.66	0.4299	0.5002	0.53	73.15	-14.62	68.69	0.4296	0.5005	0.55
25	61.83	109.38	-22.03	0.4942	0.2198	0.12	61.82	109.41	-22.05	0.4942	0.2197	0.12	61.81	109.40	-22.01	0.4943	0.2198	0.11
26	91.84	-53.71	103.60	0.3837	0.5751	0.16	91.83	-53.63	103.62	0.3838	0.5750	0.19	91.82	-53.61	103.61	0.3838	0.5750	0.19
27	68.24	-43.41	-51.55	0.1774	0.2695	0.55	68.24	-43.36	-51.47	0.1776	0.2697	0.55	68.23	-43.29	-51.50	0.1776	0.2696	0.52
28	86.60	-116.51	25.08	0.2021	0.5245	0.07	86.59	-116.31	25.05	0.2023	0.5242	0.08	86.60	-116.30	25.11	0.2024	0.5243	0.10
29	45.99	87.23	-88.47	0.2716	0.1207	0.03	45.97	87.34	-88.51	0.2716	0.1206	0.03	45.96	87.31	-88.45	0.2717	0.1206	0.03
30	81.84	29.35	101.37	0.5285	0.4480	0.30	81.83	29.28	101.38	0.5284	0.4481	0.33	81.82	29.29	101.37	0.5285	0.4481	0.32

Color	Measured Values MR10					
Color	L*	a*	b*	x	y	ΔE_{00}
1	30.66	64.54	48.41	0.6819	0.3069	0.06
2	58.75	104.83	93.90	0.6887	0.3068	0.07
3	68.38	76.93	37.43	0.5617	0.3276	0.04
4	55.54	-96.84	64.21	0.2220	0.7132	0.14
5	84.85	-137.22	92.04	0.2215	0.7168	0.13
6	88.10	-95.08	64.45	0.2794	0.5920	0.08
7	16.62	43.88	-74.92	0.1597	0.0733	0.12
8	31.68	66.90	-112.42	0.1582	0.0705	0.08
9	52.29	30.83	-78.08	0.2133	0.1641	0.07
10	52.51	-62.98	-6.69	0.1922	0.4094	0.17
11	88.65	-91.05	-18.61	0.1887	0.3850	0.08
12	92.45	-52.65	-12.75	0.2515	0.3733	0.21
13	29.68	63.21	-41.35	0.3615	0.1626	0.05
14	64.60	113.44	-56.66	0.4054	0.1801	0.05
15	78.02	68.42	-34.84	0.3831	0.2488	0.07
16	59.83	-11.46	73.84	0.4479	0.5170	0.05
17	96.96	-15.59	112.04	0.4513	0.5161	0.05
18	98.08	-11.06	54.22	0.4068	0.4517	0.13
19	50.38	60.83	29.89	0.5633	0.3277	0.48
20	69.73	-84.77	55.57	0.2688	0.6091	0.50
21	37.53	26.01	-64.85	0.2075	0.1562	0.35
22	67.10	-61.21	-9.05	0.2163	0.3936	0.36
23	49.16	69.50	-40.86	0.3771	0.2015	0.41
24	73.17	-14.50	68.70	0.4298	0.5003	0.55
25	61.81	109.24	-22.12	0.4937	0.2198	0.15
26	91.83	-53.73	103.62	0.3836	0.5752	0.16
27	68.23	-43.29	-51.50	0.1776	0.2696	0.52
28	86.60	-116.30	25.11	0.2024	0.5243	0.10
29	45.96	87.38	-88.53	0.2716	0.1205	0.04
30	81.82	29.29	101.37	0.5285	0.4481	0.32

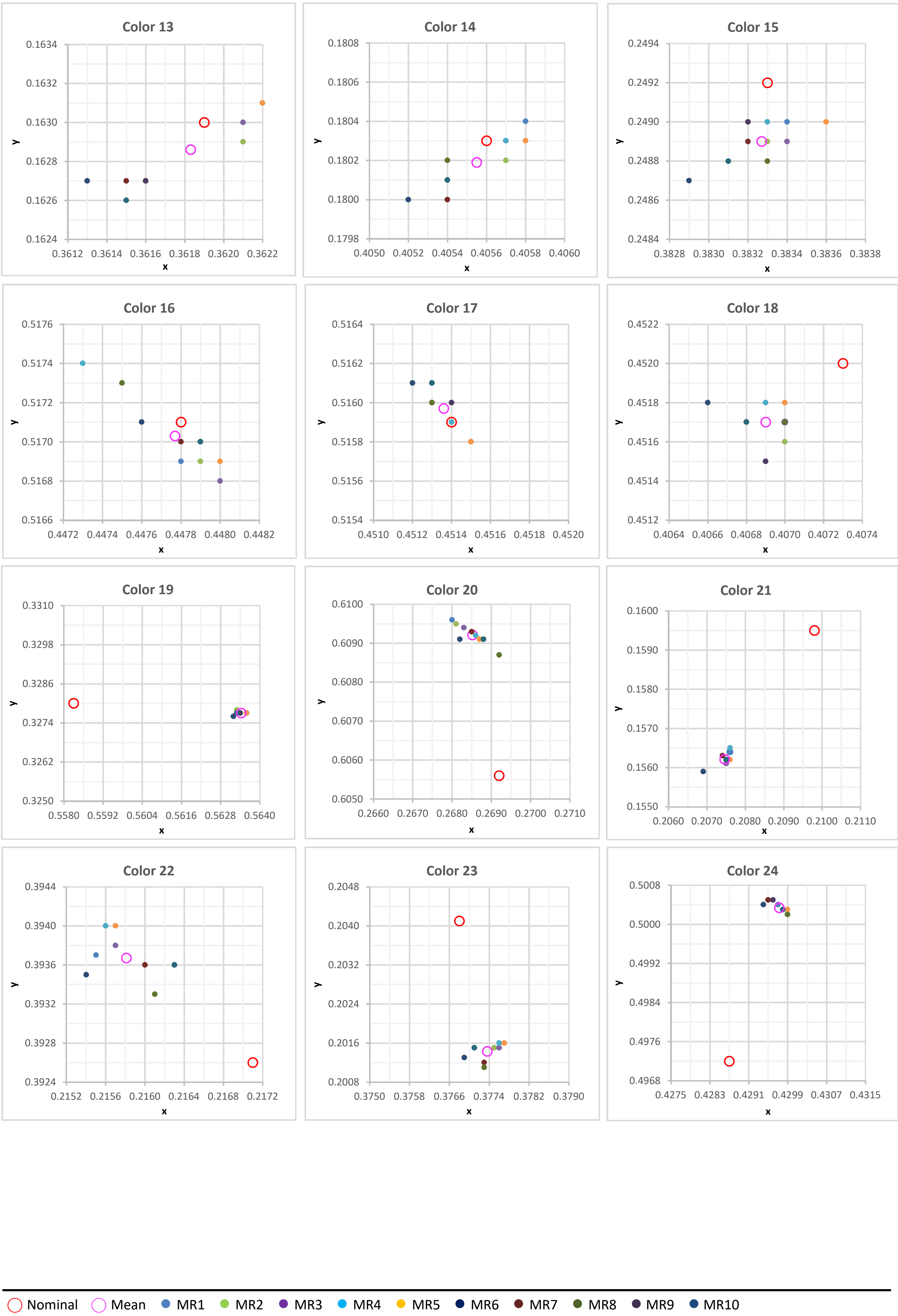
2| 1 Display calibration device performance data

1.3 - Visualization of the measured values in the CIExy chromaticity diagram



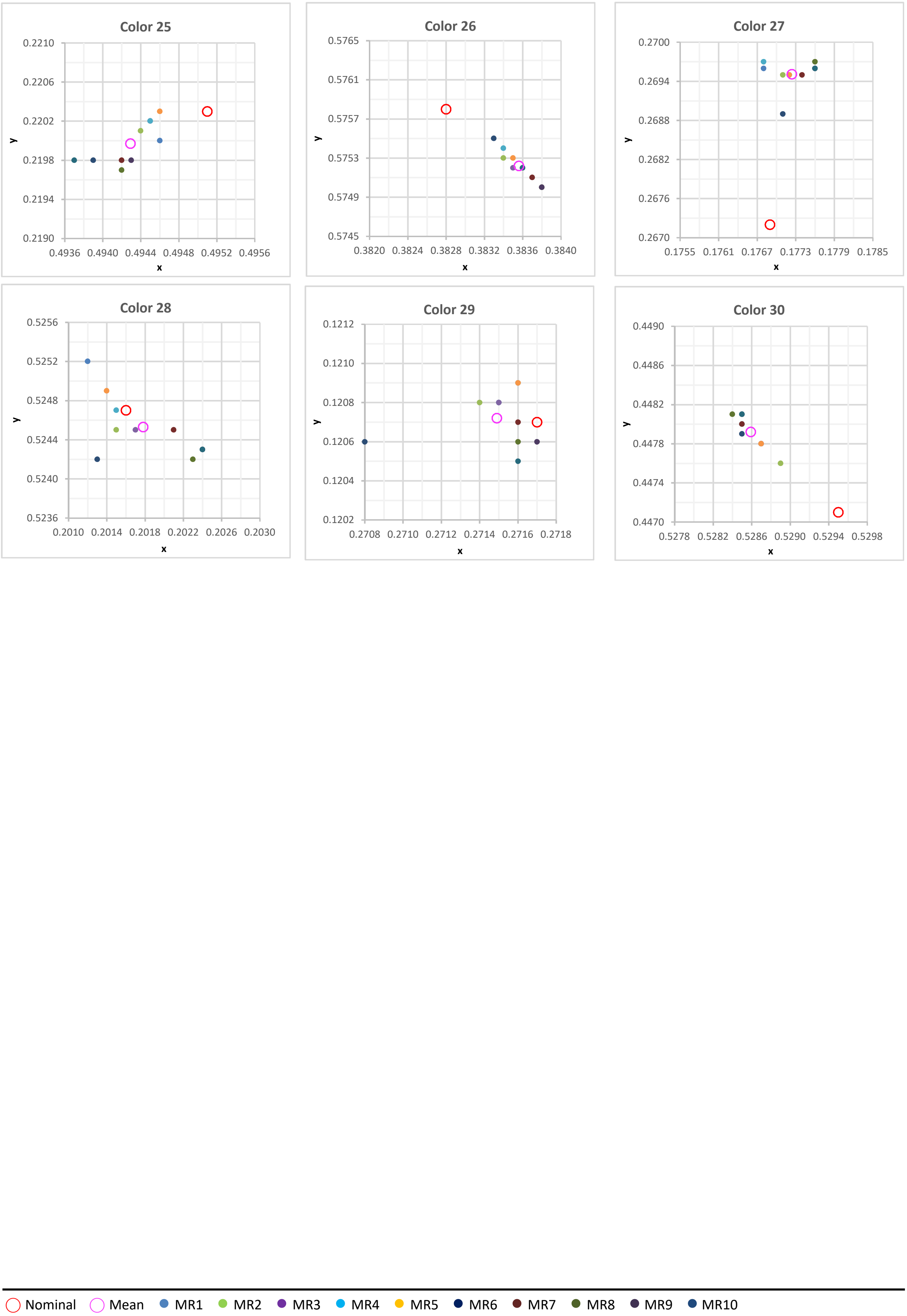
2| 1 Display calibration device performance data

1.3 - Visualization of the measured values in the CIExy chromaticity diagram



2| 1 Display calibration device performance data

1.3 - Visualization of the measured values in the CIExy chromaticity diagram



2| 1 Display calibration device performance data

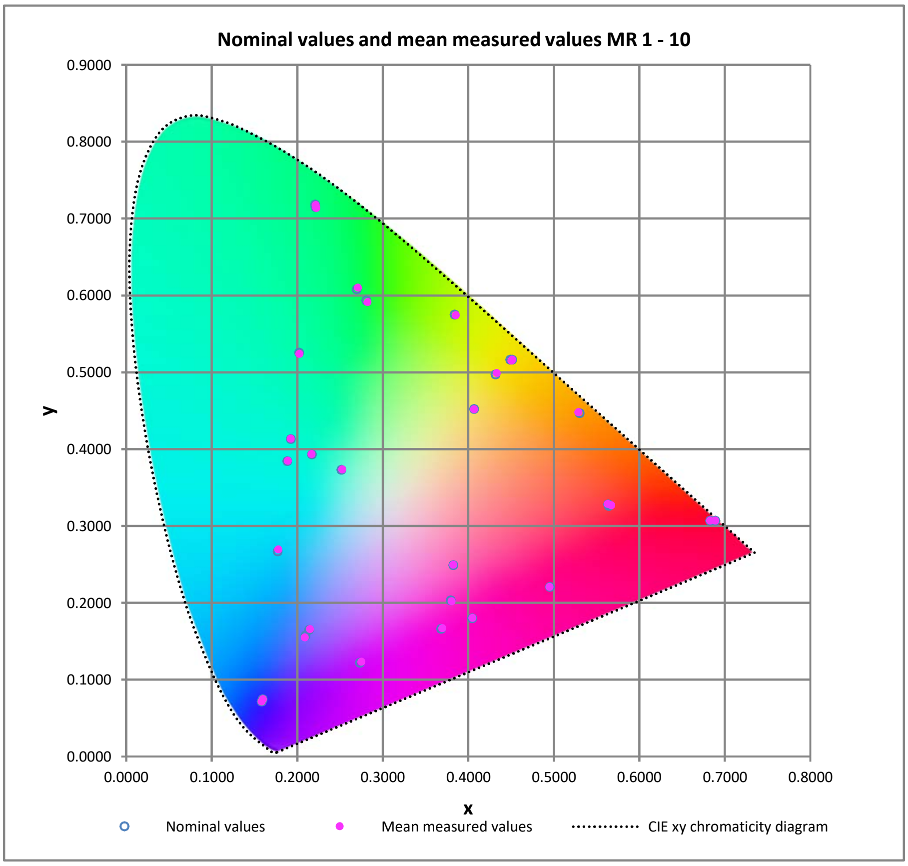
1.4 - Color accuracy and repeatability of the measurements

	Device Values			Nominal Values					Accuracy (ΔE_{00} MR1 – MR10)				Repeatability (ΔE_{00} MR1 – MR10)			
Color	R	G	B	L*	a*	b*	x	y	Mean	Min	Max	SD	Mean	Min	Max	SD
1	128	0	0	30.73	64.64	48.49	0.6819	0.3069	0.04	0.02	0.06	0.0173	0.02	0.01	0.02	0.0048
2	255	0	0	58.82	104.87	93.98	0.6886	0.3069	0.03	0.00	0.07	0.0244	0.02	0.01	0.04	0.0113
3	255	128	128	68.38	77.12	37.49	0.5621	0.3274	0.05	0.03	0.06	0.0126	0.03	0.02	0.05	0.0100
4	0	128	0	55.46	-97.26	64.06	0.2206	0.7142	0.08	0.03	0.14	0.0443	0.05	0.05	0.09	0.0160
5	0	255	0	84.76	-137.79	91.88	0.2203	0.7178	0.05	0.02	0.13	0.0369	0.06	0.02	0.08	0.0177
6	128	255	128	88.01	-95.27	64.37	0.2789	0.5924	0.05	0.01	0.10	0.0270	0.04	0.02	0.08	0.0196
7	0	0	128	16.63	43.55	-74.76	0.1594	0.0736	0.08	0.01	0.14	0.0416	0.04	0.01	0.08	0.0304
8	0	0	255	31.70	66.67	-112.36	0.1581	0.0706	0.08	0.05	0.18	0.0372	0.03	0.00	0.10	0.0311
9	128	128	255	52.23	30.77	-78.08	0.2131	0.1640	0.08	0.06	0.15	0.0283	0.03	0.01	0.09	0.0283
10	0	128	128	52.42	-63.49	-6.60	0.1912	0.4103	0.08	0.04	0.17	0.0398	0.05	0.04	0.13	0.0255
11	0	255	255	88.57	-91.25	-18.75	0.1882	0.3848	0.07	0.03	0.10	0.0210	0.06	0.04	0.08	0.0127
12	170	255	255	92.32	-53.30	-12.88	0.2503	0.3734	0.14	0.09	0.21	0.0444	0.06	0.03	0.10	0.0213
13	128	0	128	29.70	63.13	-41.21	0.3619	0.1630	0.04	0.03	0.06	0.0114	0.04	0.02	0.05	0.0062
14	255	0	255	64.65	113.43	-56.57	0.4056	0.1803	0.03	0.01	0.05	0.0142	0.03	0.02	0.04	0.0085
15	255	170	255	78.06	68.31	-34.66	0.3833	0.2492	0.06	0.03	0.09	0.0175	0.03	0.01	0.05	0.0129
16	128	128	0	59.79	-11.50	73.79	0.4478	0.5171	0.06	0.03	0.10	0.0211	0.04	0.02	0.10	0.0252
17	255	255	0	96.92	-15.49	111.96	0.4514	0.5159	0.04	0.01	0.08	0.0193	0.04	0.01	0.05	0.0160
18	255	255	170	98.03	-10.96	54.52	0.4073	0.4520	0.10	0.07	0.18	0.0351	0.03	0.02	0.10	0.0226
19	170	85	85	50.38	59.69	28.73	0.5583	0.3280	0.50	0.46	0.53	0.0213	0.03	0.02	0.04	0.0076
20	85	170	85	69.25	-83.59	54.31	0.2692	0.6056	0.48	0.45	0.50	0.0200	0.03	0.03	0.08	0.0160
21	85	85	170	37.77	25.27	-63.60	0.2098	0.1595	0.36	0.34	0.41	0.0213	0.04	0.02	0.11	0.0286
22	85	170	170	66.79	-60.36	-9.17	0.2171	0.3926	0.38	0.32	0.41	0.0297	0.05	0.03	0.08	0.0148
23	170	85	170	49.37	68.10	-40.04	0.3768	0.2041	0.43	0.41	0.47	0.0193	0.04	0.01	0.05	0.0118
24	170	170	85	72.91	-14.02	66.66	0.4287	0.4972	0.53	0.51	0.55	0.0146	0.04	0.01	0.07	0.0178
25	255	0	170	61.82	109.31	-21.62	0.4951	0.2203	0.11	0.08	0.15	0.0240	0.04	0.03	0.07	0.0118
26	170	255	0	91.74	-54.11	103.44	0.3828	0.5758	0.14	0.10	0.19	0.0344	0.04	0.01	0.06	0.0177
27	0	170	255	67.78	-42.55	-52.16	0.1769	0.2672	0.55	0.48	0.61	0.0372	0.05	0.02	0.11	0.0352
28	0	255	170	86.51	-116.69	25.04	0.2016	0.5247	0.06	0.02	0.10	0.0290	0.05	0.03	0.07	0.0184
29	170	0	255	45.97	87.19	-88.38	0.2717	0.1207	0.05	0.03	0.12	0.0274	0.05	0.02	0.09	0.0211
30	255	170	0	81.67	29.87	101.25	0.5295	0.4471	0.28	0.20	0.33	0.0441	0.04	0.01	0.09	0.0211
								Mean	0.17	0.13	0.21	0.0272	0.04	0.02	0.08	0.0181

2| 2 Display calibration device performance data

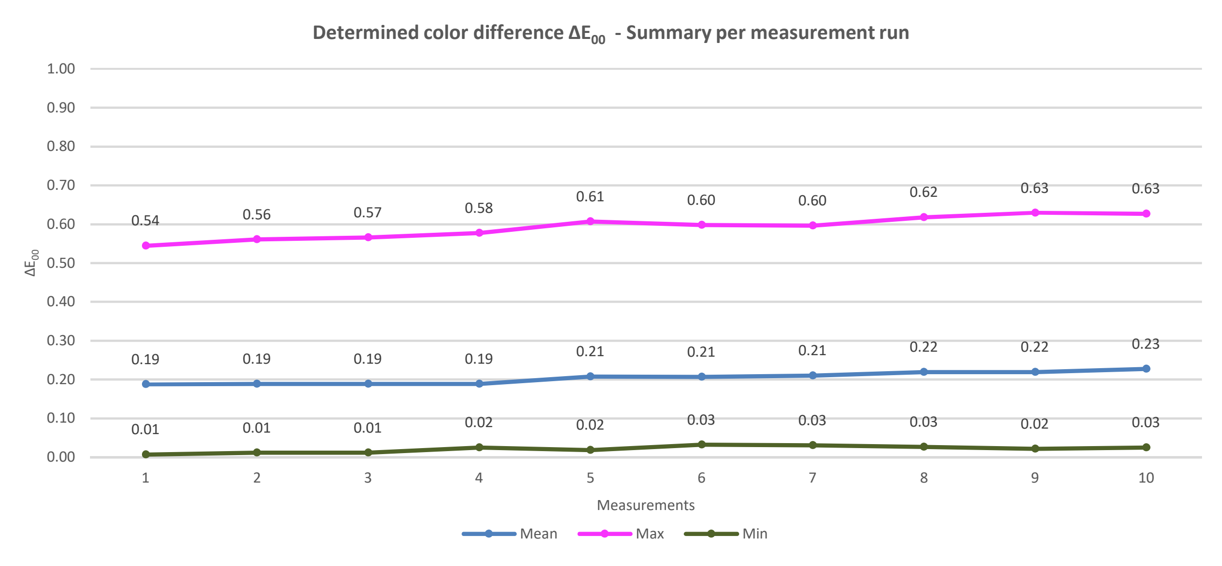
1.1 - Summary and visualization of the measured values

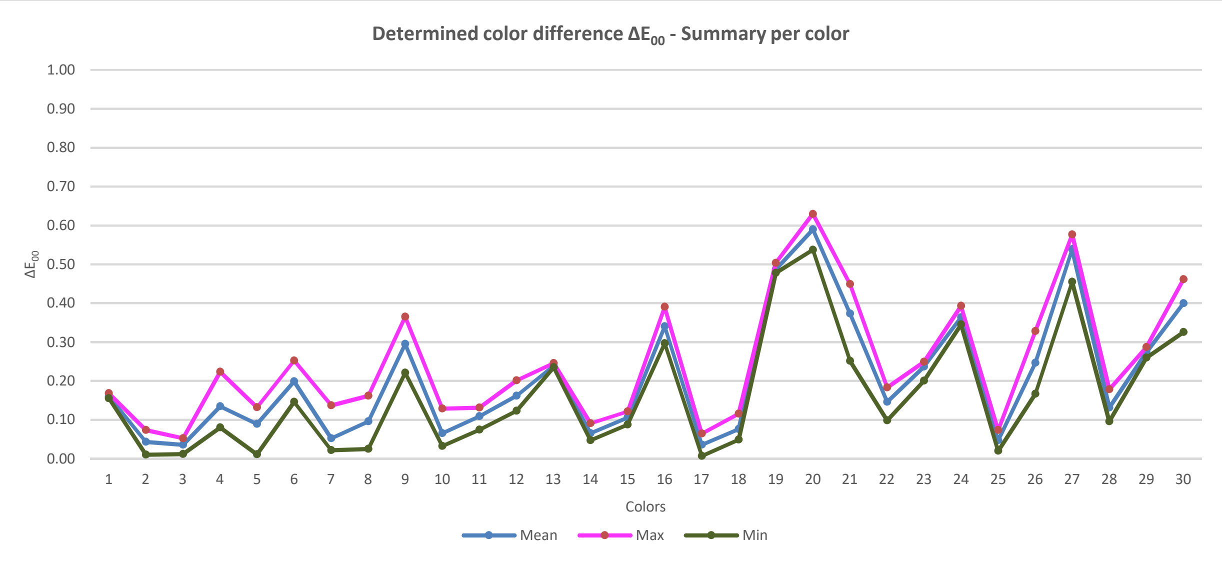
		Device Values			Nominal Values					Mean Measured Values MR1 - MR10					
Color		R	G	B	L*	a*	b*	x	y	L*	a*	b*	x	y	ΔE_{00}
	1	128	0	0	30.81	64.94	48.86	0.6829	0.3066	30.97	65.20	49.17	0.6830	0.3066	0.16
	2	255	0	0	58.74	104.96	93.85	0.6889	0.3066	58.70	104.93	93.80	0.6890	0.3065	0.04
	3	255	128	128	68.29	77.11	38.23	0.5636	0.3281	68.28	77.00	38.18	0.5633	0.3282	0.03
	4	0	128	0	55.32	-96.86	64.27	0.2214	0.7146	55.28	-96.34	64.28	0.2225	0.7136	0.12
	5	0	255	0	84.86	-137.61	92.33	0.2210	0.7179	84.88	-137.12	92.40	0.2219	0.7172	0.09
	6	128	255	128	88.11	-94.66	65.26	0.2809	0.5930	88.19	-93.65	65.01	0.2825	0.5909	0.20
	7	0	0	128	16.35	42.83	-73.67	0.1599	0.0743	16.35	42.76	-73.58	0.1600	0.0744	0.02
	8	0	0	255	31.97	66.18	-112.09	0.1585	0.0715	31.96	66.39	-112.12	0.1587	0.0714	0.08
	9	128	128	255	52.56	30.85	-77.93	0.2141	0.1648	52.61	31.13	-77.60	0.2153	0.1653	0.29
	10	0	128	128	52.37	-63.33	-5.90	0.1927	0.4129	52.35	-63.37	-5.88	0.1926	0.4131	0.03
	11	0	255	255	88.69	-90.90	-18.96	0.1886	0.3840	88.69	-90.71	-18.71	0.1891	0.3845	0.10
	12	170	255	255	92.53	-52.29	-12.87	0.2519	0.3728	92.55	-51.98	-12.60	0.2527	0.3731	0.15
	13	128	0	128	29.92	63.40	-39.86	0.3685	0.1660	30.17	63.78	-39.74	0.3700	0.1667	0.24
	14	255	0	255	64.66	113.47	-56.90	0.4048	0.1799	64.65	113.33	-56.66	0.4052	0.1802	0.06
	15	255	170	255	78.06	68.33	-34.99	0.3826	0.2487	78.10	68.04	-34.71	0.3828	0.2493	0.10
	16	128	128	0	59.74	-10.92	74.01	0.4493	0.5161	59.85	-10.37	74.21	0.4507	0.5149	0.34
	17	255	255	0	96.95	-15.67	112.21	0.4513	0.5163	96.95	-15.67	112.25	0.4513	0.5163	0.01
	18	255	255	170	98.05	-11.09	54.49	0.4071	0.4521	98.06	-10.99	54.30	0.4070	0.4517	0.07
	19	170	85	85	50.34	61.63	29.53	0.5644	0.3259	50.46	62.18	30.65	0.5676	0.3265	0.49
	20	85	170	85	69.27	-83.77	55.13	0.2697	0.6078	69.87	-84.18	56.50	0.2712	0.6099	0.59
	21	85	85	170	37.47	26.43	-64.20	0.2099	0.1572	37.27	27.38	-65.11	0.2090	0.1546	0.36
	22	85	170	170	66.92	-60.33	-9.08	0.2175	0.3928	67.03	-60.71	-9.05	0.2170	0.3931	0.14
	23	170	85	170	49.30	69.50	-39.97	0.3798	0.2032	49.26	70.48	-40.30	0.3808	0.2019	0.24
	24	170	170	85	73.12	-13.05	68.01	0.4320	0.4970	73.17	-13.07	69.41	0.4334	0.4987	0.36
	25	255	0	170	61.80	109.23	-21.43	0.4956	0.2206	61.77	109.24	-21.52	0.4954	0.2204	0.03
	26	170	255	0	91.86	-53.50	103.90	0.3842	0.5750	91.94	-52.83	104.07	0.3855	0.5740	0.25
	27	0	170	255	67.93	-42.17	-52.37	0.1773	0.2668	68.28	-43.05	-51.56	0.1779	0.2694	0.54
	28	0	255	170	86.59	-116.56	25.36	0.2023	0.5253	86.61	-115.98	25.01	0.2028	0.5237	0.13
	29	170	0	255	46.39	87.50	-88.04	0.2736	0.1219	46.59	87.58	-87.48	0.2754	0.1229	0.27
	30	255	170	0	81.48	30.25	101.27	0.5304	0.4465	81.69	29.55	101.42	0.5291	0.4477	0.40

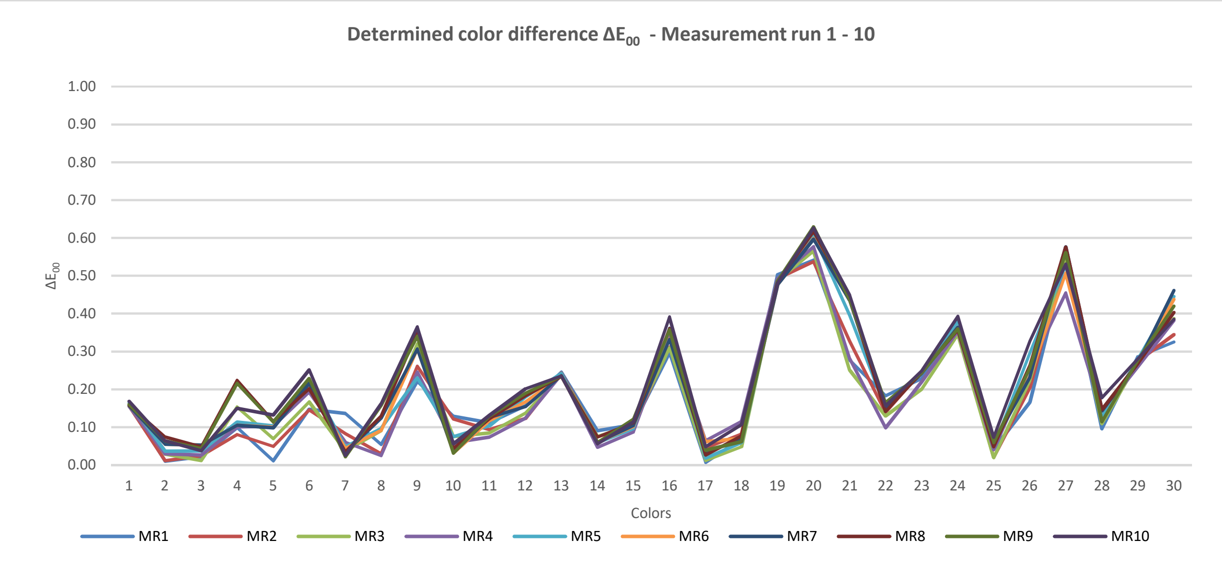


2| 2 Display calibration device performance data

1.1 - Summary and visualization of the measured values







2| 2 Display calibration device performance data

1.2 - Measured values

	Measured Values MR1						Measured Values MR2						Measured Values MR3					
Color	L*	a*	b*	x	y	ΔE_{00}	L*	a*	b*	x	y	ΔE_{00}	L*	a*	b*	x	y	ΔE_{00}
1	30.98	65.19	49.16	0.6829	0.3066	0.16	30.97	65.17	49.15	0.6829	0.3066	0.15	30.98	65.19	49.15	0.6830	0.3066	0.16
2	58.75	104.95	93.83	0.6889	0.3066	0.01	58.73	104.95	93.82	0.6889	0.3066	0.01	58.71	104.93	93.80	0.6889	0.3066	0.03
3	68.31	77.17	38.27	0.5637	0.3281	0.02	68.30	77.05	38.25	0.5635	0.3282	0.02	68.30	77.09	38.24	0.5635	0.3282	0.01
4	55.22	-96.90	64.17	0.2209	0.7149	0.10	55.24	-96.71	64.20	0.2214	0.7145	0.08	55.25	-96.18	64.23	0.2228	0.7133	0.15
5	84.85	-137.55	92.29	0.2211	0.7178	0.01	84.85	-137.30	92.32	0.2215	0.7174	0.05	84.87	-137.19	92.35	0.2217	0.7172	0.07
6	88.17	-93.89	64.97	0.2820	0.5912	0.15	88.16	-93.90	65.03	0.2820	0.5914	0.15	88.17	-93.79	64.98	0.2822	0.5911	0.17
7	16.36	42.43	-73.43	0.1598	0.0747	0.14	16.35	42.58	-73.51	0.1598	0.0745	0.08	16.35	42.71	-73.58	0.1599	0.0744	0.04
8	32.01	66.04	-112.03	0.1585	0.0716	0.05	31.98	66.24	-112.08	0.1586	0.0715	0.03	31.96	66.41	-112.12	0.1587	0.0714	0.09
9	52.59	31.04	-77.65	0.2150	0.1653	0.22	52.61	31.09	-77.63	0.2151	0.1653	0.26	52.60	31.21	-77.65	0.2153	0.1652	0.32
10	52.30	-63.75	-5.93	0.1916	0.4133	0.13	52.32	-63.69	-5.81	0.1920	0.4137	0.12	52.31	-63.51	-5.92	0.1921	0.4131	0.08
11	88.69	-91.11	-18.75	0.1885	0.3847	0.11	88.67	-91.02	-18.77	0.1886	0.3845	0.09	88.68	-90.90	-18.76	0.1888	0.3845	0.08
12	92.55	-52.39	-12.61	0.2521	0.3734	0.16	92.53	-52.09	-12.64	0.2525	0.3731	0.12	92.55	-52.13	-12.61	0.2525	0.3732	0.14
13	30.18	63.74	-39.70	0.3701	0.1668	0.25	30.17	63.67	-39.62	0.3702	0.1670	0.24	30.17	63.77	-39.73	0.3700	0.1667	0.24
14	64.72	113.23	-56.57	0.4052	0.1805	0.09	64.70	113.28	-56.61	0.4052	0.1804	0.07	64.68	113.26	-56.58	0.4053	0.1804	0.08
15	78.12	68.08	-34.70	0.3829	0.2493	0.11	78.12	68.11	-34.71	0.3829	0.2493	0.10	78.12	68.06	-34.70	0.3828	0.2493	0.11
16	59.80	-10.41	74.11	0.4506	0.5150	0.30	59.81	-10.39	74.14	0.4506	0.5149	0.31	59.85	-10.42	74.20	0.4506	0.5150	0.31
17	96.96	-15.67	112.19	0.4513	0.5163	0.01	96.94	-15.57	112.18	0.4514	0.5161	0.04	96.96	-15.65	112.23	0.4513	0.5163	0.01
18	98.06	-10.98	54.33	0.4070	0.4517	0.07	98.05	-10.97	54.27	0.4070	0.4516	0.08	98.05	-11.02	54.36	0.4070	0.4518	0.05
19	50.47	62.17	30.68	0.5676	0.3266	0.50	50.46	62.16	30.66	0.5676	0.3266	0.49	50.46	62.16	30.65	0.5675	0.3266	0.49
20	69.83	-84.45	56.42	0.2705	0.6103	0.54	69.82	-84.29	56.41	0.2708	0.6100	0.54	69.85	-84.23	56.46	0.2710	0.6099	0.57
21	37.27	27.13	-65.06	0.2086	0.1548	0.28	37.24	27.26	-65.10	0.2087	0.1546	0.33	37.28	26.95	-65.05	0.2083	0.1549	0.25
22	66.99	-60.96	-9.07	0.2165	0.3933	0.18	66.99	-60.79	-9.08	0.2168	0.3931	0.14	67.01	-60.71	-9.06	0.2170	0.3931	0.13
23	49.27	70.45	-40.24	0.3809	0.2021	0.23	49.25	70.52	-40.29	0.3809	0.2019	0.25	49.28	70.34	-40.25	0.3806	0.2021	0.20
24	73.14	-13.03	69.35	0.4334	0.4986	0.35	73.14	-12.98	69.34	0.4336	0.4985	0.36	73.15	-13.10	69.37	0.4333	0.4987	0.35
25	61.83	109.17	-21.31	0.4957	0.2208	0.04	61.79	109.14	-21.38	0.4956	0.2207	0.02	61.79	109.22	-21.49	0.4954	0.2205	0.02
26	91.93	-53.04	103.98	0.3851	0.5742	0.17	91.91	-52.91	103.97	0.3853	0.5740	0.20	91.94	-52.89	104.04	0.3854	0.5740	0.22
27	68.24	-43.20	-51.66	0.1775	0.2692	0.54	68.25	-43.24	-51.65	0.1775	0.2693	0.56	68.27	-43.14	-51.62	0.1777	0.2693	0.55
28	86.60	-116.44	25.05	0.2021	0.5243	0.10	86.58	-116.18	24.99	0.2024	0.5239	0.12	86.60	-116.24	25.01	0.2024	0.5240	0.11
29	46.63	87.41	-87.43	0.2753	0.1231	0.29	46.61	87.51	-87.48	0.2753	0.1229	0.27	46.59	87.62	-87.50	0.2754	0.1229	0.27
30	81.69	29.70	101.39	0.5293	0.4474	0.33	81.67	29.64	101.37	0.5292	0.4475	0.34	81.68	29.56	101.39	0.5291	0.4476	0.39

	Measured Values MR4						Measured Values MR5						Measured Values MR6					
Color	L*	a*	b*	x	y	ΔE_{00}	L*	a*	b*	x	y	ΔE_{00}	L*	a*	b*	x	y	ΔE_{00}
1	30.97	65.19	49.15	0.6830	0.3066	0.15	30.98	65.21	49.18	0.6830	0.3066	0.17	30.97	65.19	49.16	0.6830	0.3066	0.16
2	58.71	104.94	93.80	0.6889	0.3065	0.03	58.70	104.95	93.83	0.6890	0.3065	0.04	58.68	104.92	93.79	0.6890	0.3065	0.06
3	68.28	77.07	38.16	0.5634	0.3281	0.03	68.27	77.07	38.14	0.5634	0.3280	0.04	68.27	76.89	38.13	0.5631	0.3283	0.05
4	55.25	-96.48	64.24	0.2221	0.7139	0.10	55.30	-96.36	64.32	0.2226	0.7136	0.11	55.29	-96.40	64.30	0.2224	0.7137	0.10
5	84.86	-136.99	92.36	0.2221	0.7169	0.10	84.90	-137.06	92.43	0.2221	0.7171	0.10	84.90	-137.10	92.45	0.2220	0.7171	0.10
6	88.16	-93.64	64.94	0.2824	0.5908	0.19	88.21	-93.53	65.01	0.2827	0.5907	0.23	88.19	-93.58	65.01	0.2826	0.5908	0.21
7	16.36	42.64	-73.53	0.1599	0.0745	0.06	16.35	42.93	-73.68	0.1601	0.0742	0.05	16.34	42.90	-73.65	0.1601	0.0743	0.04
8	32.00	66.21	-112.13	0.1585	0.0715	0.02	31.97	66.43	-112.13	0.1587	0.0714	0.10	31.95	66.39	-112.09	0.1588	0.0714	0.09
9	52.61	31.07	-77.64	0.2151	0.1653	0.25	52.62	31.04	-77.64	0.2150	0.1653	0.23	52.62	31.12	-77.56	0.2154	0.1654	0.31
10	52.34	-63.45	-5.83	0.1925	0.4134	0.06	52.38	-63.34	-5.76	0.1929	0.4135	0.07	52.37	-63.22	-5.92	0.1929	0.4127	0.03
11	88.67	-90.72	-18.78	0.1890	0.3843	0.07	88.71	-90.53	-18.73	0.1893	0.3844	0.10	88.70	-90.76	-18.67	0.1891	0.3846	0.12
12	92.54	-51.94	-12.69	0.2526	0.3729	0.12	92.57	-51.86	-12.57	0.2529	0.3731	0.18	92.55	-51.87	-12.60	0.2528	0.3730	0.17
13	30.17	63.74	-39.70	0.3701	0.1668	0.24	30.17	63.77	-39.71	0.3701	0.1667	0.24	30.16	63.74	-39.69	0.3701	0.1668	0.23
14	64.66	113.29	-56.70	0.4050	0.1802	0.05	64.64	113.35	-56.66	0.4052	0.1802	0.06	64.61	113.35	-56.71	0.4051	0.1801	0.06
15	78.09	68.08	-34.75	0.3828	0.2492	0.09	78.11	68.10	-34.73	0.3828	0.2493	0.10	78.08	68.05	-34.70	0.3828	0.2493	0.10
16	59.83	-10.34	74.18	0.4508	0.5148	0.35	59.88	-10.35	74.27	0.4508	0.5149	0.36	59.86	-10.39	74.25	0.4507	0.5150	0.33
17	96.94	-15.53	112.21	0.4515	0.5161	0.06	96.96	-15.65	112.28	0.4514	0.5163	0.02	96.95	-15.81	112.26	0.4511	0.5165	0.06
18	98.04	-10.90	54.26	0.4071	0.4516	0.12	98.07	-11.00	54.35	0.4070	0.4518	0.06	98.06	-11.06	54.25	0.4068	0.4517	0.07
19	50.48	62.27	30.67	0.5678	0.3264	0.49	50.47	62.18	30.64	0.5675	0.3265	0.48	50.45	62.15	30.63	0.5675	0.3266	0.48
20	69.86	-84.10	56.46	0.2713	0.6097	0.58	69.90	-84.26	56.53	0.2711	0.6100	0.61	69.89	-84.30	56.52	0.2710	0.6101	0.60
21	37.26	27.10	-65.13	0.2084	0.1546	0.28	37.29	27.48	-65.09	0.2093	0.1546	0.40	37.27	27.58	-65.17	0.2092	0.1544	0.43
22	67.02	-60.54	-9.11	0.2172	0.3928	0.10	67.07	-60.64	-9.06	0.2172	0.3931	0.15	67.05	-60.69	-9.04	0.2171	0.3932	0.15
23	49.27	70.42	-40.34	0.3805	0.2019	0.22	49.27	70.54	-40.36	0.3807	0.2018	0.25	49.25	70.50	-40.33	0.3807	0.2018	0.24
24	73.16	-13.05	69.37	0.4334	0.4986	0.35	73.19	-13.02	69.44	0.4335	0.4986	0.38	73.17	-13.07	69.42	0.4334	0.4987	0.36
25	61.79	109.26	-21.57	0.4953	0.2204	0.04	61.78	109.30	-21.59	0.4953	0.2203	0.05	61.75	109.27	-21.57	0.4953	0.2203	0.06
26	91.94	-52.78	104.04	0.3856	0.5739	0.26	91.96	-52.70	104.11	0.3857	0.5738	0.30	91.95	-52.89	104.11	0.3854	0.5741	0.23
27	68.26	-42.81	-51.64	0.1781	0.2691	0.45	68.30	-42.93	-51.51	0.1782	0.2695	0.53	68.28	-42.90	-51.54	0.1782	0.2694	0.51
28	86.60	-116.01	24.93	0.2026	0.5235	0.14	86.64	-115.89	25.07	0.2030	0.5238	0.13	86.62	-115.87	24.97	0.2029	0.5235	0.14
29	46.61	87.50	-87.55	0.2751	0.1229	0.26	46.60	87.63	-87.51	0.2754	0.1229	0.28	46.58	87.60	-87.47	0.2754	0.1229	0.27
30	81.69	29.58	101.41	0.5291	0.4476	0.38	81.70	29.46	101.44	0.5289	0.4478	0.45	81.69	29.48	101.47	0.5290	0.4478	0.44

2| 2 Display calibration device performance data

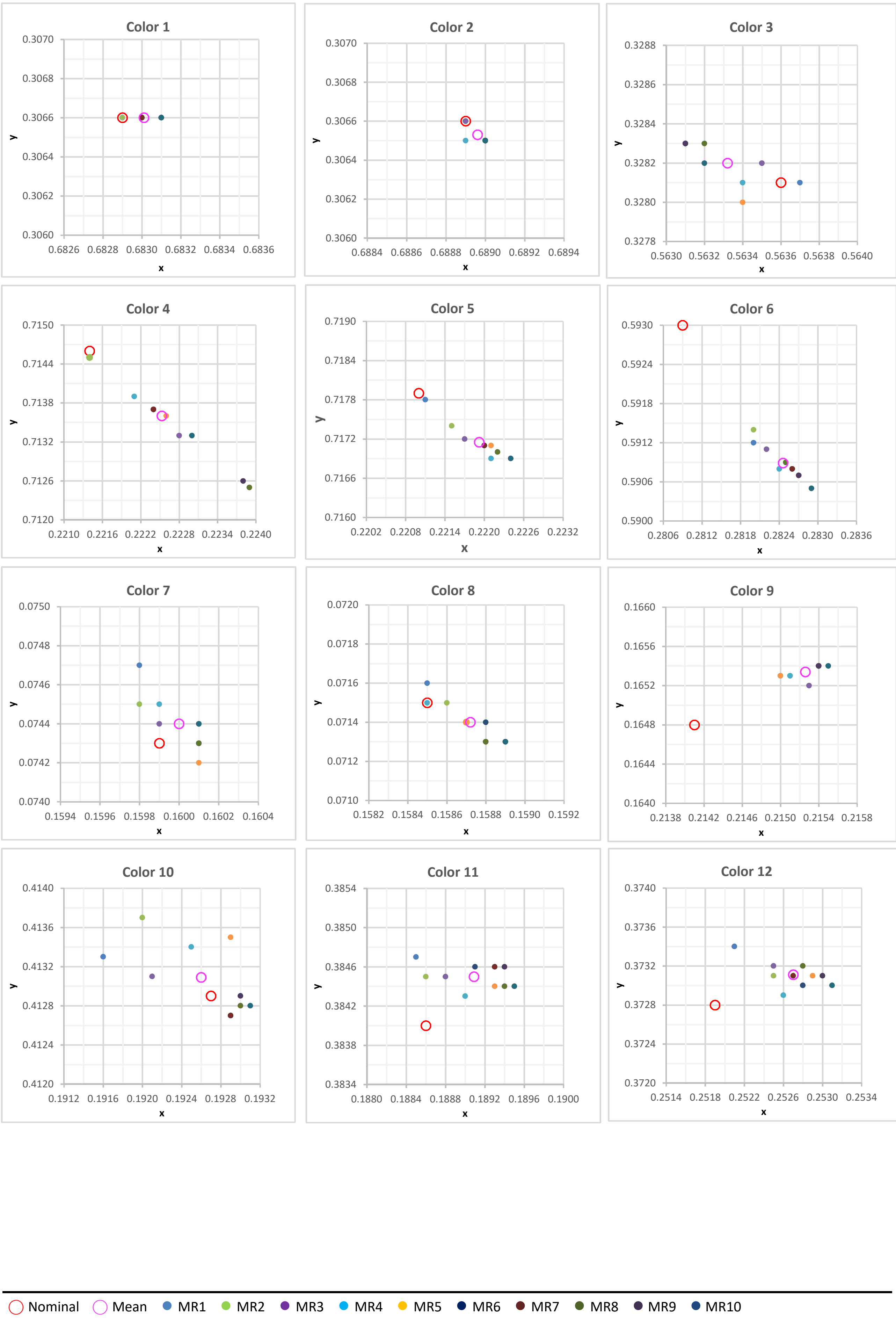
1.2 - Measured values

	Measured Values MR7						Measured Values MR8						Measured Values MR9					
Color	L*	a*	b*	x	y	ΔE_{00}	L*	a*	b*	x	y	ΔE_{00}	L*	a*	b*	x	y	ΔE_{00}
1	30.97	65.19	49.16	0.6830	0.3066	0.16	30.97	65.2	49.17	0.6831	0.3066	0.16	30.97	65.22	49.18	0.6831	0.3066	0.16
2	58.68	104.92	93.79	0.6890	0.3065	0.06	58.66	104.88	93.77	0.6890	0.3065	0.07	58.67	104.90	93.79	0.6890	0.3065	0.06
3	68.27	76.89	38.13	0.5631	0.3283	0.05	68.27	76.91	38.16	0.5632	0.3283	0.05	68.28	76.92	38.15	0.5631	0.3283	0.04
4	55.29	-96.40	64.30	0.2224	0.7137	0.10	55.3	-95.85	64.34	0.2239	0.7125	0.22	55.31	-95.89	64.35	0.2238	0.7126	0.22
5	84.90	-137.10	92.44	0.2220	0.7171	0.10	84.89	-136.98	92.44	0.2222	0.7170	0.12	84.91	-137.04	92.47	0.2221	0.7170	0.11
6	88.21	-93.59	65.03	0.2826	0.5908	0.22	88.19	-93.64	65.02	0.2825	0.5909	0.20	88.21	-93.53	65.04	0.2827	0.5907	0.23
7	16.35	42.88	-73.65	0.1601	0.0743	0.03	16.34	42.85	-73.61	0.1601	0.0743	0.03	16.35	42.81	-73.60	0.1601	0.0744	0.02
8	31.95	66.51	-112.16	0.1588	0.0713	0.12	31.94	66.49	-112.11	0.1588	0.0713	0.13	31.94	66.60	-112.18	0.1589	0.0713	0.16
9	52.62	31.12	-77.56	0.2154	0.1654	0.31	52.61	31.21	-77.57	0.2154	0.1654	0.35	52.62	31.18	-77.56	0.2154	0.1654	0.34
10	52.37	-63.22	-5.92	0.1929	0.4127	0.03	52.36	-63.17	-5.9	0.1930	0.4128	0.04	52.37	-63.21	-5.88	0.1930	0.4129	0.03
11	88.71	-90.61	-18.65	0.1893	0.3846	0.13	88.69	-90.48	-18.68	0.1894	0.3844	0.12	88.71	-90.54	-18.65	0.1894	0.3846	0.13
12	92.56	-52.00	-12.59	0.2527	0.3731	0.15	92.55	-51.93	-12.54	0.2528	0.3732	0.18	92.58	-51.83	-12.56	0.2530	0.3731	0.19
13	30.16	63.75	-39.69	0.3702	0.1668	0.24	30.16	63.88	-39.85	0.3698	0.1664	0.23	30.16	63.87	-39.83	0.3699	0.1664	0.24
14	64.61	113.35	-56.71	0.4051	0.1801	0.06	64.61	113.35	-56.64	0.4053	0.1802	0.07	64.62	113.39	-56.69	0.4052	0.1801	0.06
15	78.10	67.96	-34.75	0.3826	0.2493	0.10	78.09	67.98	-34.69	0.3828	0.2494	0.11	78.11	67.97	-34.67	0.3828	0.2494	0.12
16	59.86	-10.39	74.24	0.4507	0.5150	0.33	59.85	-10.33	74.24	0.4508	0.5149	0.36	59.87	-10.35	74.26	0.4508	0.5149	0.36
17	96.96	-15.74	112.27	0.4512	0.5164	0.03	96.94	-15.73	112.26	0.4512	0.5164	0.03	96.96	-15.76	112.29	0.4512	0.5165	0.04
18	98.06	-11.06	54.25	0.4068	0.4517	0.07	98.05	-10.98	54.28	0.4070	0.4517	0.08	98.07	-11.01	54.31	0.4069	0.4517	0.06
19	50.45	62.15	30.63	0.5675	0.3266	0.48	50.45	62.17	30.65	0.5676	0.3265	0.49	50.46	62.18	30.65	0.5676	0.3265	0.49
20	69.89	-84.30	56.51	0.2710	0.6101	0.60	69.89	-83.97	56.55	0.2717	0.6096	0.62	69.91	-84.01	56.56	0.2716	0.6096	0.63
21	37.27	27.58	-65.17	0.2092	0.1544	0.43	37.27	27.58	-65.12	0.2093	0.1545	0.44	37.27	27.56	-65.11	0.2093	0.1545	0.44
22	67.05	-60.69	-9.04	0.2171	0.3932	0.15	67.04	-60.64	-9.00	0.2173	0.3932	0.14	67.06	-60.68	-8.98	0.2172	0.3933	0.16
23	49.25	70.50	-40.33	0.3807	0.2018	0.24	49.25	70.51	-40.28	0.3809	0.2019	0.25	49.26	70.51	-40.27	0.3809	0.2020	0.24
24	73.17	-13.07	69.42	0.4334	0.4987	0.36	73.18	-13.17	69.44	0.4332	0.4989	0.36	73.20	-13.20	69.45	0.4332	0.4989	0.36
25	61.75	109.27	-21.57	0.4953	0.2203	0.06	61.75	109.27	-21.51	0.4955	0.2204	0.05	61.74	109.23	-21.53	0.4954	0.2204	0.06
26	91.95	-52.89	104.09	0.3854	0.5741	0.23	91.94	-52.79	104.1	0.3856	0.5739	0.26	91.96	-52.83	104.12	0.3855	0.5740	0.26
27	68.30	-43.12	-51.51	0.1779	0.2696	0.58	68.29	-43.09	-51.46	0.1780	0.2697	0.58	68.30	-43.06	-51.51	0.1780	0.2695	0.56
28	86.62	-115.87	24.97	0.2029	0.5235	0.14	86.61	-115.78	25.00	0.2031	0.5235	0.15	86.63	-116.03	25.05	0.2028	0.5238	0.11
29	46.58	87.60	-87.47	0.2754	0.1229	0.27	46.57	87.65	-87.48	0.2755	0.1228	0.27	46.58	87.65	-87.47	0.2755	0.1229	0.28
30	81.68	29.41	101.41	0.5288	0.4479	0.46	81.68	29.54	101.44	0.5291	0.4477	0.40	81.70	29.52	101.46	0.5290	0.4478	0.42

	Measured Values MR10					
Color	L*	a*	b*	x	y	ΔE_{00}
1	30.98	65.22	49.19	0.6831	0.3066	0.17
2	58.67	104.91	93.79	0.6890	0.3065	0.06
3	68.28	76.96	38.14	0.5632	0.3282	0.04
4	55.33	-96.22	64.37	0.2230	0.7133	0.15
5	84.89	-136.90	92.47	0.2224	0.7169	0.13
6	88.20	-93.40	65.02	0.2829	0.5905	0.25
7	16.35	42.82	-73.60	0.1601	0.0744	0.03
8	31.94	66.61	-112.18	0.1589	0.0713	0.16
9	52.62	31.23	-77.57	0.2155	0.1654	0.36
10	52.36	-63.12	-5.89	0.1931	0.4128	0.06
11	88.70	-90.41	-18.67	0.1895	0.3844	0.13
12	92.56	-51.72	-12.58	0.2531	0.3730	0.20
13	30.16	63.87	-39.83	0.3699	0.1664	0.24
14	64.63	113.41	-56.69	0.4053	0.1801	0.06
15	78.10	68.02	-34.67	0.3828	0.2494	0.11
16	59.86	-10.28	74.25	0.4510	0.5147	0.39
17	96.96	-15.58	112.30	0.4515	0.5162	0.05
18	98.06	-10.91	54.30	0.4071	0.4516	0.11
19	50.46	62.19	30.64	0.5676	0.3265	0.48
20	69.90	-83.90	56.54	0.2718	0.6094	0.63
21	37.27	27.59	-65.12	0.2094	0.1545	0.45
22	67.06	-60.73	-9.09	0.2170	0.3931	0.16
23	49.26	70.53	-40.27	0.3810	0.2019	0.25
24	73.20	-13.00	69.47	0.4336	0.4986	0.39
25	61.75	109.29	-21.64	0.4952	0.2202	0.07
26	91.96	-52.61	104.13	0.3859	0.5736	0.33
27	68.29	-42.97	-51.53	0.1781	0.2694	0.53
28	86.62	-115.51	25.02	0.2035	0.5233	0.18
29	46.58	87.67	-87.47	0.2755	0.1229	0.28
30	81.69	29.59	101.46	0.5291	0.4476	0.39

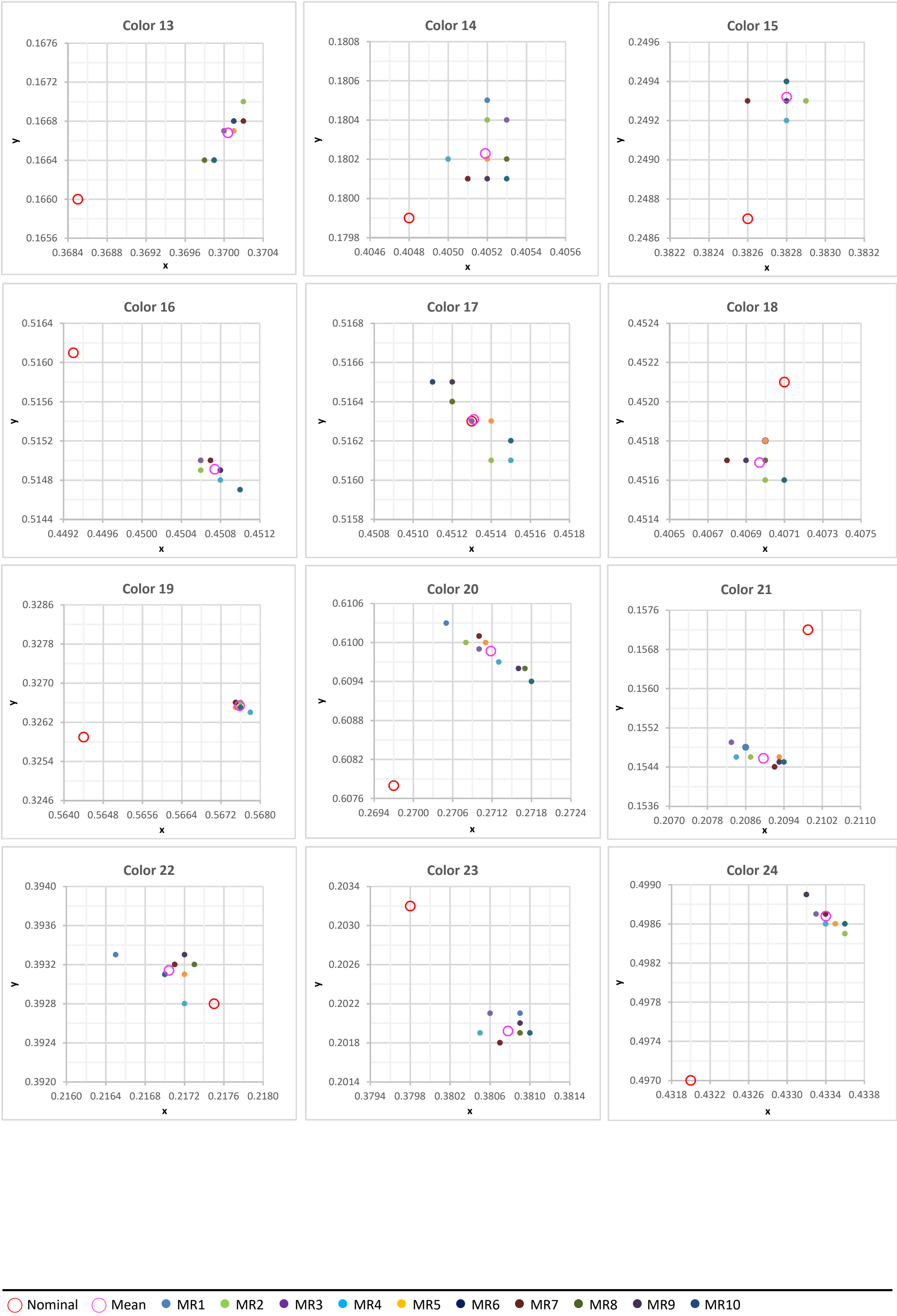
2| 2 Display calibration device performance data

1.3 - Visualization of the measured values in the CIE xy chromaticity diagram



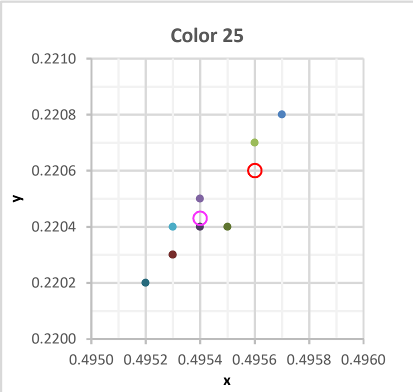
2| 2 Display calibration device performance data

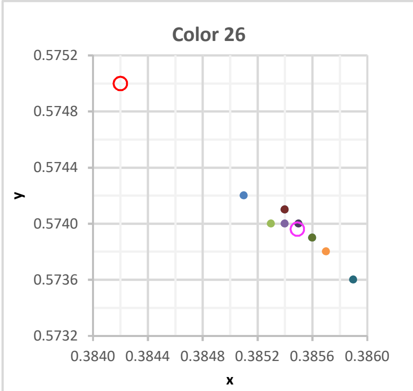
1.3 - Visualization of the measured values in the CIE xy chromaticity diagram

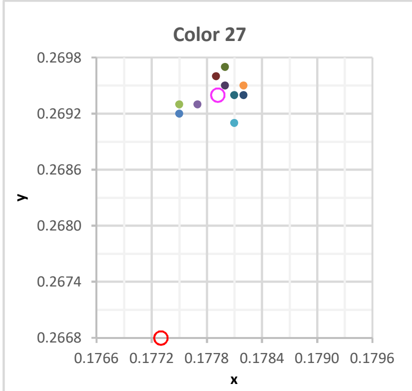


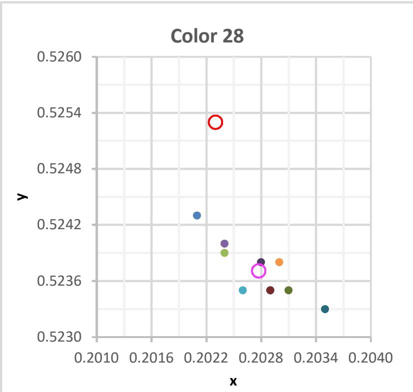
2| 2 Display calibration device performance data

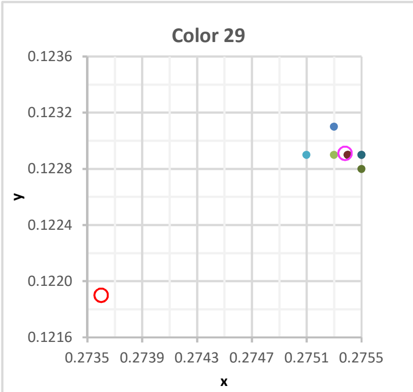
1.3 - Visualization of the measured values in the CIE xy chromaticity diagram

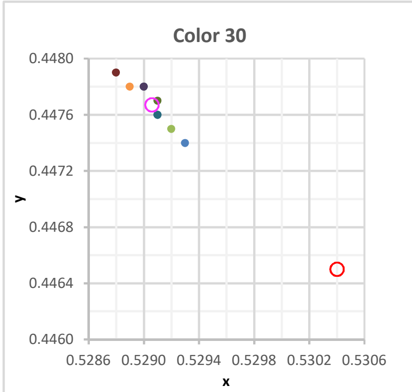












Nominal Mean MR1 MR2 MR3 MR4 MR5 MR6 MR7 MR8 MR9 MR10

2| 2 Display calibration device performance data

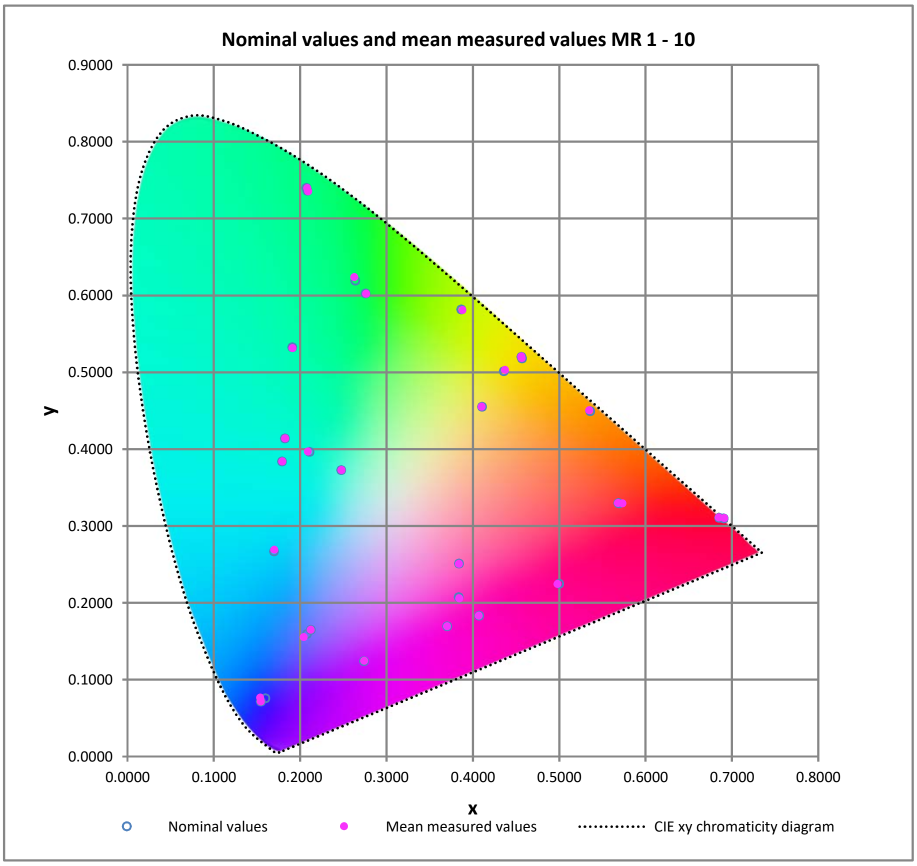
1.4 - Color accuracy and repeatability of the measurements

	Device Values			Nominal Values					Accuracy (ΔE_{00} MR1 – MR10)				Repeatability (ΔE_{00} MR1 – MR10)			
Color	R	G	B	L*	a*	b*	x	y	Mean	Min	Max	SD	Mean	Min	Max	SD
1	128	0	0	30.81	64.94	48.86	0.6829	0.3066	0.16	0.15	0.17	0.0048	0.01	0.00	0.01	0.0019
2	255	0	0	58.74	104.96	93.85	0.6889	0.3066	0.04	0.01	0.07	0.0226	0.01	0.01	0.05	0.0126
3	255	128	128	68.29	77.11	38.23	0.5636	0.3281	0.04	0.01	0.05	0.0138	0.02	0.01	0.04	0.0084
4	0	128	0	55.32	-96.86	64.27	0.2214	0.7146	0.13	0.08	0.22	0.0502	0.05	0.02	0.15	0.0466
5	0	255	0	84.86	-137.61	92.33	0.2210	0.7179	0.09	0.01	0.13	0.0362	0.05	0.02	0.09	0.0213
6	128	255	128	88.11	-94.66	65.26	0.2809	0.5930	0.20	0.15	0.25	0.0356	0.03	0.01	0.06	0.0179
7	0	0	128	16.35	42.83	-73.67	0.1599	0.0743	0.05	0.02	0.14	0.0345	0.04	0.02	0.12	0.0290
8	0	0	255	31.97	66.18	-112.09	0.1585	0.0715	0.10	0.02	0.16	0.0485	0.05	0.01	0.13	0.0389
9	128	128	255	52.56	30.85	-77.93	0.2141	0.1648	0.29	0.22	0.36	0.0520	0.05	0.01	0.07	0.0221
10	0	128	128	52.37	-63.33	-5.90	0.1927	0.4129	0.07	0.03	0.13	0.0355	0.06	0.04	0.11	0.0234
11	0	255	255	88.69	-90.90	-18.96	0.1886	0.3840	0.11	0.07	0.13	0.0197	0.05	0.02	0.08	0.0173
12	170	255	255	92.53	-52.29	-12.87	0.2519	0.3728	0.16	0.12	0.20	0.0275	0.05	0.01	0.13	0.0323
13	128	0	128	29.92	63.40	-39.86	0.3685	0.1660	0.24	0.23	0.25	0.0040	0.04	0.00	0.04	0.0128
14	255	0	255	64.66	113.47	-56.90	0.4048	0.1799	0.07	0.05	0.09	0.0127	0.03	0.01	0.06	0.0151
15	255	170	255	78.06	68.33	-34.99	0.3826	0.2487	0.11	0.09	0.12	0.0096	0.02	0.01	0.03	0.0055
16	128	128	0	59.74	-10.92	74.01	0.4493	0.5161	0.34	0.30	0.39	0.0291	0.03	0.02	0.06	0.0141
17	255	255	0	96.95	-15.67	112.21	0.4513	0.5163	0.04	0.01	0.06	0.0198	0.03	0.01	0.06	0.0198
18	255	255	170	98.05	-11.09	54.49	0.4071	0.4521	0.08	0.05	0.12	0.0208	0.03	0.01	0.05	0.0188
19	170	85	85	50.34	61.63	29.53	0.5644	0.3259	0.49	0.48	0.50	0.0079	0.02	0.00	0.03	0.0083
20	85	170	85	69.27	-83.77	55.13	0.2697	0.6078	0.59	0.54	0.63	0.0332	0.03	0.02	0.08	0.0233
21	85	85	170	37.47	26.43	-64.20	0.2099	0.1572	0.37	0.25	0.45	0.0800	0.09	0.07	0.24	0.0511
22	85	170	170	66.92	-60.33	-9.08	0.2175	0.3928	0.15	0.10	0.18	0.0223	0.08	0.01	0.08	0.0201
23	170	85	170	49.30	69.50	-39.97	0.3798	0.2032	0.24	0.20	0.25	0.0157	0.03	0.01	0.04	0.0078
24	170	170	85	73.12	-13.05	68.01	0.4320	0.4970	0.36	0.35	0.39	0.0141	0.03	0.00	0.07	0.0235
25	255	0	170	61.80	109.23	-21.43	0.4956	0.2206	0.05	0.02	0.07	0.0170	0.03	0.02	0.08	0.0178
26	170	255	0	91.86	-53.50	103.90	0.3842	0.5750	0.25	0.17	0.33	0.0457	0.03	0.01	0.08	0.0270
27	0	170	255	67.93	-42.17	-52.37	0.1773	0.2668	0.54	0.45	0.58	0.0368	0.04	0.03	0.09	0.0211
28	0	255	170	86.59	-116.56	25.36	0.2023	0.5253	0.13	0.10	0.18	0.0237	0.04	0.02	0.08	0.0223
29	170	0	255	46.39	87.50	-88.04	0.2736	0.1219	0.27	0.26	0.29	0.0076	0.03	0.01	0.05	0.0146
30	255	170	0	81.48	30.25	101.27	0.5304	0.4465	0.40	0.33	0.46	0.0434	0.03	0.01	0.08	0.0252
								Mean	0.20	0.16	0.25	0.0275	0.04	0.02	0.08	0.0207

2| 3 Display calibration device performance data

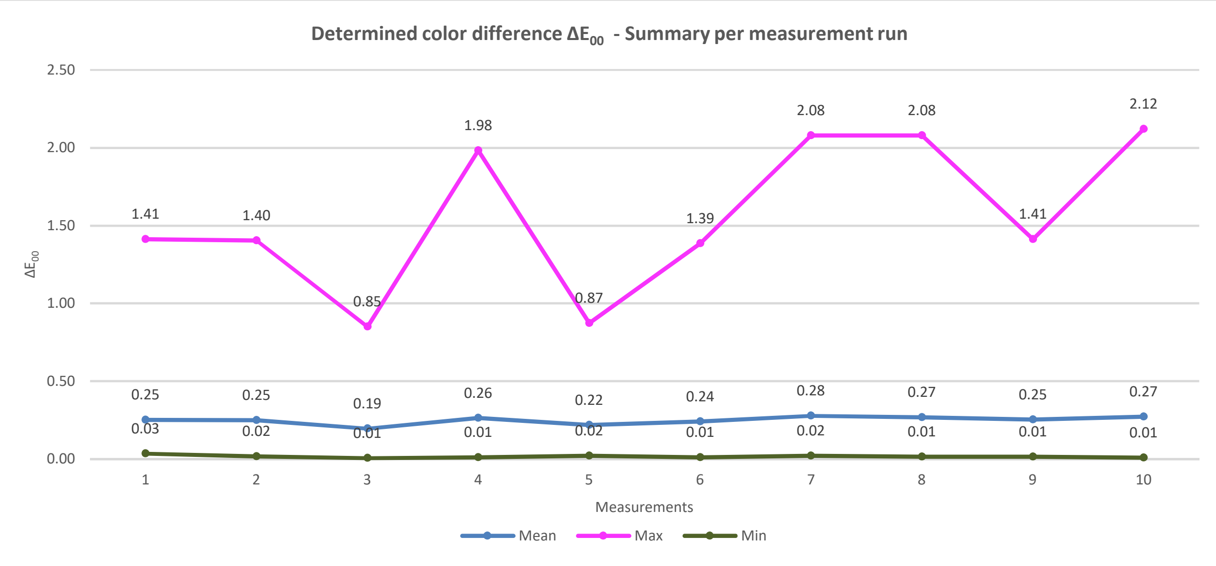
1.1 - Summary and visualization of the measured values

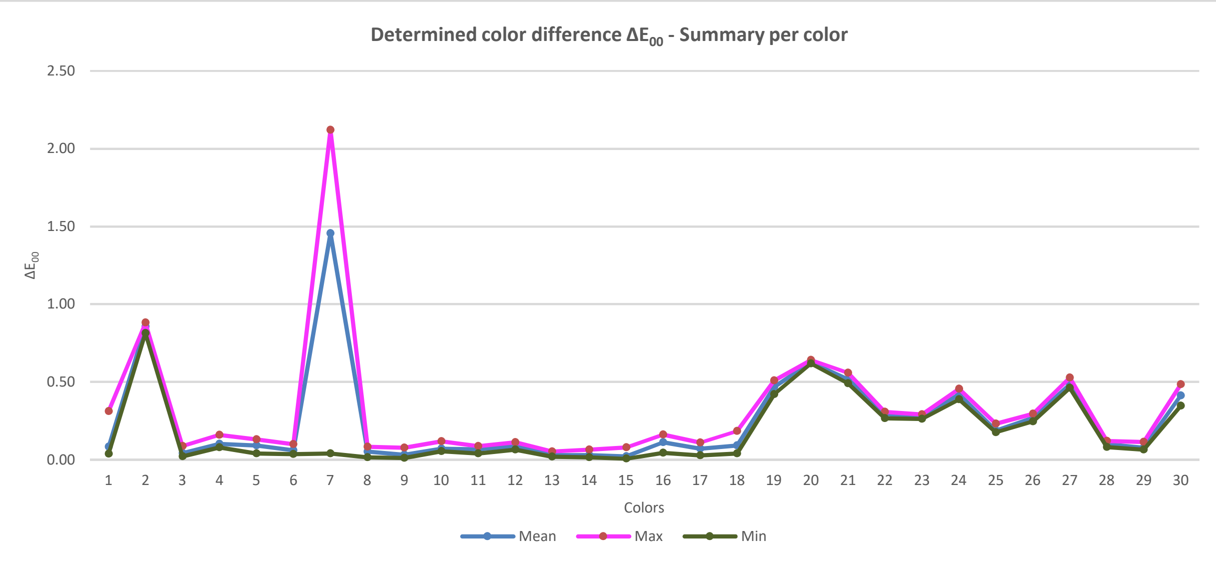
Color		Device Values			Nominal Values					Mean Measured Values MR1 - MR10					
Color		R	G	B	L*	a*	b*	x	y	L*	a*	b*	x	y	ΔE_{00}
	1	128	0	0	31.86	65.59	53.26	0.6855	0.3106	31.83	65.46	53.08	0.6851	0.3107	0.06
	2	255	0	0	59.95	105.65	103.37	0.6905	0.3095	59.91	105.47	106.11	0.6915	0.3102	0.86
	3	255	128	128	69.00	78.48	40.87	0.5686	0.3295	69.00	78.39	40.77	0.5683	0.3295	0.03
	4	0	128	0	54.73	-102.17	67.05	0.2086	0.7360	54.78	-101.84	67.10	0.2096	0.7351	0.09
	5	0	255	0	84.14	-145.64	96.35	0.2075	0.7398	84.19	-145.25	96.50	0.2084	0.7392	0.09
	6	128	255	128	87.57	-98.03	66.89	0.2761	0.6024	87.62	-97.84	66.94	0.2765	0.6021	0.06
	7	0	0	128	17.07	42.46	-74.32	0.1598	0.0758	17.11	39.74	-74.32	0.1541	0.0765	1.44
	8	0	0	255	32.28	64.56	-113.14	0.1549	0.0714	32.31	64.42	-113.08	0.1549	0.0716	0.05
	9	128	128	255	52.82	30.11	-78.42	0.2124	0.1648	52.84	30.13	-78.42	0.2124	0.1648	0.02
	10	0	128	128	51.93	-67.19	-6.73	0.1825	0.4138	51.98	-67.10	-6.68	0.1829	0.4139	0.06
	11	0	255	255	88.06	-96.33	-20.42	0.1791	0.3836	88.10	-96.09	-20.36	0.1795	0.3837	0.05
	12	170	255	255	92.16	-54.25	-13.63	0.2478	0.3725	92.21	-54.09	-13.52	0.2482	0.3726	0.07
	13	128	0	128	30.74	63.28	-39.29	0.3706	0.1694	30.74	63.20	-39.31	0.3704	0.1694	0.03
	14	255	0	255	65.76	113.24	-55.57	0.4074	0.1832	65.76	113.12	-55.59	0.4072	0.1832	0.02
	15	255	170	255	78.77	68.28	-34.10	0.3842	0.2507	78.78	68.26	-34.13	0.3842	0.2506	0.01
	16	128	128	0	59.73	-9.41	79.66	0.4571	0.5176	59.78	-9.60	79.78	0.4568	0.5180	0.11
	17	255	255	0	96.88	-14.97	120.68	0.4565	0.5200	96.91	-15.11	120.74	0.4563	0.5202	0.06
	18	255	255	170	97.96	-10.67	57.01	0.4107	0.4550	98.00	-10.76	56.86	0.4104	0.4549	0.08
	19	170	85	85	51.26	62.33	32.41	0.5693	0.3292	51.24	63.21	33.60	0.5736	0.3292	0.47
	20	85	170	85	69.06	-87.26	56.95	0.2641	0.6191	69.68	-89.02	58.38	0.2628	0.6234	0.63
	21	85	85	170	37.80	24.58	-63.80	0.2080	0.1595	37.61	25.27	-65.66	0.2043	0.1552	0.52
	22	85	170	170	66.74	-63.99	-9.05	0.2110	0.3961	66.90	-65.02	-9.14	0.2093	0.3966	0.29
	23	170	85	170	50.20	69.23	-38.50	0.3836	0.2073	50.12	70.31	-38.96	0.3844	0.2057	0.27
	24	170	170	85	73.29	-12.96	71.69	0.4359	0.5010	73.33	-12.91	73.33	0.4376	0.5028	0.42
	25	255	0	170	62.91	109.35	-19.08	0.5002	0.2248	62.94	109.29	-19.71	0.4984	0.2242	0.19
	26	170	255	0	91.58	-54.08	110.57	0.3867	0.5817	91.69	-53.37	110.81	0.3881	0.5806	0.27
	27	0	170	255	67.94	-46.66	-53.23	0.1700	0.2668	68.31	-47.47	-52.61	0.1704	0.2690	0.48
	28	0	255	170	85.88	-123.35	25.08	0.1909	0.5325	85.93	-122.86	24.86	0.1915	0.5312	0.09
	29	170	0	255	47.20	86.68	-87.66	0.2742	0.1241	47.27	86.62	-87.54	0.2745	0.1244	0.07
	30	255	170	0	81.99	31.15	111.10	0.5360	0.4491	82.16	30.43	111.45	0.5348	0.4504	0.41

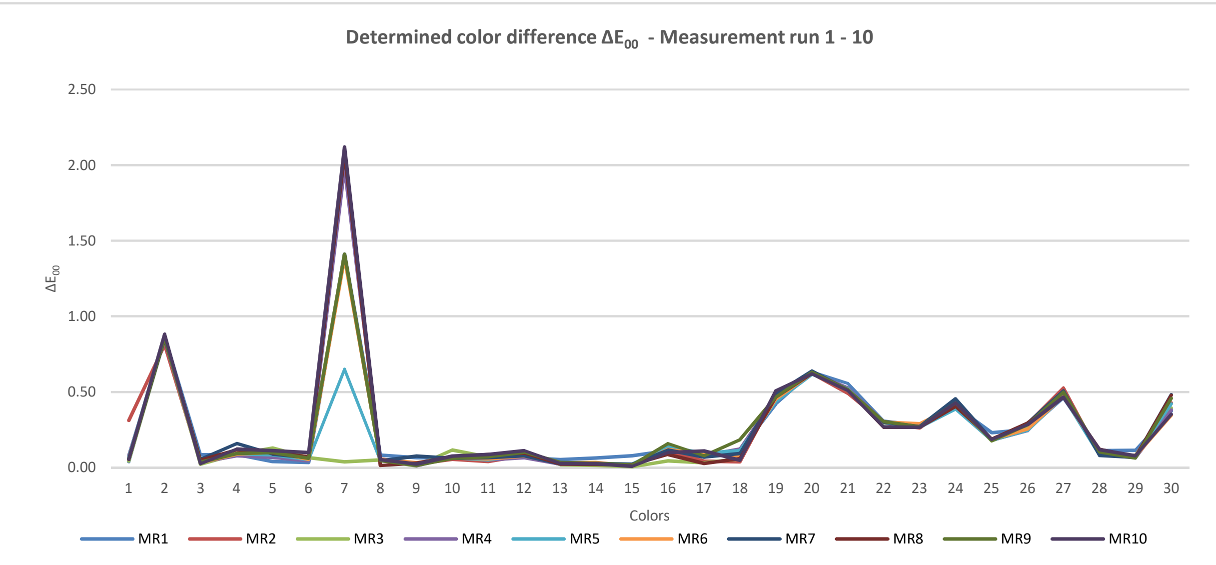


2| 3 Display calibration device performance data

1.1 - Summary and visualization of the measured values







2| 3 Display calibration device performance data

1.2 - Measured values

	Measured Values MR1						Measured Values MR2						Measured Values MR3					
Color	L*	a*	b*	x	y	ΔE_{00}	L*	a*	b*	x	y	ΔE_{00}	L*	a*	b*	x	y	ΔE_{00}
1	31.85	65.49	53.26	0.6853	0.3108	0.04	31.83	65.53	52.50	0.6843	0.3101	0.31	31.83	65.45	53.16	0.6852	0.3108	0.04
2	59.95	105.47	106.15	0.6914	0.3102	0.87	59.91	105.64	106.10	0.6917	0.3099	0.81	59.92	105.51	106.12	0.6915	0.3101	0.85
3	69.02	78.47	40.67	0.5682	0.3293	0.09	69.01	78.48	40.79	0.5685	0.3294	0.04	69.00	78.39	40.85	0.5684	0.3296	0.02
4	54.78	-102.24	67.37	0.2088	0.7366	0.09	54.77	-101.79	66.99	0.2096	0.7348	0.08	54.77	-101.80	67.07	0.2096	0.7350	0.09
5	84.19	-145.64	96.47	0.2077	0.7398	0.04	84.18	-145.40	96.58	0.2081	0.7396	0.08	84.18	-145.24	96.79	0.2085	0.7397	0.13
6	87.62	-97.98	66.90	0.2762	0.6022	0.03	87.61	-97.84	66.94	0.2765	0.6021	0.05	87.61	-97.78	66.94	0.2766	0.6020	0.06
7	17.22	39.77	-74.27	0.1546	0.0769	1.41	17.20	39.72	-74.17	0.1548	0.0770	1.40	17.08	42.52	-74.30	0.1600	0.0758	0.04
8	32.35	64.49	-113.24	0.1548	0.0715	0.08	32.31	64.40	-113.07	0.1549	0.0716	0.06	32.30	64.39	-113.04	0.1549	0.0716	0.05
9	52.87	30.17	-78.60	0.2122	0.1646	0.07	52.84	30.13	-78.42	0.2124	0.1648	0.02	52.83	30.09	-78.39	0.2124	0.1649	0.01
10	51.98	-67.22	-6.81	0.1825	0.4135	0.06	51.98	-67.13	-6.69	0.1828	0.4139	0.05	51.98	-67.35	-6.55	0.1826	0.4147	0.12
11	88.12	-96.24	-20.56	0.1791	0.3832	0.08	88.10	-96.17	-20.38	0.1794	0.3836	0.04	88.08	-95.96	-20.37	0.1796	0.3835	0.07
12	92.23	-54.30	-13.73	0.2477	0.3723	0.07	92.21	-54.11	-13.49	0.2482	0.3727	0.08	92.20	-54.00	-13.50	0.2484	0.3726	0.09
13	30.77	63.25	-39.40	0.3701	0.1693	0.05	30.75	63.20	-39.28	0.3705	0.1695	0.02	30.75	63.21	-39.27	0.3705	0.1695	0.02
14	65.80	113.14	-55.74	0.4068	0.1831	0.06	65.77	113.11	-55.56	0.4072	0.1833	0.02	65.76	113.15	-55.54	0.4073	0.1832	0.01
15	78.81	68.29	-34.30	0.3838	0.2504	0.08	78.79	68.31	-34.11	0.3843	0.2506	0.02	78.77	68.29	-34.09	0.3843	0.2507	0.01
16	59.78	-9.60	79.85	0.4568	0.5181	0.11	59.78	-9.58	79.91	0.4569	0.5181	0.11	59.77	-9.46	79.71	0.4570	0.5177	0.04
17	96.93	-15.12	120.88	0.4563	0.5203	0.07	96.91	-15.04	120.88	0.4565	0.5202	0.04	96.91	-15.02	120.82	0.4565	0.5201	0.03
18	98.03	-10.77	56.77	0.4103	0.4548	0.11	98.00	-10.66	56.90	0.4106	0.4548	0.04	98.00	-10.68	56.84	0.4105	0.4548	0.06
19	51.25	63.32	33.49	0.5736	0.3289	0.42	51.25	63.23	33.64	0.5737	0.3292	0.48	51.24	63.22	33.65	0.5737	0.3292	0.49
20	69.68	-89.14	58.33	0.2625	0.6235	0.63	69.67	-89.03	58.39	0.2628	0.6235	0.62	69.67	-88.99	58.42	0.2629	0.6235	0.62
21	37.64	25.26	-65.77	0.2040	0.1551	0.56	37.60	25.37	-65.66	0.2045	0.1551	0.49	37.60	25.26	-65.62	0.2043	0.1552	0.51
22	66.90	-65.05	-9.29	0.2090	0.3962	0.31	66.90	-65.03	-9.14	0.2093	0.3966	0.30	66.89	-65.04	-9.11	0.2093	0.3967	0.30
23	50.14	70.34	-39.07	0.3841	0.2056	0.28	50.13	70.29	-38.92	0.3844	0.2058	0.26	50.11	70.36	-39.00	0.3843	0.2056	0.29
24	73.34	-12.92	73.28	0.4375	0.5027	0.40	73.32	-12.82	73.32	0.4378	0.5026	0.44	73.32	-12.81	73.24	0.4377	0.5025	0.42
25	62.97	109.45	-19.86	0.4982	0.2239	0.23	62.95	109.33	-19.71	0.4985	0.2241	0.19	62.94	109.25	-19.66	0.4985	0.2242	0.18
26	91.70	-53.49	110.93	0.3879	0.5808	0.25	91.68	-53.30	110.81	0.3882	0.5805	0.29	91.68	-53.33	110.69	0.3881	0.5804	0.26
27	68.33	-47.49	-52.83	0.1701	0.2685	0.46	68.31	-47.63	-52.59	0.1703	0.2691	0.53	68.30	-47.45	-52.59	0.1705	0.2690	0.48
28	85.95	-123.15	24.74	0.1909	0.5311	0.11	85.93	-122.97	24.86	0.1913	0.5313	0.08	85.92	-122.86	24.90	0.1915	0.5314	0.09
29	47.31	86.58	-87.69	0.2741	0.1244	0.11	47.28	86.60	-87.55	0.2744	0.1245	0.08	47.27	86.61	-87.49	0.2746	0.1245	0.08
30	82.18	30.53	111.49	0.5350	0.4502	0.37	82.17	30.43	111.56	0.5349	0.4504	0.43	82.16	30.48	111.50	0.5349	0.4503	0.39

	Measured Values MR4						Measured Values MR5						Measured Values MR6					
Color	L*	a*	b*	x	y	ΔE_{00}	L*	a*	b*	x	y	ΔE_{00}	L*	a*	b*	x	y	ΔE_{00}
1	31.82	65.47	53.03	0.6851	0.3106	0.08	31.82	65.48	53.07	0.6852	0.3106	0.07	31.83	65.42	53.20	0.6852	0.3109	0.05
2	59.90	105.46	106.07	0.6915	0.3101	0.85	59.91	105.38	106.09	0.6914	0.3103	0.87	59.91	105.43	106.10	0.6914	0.3102	0.86
3	68.99	78.36	40.77	0.5683	0.3295	0.04	68.99	78.34	40.79	0.5683	0.3295	0.03	69.00	78.33	40.80	0.5683	0.3296	0.03
4	54.78	-101.81	66.92	0.2095	0.7347	0.08	54.78	-101.73	66.81	0.2097	0.7342	0.09	54.79	-101.85	67.08	0.2096	0.7350	0.09
5	84.19	-145.54	96.61	0.2079	0.7399	0.07	84.19	-145.20	96.44	0.2084	0.7390	0.08	84.19	-144.96	96.27	0.2087	0.7384	0.10
6	87.62	-97.94	66.96	0.2763	0.6023	0.05	87.63	-97.95	66.99	0.2763	0.6023	0.05	87.63	-97.85	66.90	0.2764	0.6020	0.05
7	17.06	38.81	-74.42	0.1516	0.0763	1.98	16.97	41.35	-74.50	0.1565	0.0755	0.65	17.19	39.77	-74.20	0.1548	0.0769	1.39
8	32.30	64.39	-113.06	0.1549	0.0716	0.06	32.30	64.42	-113.07	0.1549	0.0716	0.05	32.30	64.39	-113.06	0.1549	0.0716	0.06
9	52.83	30.10	-78.42	0.2124	0.1648	0.01	52.83	30.14	-78.42	0.2124	0.1648	0.02	52.83	30.15	-78.40	0.2125	0.1648	0.03
10	51.97	-66.96	-6.71	0.1831	0.4137	0.07	51.99	-67.16	-6.67	0.1828	0.4140	0.07	51.99	-67.09	-6.69	0.1829	0.4138	0.07
11	88.10	-96.10	-20.35	0.1795	0.3837	0.05	88.10	-96.16	-20.32	0.1795	0.3838	0.05	88.11	-96.09	-20.35	0.1795	0.3837	0.06
12	92.20	-54.12	-13.52	0.2482	0.3726	0.06	92.22	-54.18	-13.47	0.2482	0.3728	0.09	92.22	-54.07	-13.52	0.2482	0.3726	0.08
13	30.73	63.22	-39.31	0.3704	0.1694	0.02	30.74	63.18	-39.30	0.3703	0.1694	0.03	30.74	63.18	-39.30	0.3704	0.1695	0.03
14	65.74	113.12	-55.58	0.4072	0.1832	0.03	65.75	113.12	-55.58	0.4072	0.1832	0.02	65.75	113.07	-55.59	0.4071	0.1832	0.03
15	78.77	68.22	-34.11	0.3841	0.2507	0.02	78.77	68.21	-34.12	0.3841	0.2507	0.02	78.77	68.28	-34.13	0.3842	0.2506	0.01
16	59.77	-9.64	79.60	0.4565	0.5180	0.13	59.78	-9.65	79.83	0.4567	0.5182	0.13	59.78	-9.62	79.80	0.4567	0.5181	0.12
17	96.90	-15.16	120.88	0.4563	0.5203	0.08	96.92	-15.19	120.79	0.4562	0.5203	0.10	96.91	-15.16	120.70	0.4562	0.5203	0.08
18	98.00	-10.84	56.87	0.4103	0.4550	0.12	98.00	-10.81	56.84	0.4103	0.4549	0.11	98.00	-10.73	56.82	0.4104	0.4548	0.08
19	51.23	63.22	33.61	0.5737	0.3291	0.47	51.23	63.25	33.53	0.5736	0.3290	0.44	51.23	63.26	33.57	0.5737	0.3290	0.45
20	69.67	-89.09	58.43	0.2627	0.6237	0.63	69.68	-88.94	58.33	0.2629	0.6232	0.62	69.68	-89.09	58.26	0.2625	0.6233	0.62
21	37.60	25.23	-65.64	0.2042	0.1552	0.53	37.60	25.26	-65.65	0.2043	0.1552	0.52	37.60	25.29	-65.66	0.2043	0.1552	0.51
22	66.89	-65.08	-9.16	0.2092	0.3966	0.30	66.90	-65.04	-9.13	0.2093	0.3967	0.30	66.90	-65.05	-9.12	0.2093	0.3967	0.30
23	50.11	70.29	-38.94	0.3844	0.2057	0.27	50.11	70.28	-38.95	0.3844	0.2057	0.27	50.11	70.39	-38.97	0.3845	0.2056	0.29
24	73.33	-13.03	73.50	0.4375	0.5032	0.44	73.34	-12.94	73.23	0.4375	0.5027	0.39	73.34	-12.93	73.31	0.4376	0.5027	0.41
25	62.93	109.24	-19.68	0.4984	0.2242	0.18	62.93	109.24	-19.68	0.4984	0.2242	0.18	62.94	109.29	-19.70	0.4985	0.2242	0.19
26	91.69	-53.47	110.85	0.3879	0.5808	0.24	91.69	-53.44	110.80	0.3879	0.5807	0.25	91.70	-53.41	110.77	0.3880	0.5806	0.25
27	68.31	-47.52	-52.60	0.1704	0.2691	0.50	68.31	-47.41	-52.61	0.1705	0.2690	0.47	68.31	-47.41	-52.62	0.1705	0.2690	0.47
28	85.93	-122.94	24.86	0.1913	0.5313	0.09	85.93	-122.97	24.86	0.1913	0.5313	0.08	85.93	-122.74	24.84	0.1916	0.5311	0.11
29	47.26	86.63	-87.53	0.2745	0.1244	0.07	47.27	86.59	-87.52	0.2744	0.1245	0.07	47.27	86.62	-87.53	0.2745	0.1244	0.07
30	82.15	30.44	111.28	0.5348	0.4503	0.38	82.16	30.37	111.33	0.5347	0.4504	0.42	82.17	30.43	110.89	0.5346	0.4502	0.35

2| 3 Display calibration device performance data

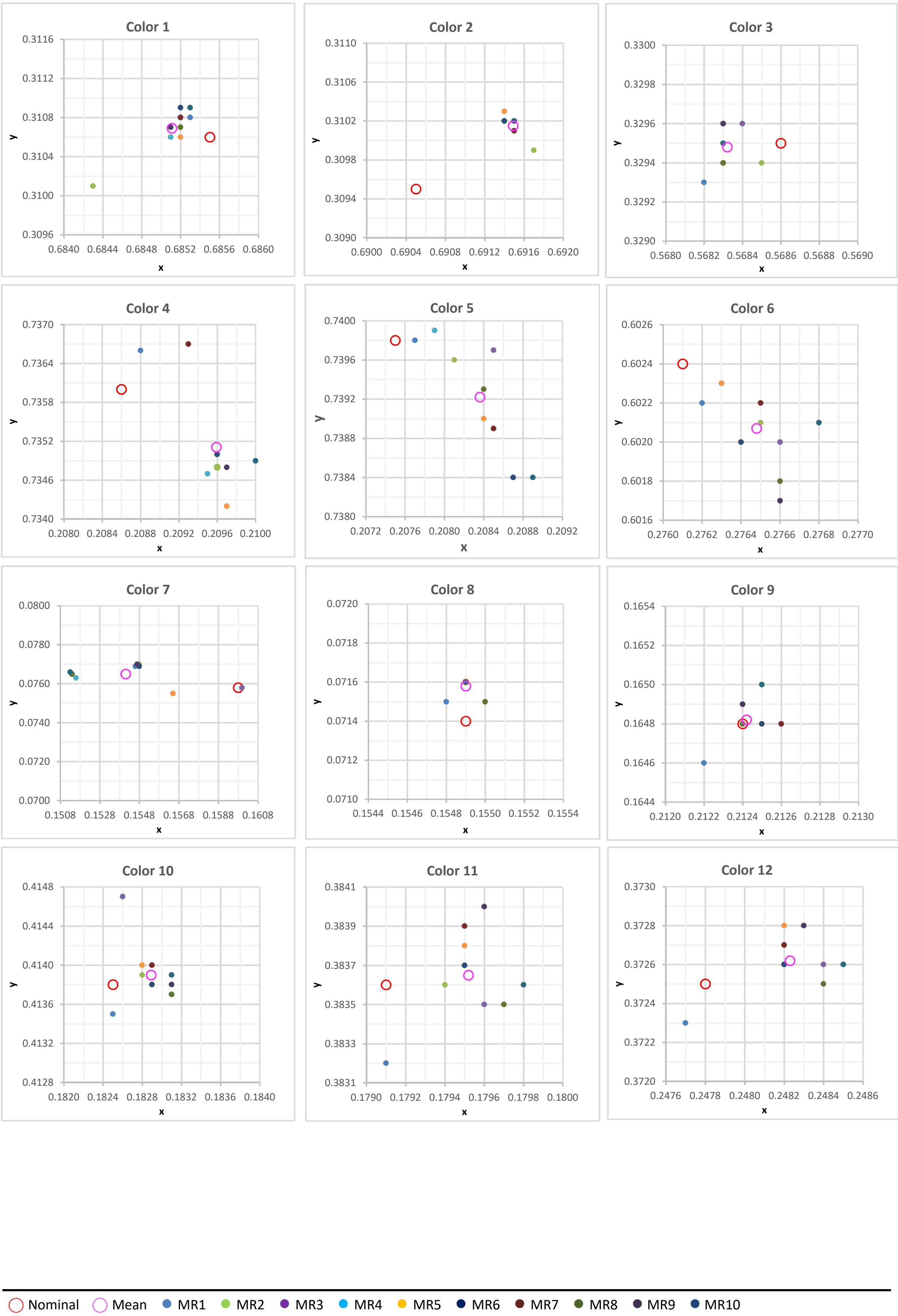
1.2 - Measured values

Color	Measured Values MR7						Measured Values MR8						Measured Values MR9					
Color	L*	a*	b*	x	y	ΔE_{00}	L*	a*	b*	x	y	ΔE_{00}	L*	a*	b*	x	y	ΔE_{00}
1	31.82	65.43	53.13	0.6852	0.3108	0.05	31.82	65.47	53.11	0.6852	0.3107	0.05	31.82	65.44	53.09	0.6851	0.3107	0.06
2	59.89	105.46	106.08	0.6915	0.3101	0.85	59.91	105.44	106.10	0.6915	0.3102	0.86	59.89	105.43	106.07	0.6915	0.3102	0.86
3	68.98	78.40	40.72	0.5683	0.3294	0.06	68.99	78.42	40.74	0.5683	0.3294	0.05	68.99	78.32	40.81	0.5683	0.3296	0.04
4	54.79	-102.08	67.60	0.2093	0.7367	0.16	54.77	-101.60	67.00	0.2101	0.7344	0.12	54.79	-101.78	67.02	0.2097	0.7348	0.09
5	84.19	-145.15	96.43	0.2085	0.7389	0.09	84.19	-145.23	96.57	0.2084	0.7393	0.10	84.20	-145.21	96.55	0.2085	0.7392	0.10
6	87.62	-97.84	66.99	0.2765	0.6022	0.07	87.62	-97.73	66.90	0.2766	0.6018	0.07	87.62	-97.75	66.84	0.2766	0.6017	0.06
7	17.07	38.61	-74.38	0.1514	0.0765	2.08	17.07	38.62	-74.40	0.1514	0.0765	2.08	17.19	39.69	-74.15	0.1547	0.0770	1.41
8	32.30	64.41	-113.05	0.1549	0.0716	0.05	32.29	64.51	-113.09	0.1550	0.0715	0.01	32.30	64.40	-113.04	0.1549	0.0716	0.05
9	52.82	30.24	-78.42	0.2126	0.1648	0.08	52.83	30.15	-78.41	0.2124	0.1648	0.03	52.83	30.10	-78.38	0.2124	0.1649	0.01
10	51.98	-67.11	-6.66	0.1829	0.4140	0.06	51.98	-66.99	-6.70	0.1831	0.4137	0.07	51.97	-67.01	-6.68	0.1831	0.4138	0.06
11	88.11	-96.22	-20.27	0.1795	0.3839	0.07	88.10	-95.89	-20.38	0.1797	0.3835	0.09	88.11	-96.18	-20.25	0.1796	0.3840	0.07
12	92.21	-54.14	-13.49	0.2482	0.3727	0.08	92.21	-53.96	-13.52	0.2484	0.3725	0.10	92.21	-54.14	-13.44	0.2483	0.3728	0.10
13	30.74	63.19	-39.29	0.3704	0.1694	0.03	30.74	63.24	-39.33	0.3704	0.1694	0.02	30.73	63.17	-39.29	0.3704	0.1695	0.03
14	65.74	113.14	-55.59	0.4072	0.1831	0.03	65.75	113.14	-55.58	0.4072	0.1832	0.02	65.74	113.10	-55.55	0.4072	0.1832	0.03
15	78.76	68.21	-34.11	0.3841	0.2507	0.02	78.77	68.35	-34.14	0.3843	0.2505	0.02	78.77	68.21	-34.08	0.3842	0.2507	0.02
16	59.78	-9.60	79.60	0.4566	0.5179	0.12	59.78	-9.55	79.77	0.4568	0.5179	0.09	59.78	-9.70	79.85	0.4566	0.5183	0.16
17	96.90	-15.13	120.88	0.4563	0.5203	0.07	96.91	-14.96	120.55	0.4564	0.5199	0.03	96.91	-15.15	120.77	0.4563	0.5203	0.08
18	98.00	-10.79	56.89	0.4104	0.4550	0.09	98.00	-10.65	56.82	0.4105	0.4547	0.06	98.01	-10.97	57.00	0.4103	0.4553	0.18
19	51.23	63.17	33.65	0.5736	0.3293	0.49	51.24	63.12	33.59	0.5734	0.3293	0.47	51.22	63.25	33.60	0.5737	0.3291	0.47
20	69.68	-89.10	58.46	0.2627	0.6238	0.64	69.68	-88.92	58.40	0.2630	0.6233	0.62	69.69	-89.05	58.33	0.2627	0.6233	0.63
21	37.60	25.26	-65.63	0.2043	0.1552	0.51	37.60	25.31	-65.67	0.2043	0.1551	0.51	37.60	25.25	-65.63	0.2043	0.1552	0.52
22	66.90	-65.05	-9.12	0.2093	0.3967	0.30	66.90	-64.90	-9.17	0.2095	0.3964	0.27	66.90	-65.06	-9.09	0.2094	0.3968	0.31
23	50.11	70.30	-38.95	0.3844	0.2057	0.27	50.11	70.28	-38.96	0.3843	0.2057	0.27	50.11	70.29	-38.92	0.3844	0.2058	0.27
24	73.34	-13.03	73.56	0.4376	0.5032	0.45	73.33	-12.78	73.14	0.4377	0.5023	0.40	73.34	-13.01	73.44	0.4375	0.5031	0.43
25	62.93	109.26	-19.70	0.4984	0.2242	0.19	62.93	109.28	-19.71	0.4984	0.2241	0.19	62.93	109.24	-19.67	0.4985	0.2242	0.18
26	91.68	-53.32	110.88	0.3882	0.5805	0.29	91.68	-53.26	110.75	0.3882	0.5803	0.29	91.70	-53.52	111.18	0.3880	0.5811	0.28
27	68.31	-47.52	-52.55	0.1704	0.2692	0.51	68.31	-47.38	-52.60	0.1706	0.2690	0.47	68.31	-47.49	-52.56	0.1705	0.2691	0.50
28	85.93	-122.91	24.92	0.1915	0.5314	0.08	85.92	-122.64	24.83	0.1918	0.5309	0.12	85.93	-122.74	24.89	0.1917	0.5312	0.10
29	47.26	86.64	-87.52	0.2745	0.1244	0.07	47.26	86.68	-87.55	0.2745	0.1244	0.07	47.25	86.65	-87.51	0.2746	0.1244	0.06
30	82.16	30.37	111.77	0.5349	0.4506	0.48	82.16	30.40	111.83	0.5349	0.4505	0.48	82.16	30.34	111.49	0.5347	0.4505	0.46

Color	Measured Values MR10					
Color	L*	a*	b*	x	y	ΔE_{00}
1	31.84	65.45	53.27	0.6853	0.3109	0.06
2	59.91	105.44	106.17	0.6915	0.3102	0.88
3	69.00	78.37	40.80	0.5683	0.3295	0.03
4	54.79	-101.71	67.16	0.2100	0.7349	0.12
5	84.19	-144.90	96.30	0.2089	0.7384	0.11
6	87.62	-97.72	67.06	0.2768	0.6021	0.10
7	17.08	38.52	-74.36	0.1513	0.0766	2.12
8	32.30	64.38	-113.03	0.1549	0.0716	0.05
9	52.84	30.07	-78.35	0.2125	0.1650	0.02
10	51.99	-67.02	-6.67	0.1831	0.4139	0.08
11	88.09	-95.88	-20.34	0.1798	0.3836	0.09
12	92.21	-53.92	-13.48	0.2485	0.3726	0.11
13	30.75	63.19	-39.29	0.3704	0.1695	0.03
14	65.75	113.12	-55.58	0.4072	0.1832	0.02
15	78.77	68.27	-34.12	0.3842	0.2506	0.01
16	59.79	-9.56	79.86	0.4569	0.5180	0.10
17	96.91	-15.12	120.26	0.4561	0.5200	0.11
18	98.00	-10.69	56.88	0.4105	0.4548	0.05
19	51.25	63.07	33.68	0.5734	0.3295	0.51
20	69.68	-88.88	58.40	0.2631	0.6232	0.62
21	37.61	25.25	-65.62	0.2044	0.1553	0.51
22	66.90	-64.91	-9.10	0.2096	0.3966	0.27
23	50.12	70.30	-38.92	0.3845	0.2058	0.27
24	73.34	-12.84	73.30	0.4377	0.5026	0.43
25	62.94	109.28	-19.70	0.4984	0.2242	0.19
26	91.69	-53.18	110.45	0.3882	0.5800	0.28
27	68.31	-47.36	-52.58	0.1706	0.2690	0.47
28	85.93	-122.63	24.87	0.1918	0.5310	0.12
29	47.27	86.61	-87.49	0.2746	0.1245	0.08
30	82.16	30.52	111.34	0.5349	0.4502	0.35

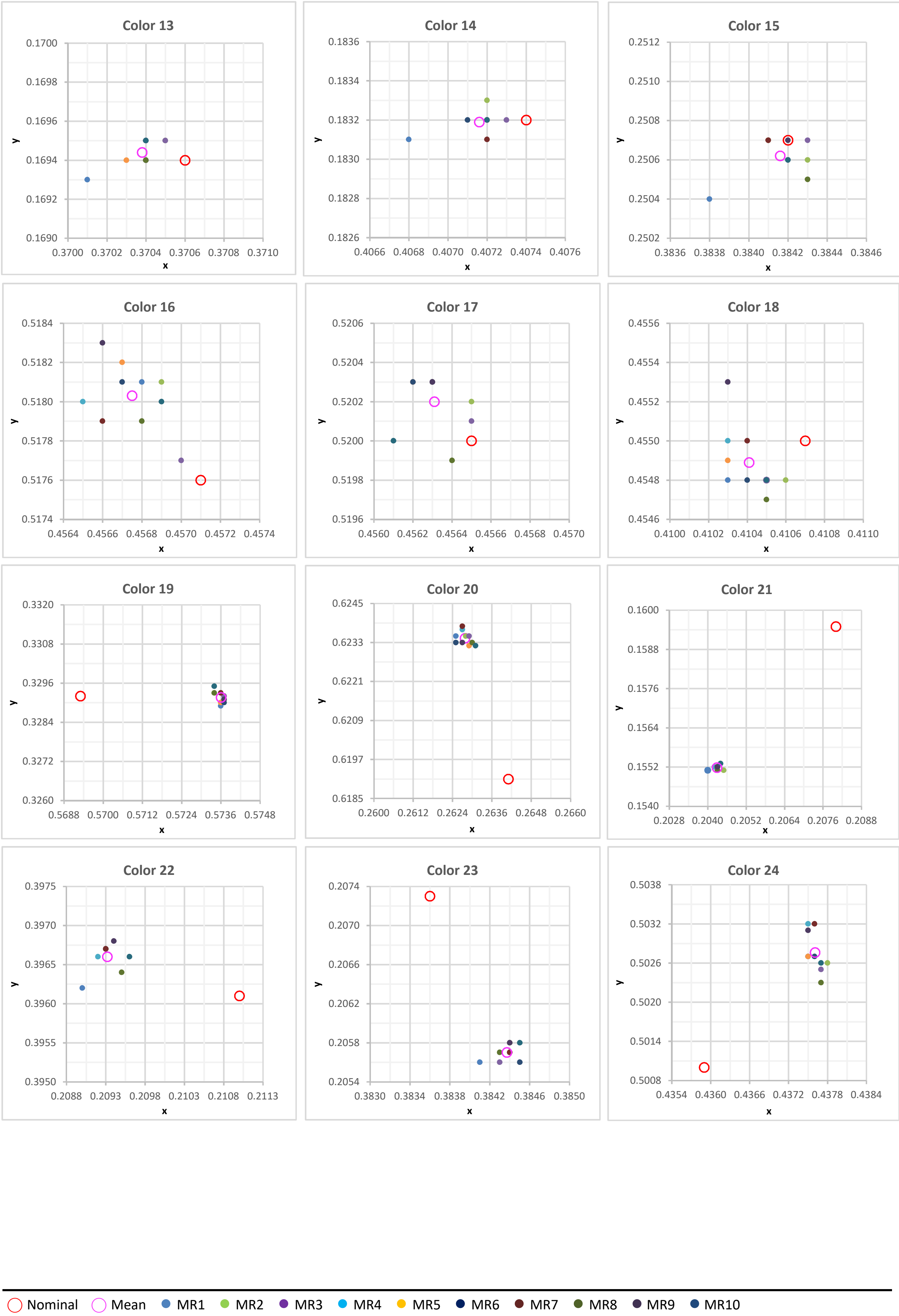
2| 3 Display calibration device performance data

1.3 - Visualization of the measured values in the CIE xy chromaticity diagram



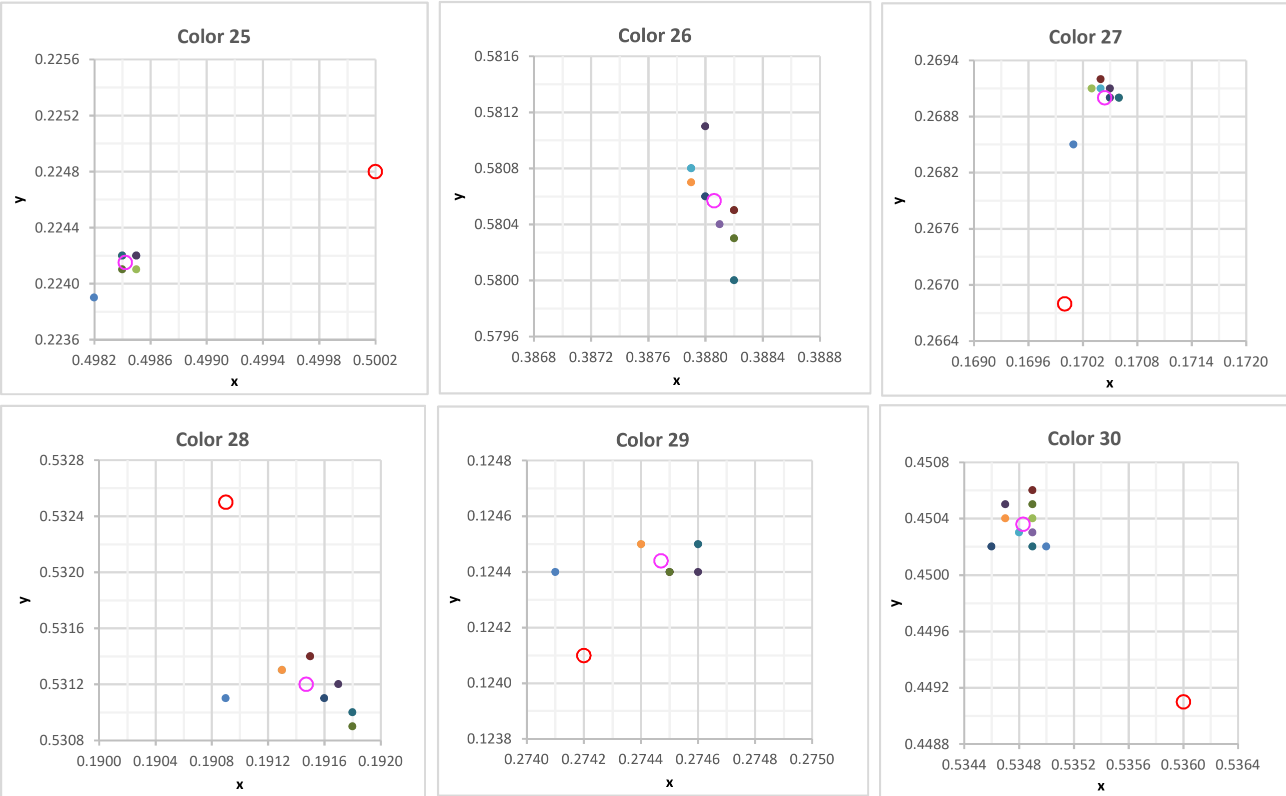
2| 3 Display calibration device performance data

1.3 - Visualization of the measured values in the CIE xy chromaticity diagram



2| 3 Display calibration device performance data

1.3 - Visualization of the measured values in the CIE xy chromaticity diagram



Nominal Mean MR1 MR2 MR3 MR4 MR5 MR6 MR7 MR8 MR9 MR10

2| 3 Display calibration device performance data

1.4 - Color accuracy and repeatability of the measurements

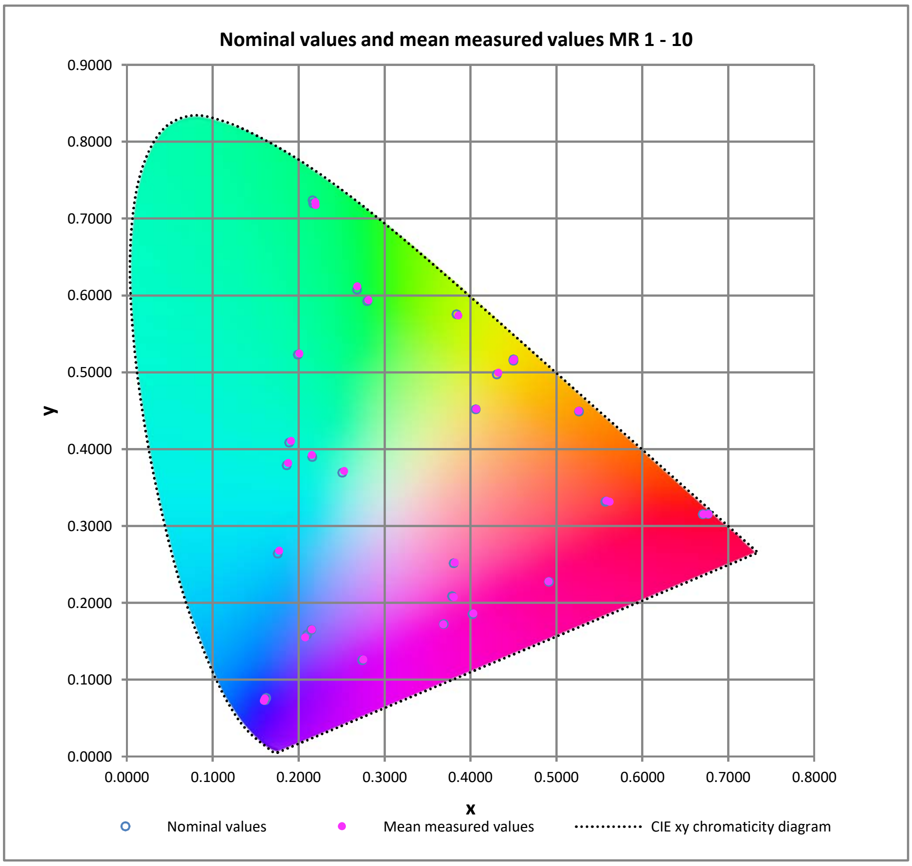
	Device Values			Nominal Values					Accuracy (ΔE_{00} MR1 – MR10)				Repeatability (ΔE_{00} MR1 – MR10)			
Color	R	G	B	L*	a*	b*	x	y	Mean	Min	Max	SD	Mean	Min	Max	SD
1	128	0	0	31.86	65.59	53.26	0.6855	0.3106	0.08	0.04	0.31	0.0814	0.06	0.01	0.27	0.0769
2	255	0	0	59.95	105.65	103.37	0.6905	0.3095	0.86	0.81	0.88	0.0188	0.04	0.01	0.05	0.0140
3	255	128	128	69.00	78.48	40.87	0.5686	0.3295	0.04	0.02	0.09	0.0184	0.02	0.01	0.06	0.0149
4	0	128	0	54.73	-102.17	67.05	0.2086	0.7360	0.10	0.08	0.16	0.0250	0.04	0.01	0.11	0.0308
5	0	255	0	84.14	-145.64	96.35	0.2075	0.7398	0.09	0.04	0.13	0.0250	0.04	0.01	0.06	0.0194
6	128	255	128	87.57	-98.03	66.89	0.2761	0.6024	0.06	0.03	0.10	0.0175	0.03	0.01	0.05	0.0122
7	0	0	128	17.07	42.46	-74.32	0.1598	0.0758	1.46	0.04	2.12	0.6804	0.27	0.07	1.48	0.4517
8	0	0	255	32.28	64.56	-113.14	0.1549	0.0714	0.05	0.01	0.08	0.0170	0.26	0.00	0.05	0.0151
9	128	128	255	52.82	30.11	-78.42	0.2124	0.1648	0.03	0.01	0.08	0.0226	0.02	0.01	0.07	0.0219
10	0	128	128	51.93	-67.19	-6.73	0.1825	0.4138	0.07	0.05	0.12	0.0170	0.03	0.01	0.10	0.0288
11	0	255	255	88.06	-96.33	-20.42	0.1791	0.3836	0.07	0.04	0.09	0.0160	0.03	0.00	0.08	0.0234
12	170	255	255	92.16	-54.25	-13.63	0.2478	0.3725	0.09	0.06	0.11	0.0151	0.04	0.01	0.11	0.0304
13	128	0	128	30.74	63.28	-39.29	0.3706	0.1694	0.03	0.02	0.05	0.0092	0.03	0.01	0.04	0.0092
14	255	0	255	65.76	113.24	-55.57	0.4074	0.1832	0.03	0.01	0.06	0.0134	0.01	0.00	0.05	0.0140
15	255	170	255	78.77	68.28	-34.10	0.3842	0.2507	0.02	0.01	0.08	0.0205	0.02	0.01	0.06	0.0167
16	128	128	0	59.73	-9.41	79.66	0.4571	0.5176	0.11	0.04	0.16	0.0313	0.03	0.01	0.07	0.0186
17	255	255	0	96.88	-14.97	120.68	0.4565	0.5200	0.07	0.03	0.11	0.0276	0.04	0.02	0.08	0.0196
18	255	255	170	97.96	-10.67	57.01	0.4107	0.4550	0.09	0.04	0.18	0.0442	0.04	0.02	0.12	0.0299
19	170	85	85	51.26	62.33	32.41	0.5693	0.3292	0.47	0.42	0.51	0.0259	0.04	0.01	0.08	0.0241
20	85	170	85	69.06	-87.26	56.95	0.2641	0.6191	0.63	0.62	0.64	0.0070	0.03	0.01	0.04	0.0107
21	85	85	170	37.80	24.58	-63.80	0.2080	0.1595	0.52	0.49	0.56	0.0169	0.02	0.01	0.07	0.0218
22	85	170	170	66.74	-63.99	-9.05	0.2110	0.3961	0.29	0.27	0.31	0.0144	0.02	0.00	0.07	0.0202
23	170	85	170	50.20	69.23	-38.50	0.3836	0.2073	0.27	0.26	0.29	0.0093	0.02	0.01	0.04	0.0106
24	170	170	85	73.29	-12.96	71.69	0.4359	0.5010	0.42	0.39	0.45	0.0198	0.03	0.01	0.07	0.0209
25	255	0	170	62.91	109.35	-19.08	0.5002	0.2248	0.19	0.18	0.23	0.0156	0.03	0.00	0.05	0.0148
26	170	255	0	91.58	-54.08	110.57	0.3867	0.5817	0.27	0.24	0.29	0.0204	0.02	0.02	0.06	0.0159
27	0	170	255	67.94	-46.66	-53.23	0.1700	0.2668	0.48	0.46	0.53	0.0224	0.03	0.01	0.06	0.0176
28	0	255	170	85.88	-123.35	25.08	0.1909	0.5325	0.10	0.08	0.12	0.0159	0.03	0.01	0.07	0.0170
29	170	0	255	47.20	86.68	-87.66	0.2742	0.1241	0.08	0.06	0.11	0.0144	0.02	0.00	0.07	0.0186
30	255	170	0	81.99	31.15	111.10	0.5360	0.4491	0.41	0.35	0.48	0.0495	0.04	0.02	0.11	0.0316

Mean	0.25	0.17	0.31	0.0444	0.05	0.01	0.12	0.0357

2| 4 Display calibration device performance data

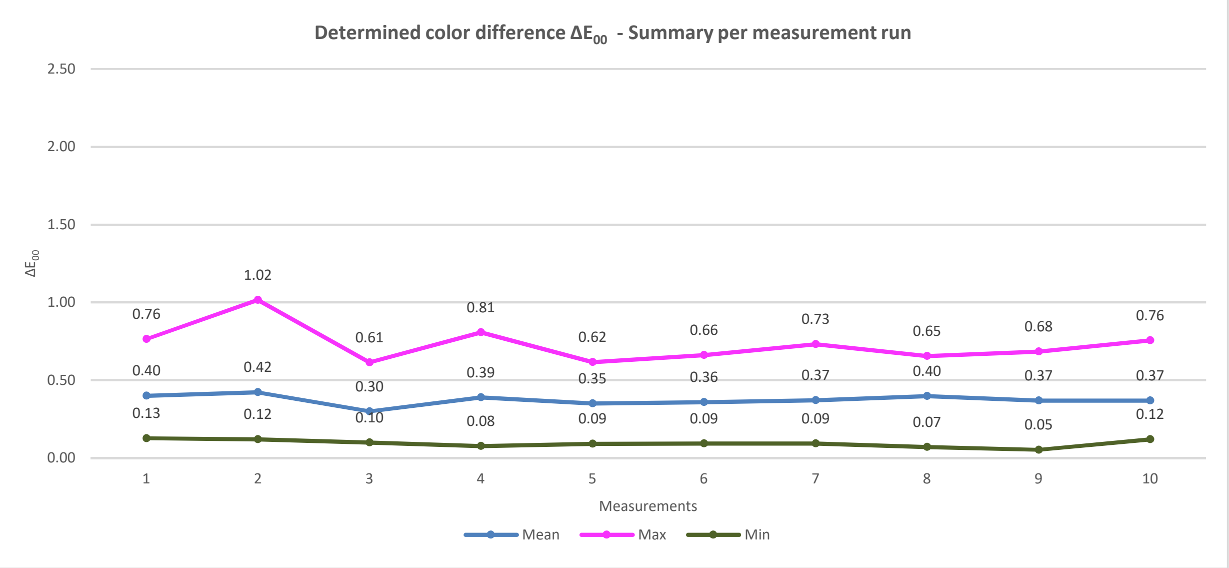
1.1 - Summary and visualization of the measured values

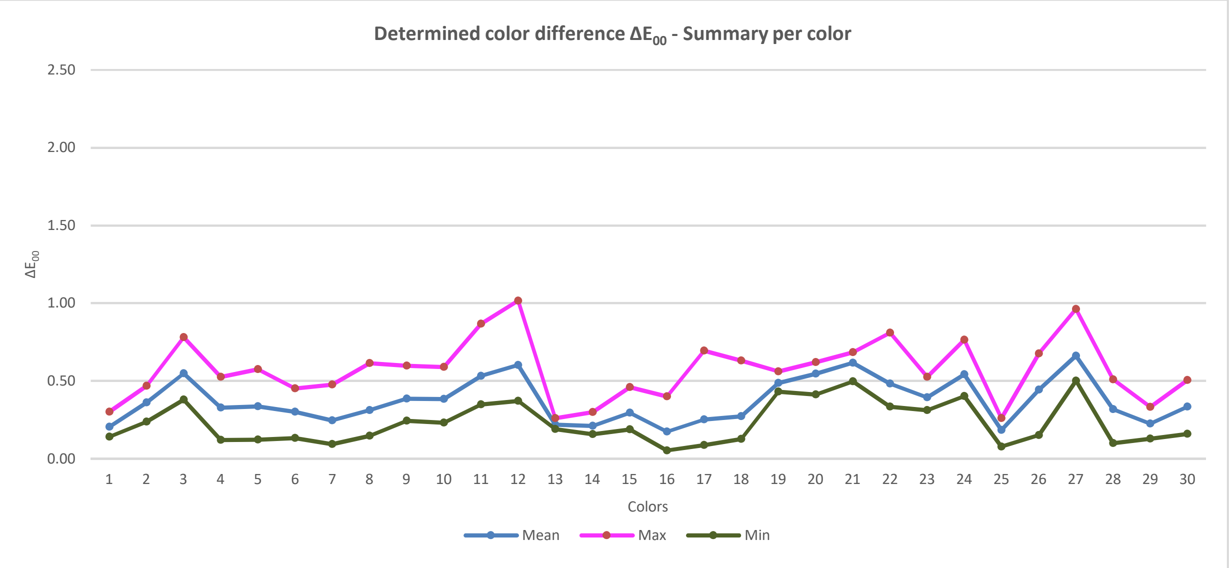
Color		Device Values			Nominal Values					Mean Measured Values MR1 - MR10					
Color		R	G	B	L*	a*	b*	x	y	L*	a*	b*	x	y	ΔE_{00}
	1	128	0	0	31.92	62.40	48.93	0.6705	0.3150	31.73	62.34	49.04	0.6716	0.3149	0.16
	2	255	0	0	60.40	100.64	90.13	0.6765	0.3153	60.04	100.55	90.36	0.6774	0.3148	0.33
	3	255	128	128	69.17	74.85	37.91	0.5572	0.3312	69.08	74.53	38.98	0.5587	0.3327	0.54
	4	0	128	0	54.64	-97.80	63.92	0.2170	0.7194	54.67	-96.61	64.29	0.2202	0.7174	0.31
	5	0	255	0	83.99	-139.22	92.06	0.2164	0.7233	84.02	-137.51	92.50	0.2196	0.7211	0.33
	6	128	255	128	87.43	-94.37	64.31	0.2799	0.5924	87.49	-93.97	65.14	0.2814	0.5934	0.28
	7	0	0	128	16.67	42.61	-73.06	0.1623	0.0762	16.47	42.60	-73.27	0.1610	0.0752	0.16
	8	0	0	255	32.40	66.30	-111.50	0.1608	0.0729	32.16	66.28	-111.73	0.1598	0.0722	0.21
	9	128	128	255	52.80	31.38	-78.17	0.2148	0.1647	52.59	31.39	-77.59	0.2157	0.1653	0.32
	10	0	128	128	51.82	-63.23	-7.16	0.1894	0.4082	51.84	-62.89	-6.49	0.1914	0.4105	0.35
	11	0	255	255	87.88	-90.09	-20.86	0.1862	0.3789	87.98	-89.90	-19.64	0.1881	0.3818	0.51
	12	170	255	255	92.03	-51.13	-14.19	0.2511	0.3692	92.14	-50.82	-13.10	0.2532	0.3713	0.58
	13	128	0	128	30.94	61.67	-38.67	0.3690	0.1723	30.69	61.54	-38.66	0.3687	0.1718	0.20
	14	255	0	255	66.01	109.97	-55.40	0.4026	0.1853	65.86	109.54	-54.79	0.4036	0.1860	0.19
	15	255	170	255	78.80	66.43	-34.55	0.3805	0.2512	78.73	66.26	-33.77	0.3820	0.2523	0.28
	16	128	128	0	59.75	-10.47	73.81	0.4502	0.5149	59.71	-10.50	74.08	0.4504	0.5153	0.07
	17	255	255	0	96.92	-16.14	111.74	0.4503	0.5167	96.87	-15.77	112.16	0.4511	0.5165	0.20
	18	255	255	170	97.94	-11.14	53.94	0.4064	0.4515	98.00	-11.16	54.46	0.4069	0.4522	0.16
	19	170	85	85	51.39	59.07	30.24	0.5574	0.3318	51.18	60.14	31.26	0.5625	0.3312	0.47
	20	85	170	85	68.88	-83.92	54.34	0.2680	0.6075	69.31	-84.72	55.97	0.2687	0.6114	0.53
	21	85	85	170	37.81	25.92	-64.00	0.2101	0.1586	37.21	26.75	-65.03	0.2078	0.1548	0.58
	22	85	170	170	66.52	-59.99	-10.04	0.2159	0.3897	66.71	-60.79	-9.42	0.2158	0.3922	0.46
	23	170	85	170	50.30	67.27	-38.84	0.3786	0.2083	50.07	68.34	-38.77	0.3810	0.2073	0.39
	24	170	170	85	73.19	-13.43	67.62	0.4308	0.4971	73.24	-13.33	69.46	0.4329	0.4991	0.50
	25	255	0	170	63.21	105.45	-19.76	0.4914	0.2273	63.05	105.11	-19.67	0.4914	0.2275	0.15
	26	170	255	0	91.55	-53.44	103.67	0.3841	0.5752	91.60	-52.33	104.16	0.3863	0.5738	0.44
	27	0	170	255	67.65	-41.57	-53.53	0.1760	0.2636	67.91	-42.31	-52.03	0.1777	0.2676	0.64
	28	0	255	170	85.71	-116.76	23.93	0.1991	0.5230	85.82	-115.95	24.59	0.2012	0.5239	0.30
	29	170	0	255	47.34	85.65	-87.13	0.2740	0.1253	47.29	85.41	-86.35	0.2755	0.1262	0.20
	30	255	170	0	82.05	28.63	100.64	0.5267	0.4487	82.09	28.24	101.01	0.5262	0.4496	0.25

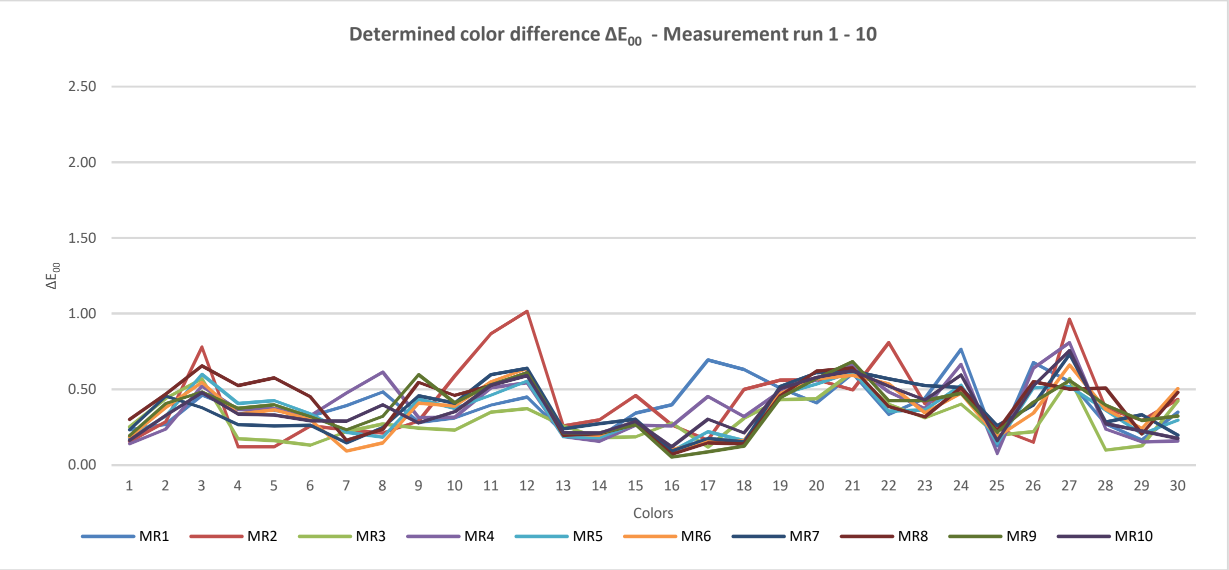


2| 4 Display calibration device performance data

1.1 - Summary and visualization of the measured values







2| 4 Display calibration device performance data

1.2 - Measured values

	Measured Values MR1						Measured Values MR2						Measured Values MR3					
Color	L*	a*	b*	x	y	ΔE_{00}	L*	a*	b*	x	y	ΔE_{00}	L*	a*	b*	x	y	ΔE_{00}
1	31.74	62.6	48.65	0.6716	0.3140	0.23	31.75	62.31	49.04	0.6714	0.3150	0.15	31.73	61.93	49.01	0.6705	0.3158	0.25
2	60.14	101.12	90.12	0.6779	0.3141	0.27	60.13	100.47	90.5	0.6771	0.3151	0.29	60.04	100.1	90.64	0.6768	0.3155	0.44
3	69.12	75.27	39.1	0.5601	0.3319	0.46	69.13	74.26	39.41	0.5589	0.3334	0.78	69.05	74.14	38.84	0.5579	0.3330	0.57
4	54.48	-96.17	63.85	0.2205	0.7164	0.37	54.64	-97.55	64.25	0.2178	0.7196	0.12	54.55	-97.31	64.19	0.2181	0.7194	0.17
5	83.86	-137.09	92.19	0.2199	0.7205	0.36	84.06	-138.95	92.48	0.2172	0.7232	0.12	83.87	-138.54	92.3	0.2174	0.7230	0.16
6	87.34	-93.47	64.96	0.2819	0.5927	0.32	87.53	-95.17	65.42	0.2796	0.5955	0.26	87.34	-94.72	64.84	0.2797	0.5942	0.13
7	16.40	42.06	-73.23	0.1597	0.0752	0.39	16.49	42.05	-72.76	0.1613	0.0761	0.23	16.51	42.44	-73.33	0.1606	0.0753	0.22
8	32.16	65.44	-111.74	0.1585	0.0723	0.48	32.24	65.66	-111.08	0.1603	0.0730	0.21	32.19	66.12	-111.93	0.1592	0.0721	0.27
9	52.53	31.18	-77.72	0.2149	0.1650	0.28	52.62	30.83	-77.04	0.2160	0.1664	0.29	52.56	31.16	-77.9	0.2146	0.1648	0.24
10	51.66	-62.8	-6.66	0.1909	0.4098	0.31	51.82	-63.72	-6.1	0.1904	0.4129	0.59	51.74	-63.28	-6.75	0.1899	0.4099	0.23
11	87.83	-89.93	-19.9	0.1875	0.3812	0.40	88.04	-91.17	-19.07	0.1872	0.3840	0.87	87.84	-90.46	-20.12	0.1866	0.3809	0.35
12	92.02	-50.6	-13.33	0.2531	0.3707	0.45	92.19	-51.91	-12.55	0.2526	0.3732	1.02	92.01	-51.36	-13.57	0.2517	0.3707	0.37
13	30.67	61.59	-38.56	0.3693	0.1719	0.21	30.69	61.21	-38.18	0.3699	0.1730	0.26	30.69	61.17	-38.76	0.3673	0.1718	0.26
14	65.95	109.73	-54.66	0.4042	0.1862	0.19	65.95	109.11	-54.15	0.4045	0.1871	0.30	65.87	109.14	-55.05	0.4023	0.1859	0.18
15	78.72	66.83	-33.81	0.3827	0.2519	0.34	78.78	65.84	-33.2	0.3825	0.2534	0.46	78.68	65.89	-34.11	0.3807	0.2520	0.19
16	59.58	-9.8	73.71	0.4518	0.5135	0.40	59.68	-10.95	74.03	0.4493	0.5162	0.26	59.61	-10.93	74.00	0.4493	0.5163	0.28
17	96.79	-14.66	111.99	0.4528	0.5148	0.69	96.94	-16.52	112.17	0.4499	0.5175	0.16	96.75	-16.28	112.01	0.4503	0.5173	0.12
18	97.93	-10.22	54.46	0.4084	0.4511	0.63	98.07	-11.96	54.96	0.4063	0.4537	0.50	97.88	-11.67	54.16	0.4059	0.4524	0.31
19	51.16	60.61	31.19	0.5634	0.3303	0.51	51.18	59.78	31.49	0.5622	0.3320	0.56	51.15	59.72	31.12	0.5614	0.3317	0.43
20	69.13	-84.17	55.68	0.2693	0.6103	0.41	69.3	-85.61	56.07	0.2669	0.6132	0.56	69.18	-85.35	55.7	0.2669	0.6123	0.44
21	37.15	26.45	-64.99	0.2072	0.1549	0.61	37.24	26.16	-64.45	0.2082	0.1562	0.50	37.18	26.52	-65.25	0.2068	0.1544	0.61
22	66.54	-60.63	-9.58	0.2156	0.3916	0.33	66.69	-61.61	-8.97	0.2151	0.3943	0.81	66.59	-61.23	-9.78	0.2143	0.3915	0.40
23	50.05	68.46	-38.66	0.3816	0.2073	0.44	50.08	67.89	-38.23	0.3818	0.2085	0.41	50.04	67.95	-38.96	0.3796	0.2072	0.31
24	73.1	-12.51	69.22	0.4344	0.4976	0.76	73.22	-13.93	69.55	0.4319	0.5003	0.48	73.12	-13.79	69.23	0.4318	0.4998	0.40
25	63.14	105.54	-19.4	0.4926	0.2276	0.13	63.12	104.72	-19.02	0.4923	0.2287	0.24	63.05	104.68	-19.83	0.4902	0.2276	0.20
26	91.47	-51.49	103.93	0.3876	0.5724	0.68	91.64	-53.28	104.15	0.3847	0.5753	0.15	91.45	-52.94	103.99	0.3851	0.5749	0.22
27	67.75	-42.42	-52.35	0.1767	0.2667	0.55	67.92	-43.07	-51.55	0.1773	0.2690	0.96	67.81	-42.57	-52.47	0.1765	0.2666	0.57
28	85.66	-115.81	24.46	0.2011	0.5237	0.27	85.87	-117.35	25.10	0.1998	0.5267	0.38	85.66	-116.73	24.21	0.1994	0.5239	0.10
29	47.31	85.12	-86.35	0.2750	0.1263	0.17	47.33	84.89	-85.78	0.2761	0.1271	0.29	47.3	85.06	-86.6	0.2743	0.1260	0.13
30	82.02	29.38	100.89	0.5281	0.4477	0.35	82.11	27.87	100.99	0.5256	0.4501	0.43	81.99	27.87	100.91	0.5257	0.4501	0.42

	Measured Values MR4						Measured Values MR5						Measured Values MR6					
Color	L*	a*	b*	x	y	ΔE_{00}	L*	a*	b*	x	y	ΔE_{00}	L*	a*	b*	x	y	ΔE_{00}
1	31.82	62.49	49.24	0.6718	0.3148	0.14	31.74	62.26	49.07	0.6714	0.3151	0.18	31.70	62.29	49.00	0.6716	0.3149	0.19
2	60.15	100.82	90.53	0.6776	0.3146	0.24	60.07	100.18	90.17	0.6767	0.3154	0.32	59.98	100.51	90.34	0.6775	0.3148	0.38
3	69.16	74.8	39.07	0.5591	0.3325	0.52	69.11	74.28	39.00	0.5583	0.3330	0.60	69.05	74.45	38.95	0.5586	0.3327	0.55
4	54.69	-96.6	64.55	0.2205	0.7179	0.37	54.66	-96.14	64.3	0.2214	0.7164	0.41	54.71	-96.57	64.36	0.2205	0.7172	0.34
5	84.03	-137.51	92.81	0.2198	0.7216	0.37	83.99	-136.83	92.44	0.2207	0.7200	0.42	84.07	-137.39	92.61	0.2200	0.7209	0.36
6	87.51	-93.8	65.24	0.2818	0.5933	0.33	87.48	-93.49	65.07	0.2821	0.5926	0.34	87.54	-93.96	65.21	0.2815	0.5934	0.30
7	16.38	42.14	-73.56	0.1588	0.0747	0.48	16.45	43.09	-73.37	0.1617	0.0749	0.22	16.54	42.72	-73.16	0.1618	0.0756	0.09
8	32.00	65.54	-112.14	0.1575	0.0716	0.61	32.19	66.6	-111.71	0.1603	0.0722	0.18	32.25	66.54	-111.57	0.1607	0.0725	0.15
9	52.54	30.87	-77.79	0.2143	0.1650	0.31	52.61	31.65	-77.57	0.2161	0.1652	0.43	52.64	31.56	-77.48	0.2162	0.1655	0.41
10	51.84	-63.32	-6.57	0.1904	0.4106	0.31	51.83	-62.37	-6.52	0.1924	0.4098	0.37	51.89	-62.75	-6.43	0.1919	0.4105	0.39
11	87.94	-90.57	-19.76	0.1870	0.3819	0.51	87.96	-89.22	-19.7	0.1888	0.3812	0.46	88.04	-89.54	-19.51	0.1887	0.3819	0.55
12	92.13	-51.03	-13.19	0.2528	0.3712	0.54	92.13	-50.36	-13.14	0.2538	0.3709	0.55	92.19	-50.68	-12.99	0.2536	0.3714	0.64
13	30.71	61.53	-38.73	0.3684	0.1717	0.19	30.70	61.59	-38.67	0.3688	0.1717	0.19	30.68	61.57	-38.69	0.3687	0.1716	0.21
14	65.90	109.6	-54.85	0.4035	0.1860	0.16	65.91	109.29	-54.74	0.4033	0.1863	0.18	65.84	109.62	-54.81	0.4037	0.1859	0.20
15	78.77	66.33	-33.82	0.3819	0.2522	0.26	78.77	66.12	-33.75	0.3818	0.2524	0.27	78.74	66.25	-33.73	0.3820	0.2524	0.29
16	59.77	-10.16	74.44	0.4514	0.5148	0.26	59.71	-10.42	74.11	0.4506	0.5151	0.09	59.73	-10.64	74.1	0.4501	0.5156	0.10
17	96.93	-15.29	112.55	0.4521	0.5160	0.45	96.87	-15.72	112.09	0.4512	0.5164	0.22	96.88	-15.92	112.22	0.4509	0.5167	0.15
18	98.05	-10.79	54.5	0.4075	0.4517	0.32	98.00	-11.07	54.39	0.4070	0.4520	0.16	98.02	-11.27	54.46	0.4068	0.4523	0.16
19	51.27	60.43	31.36	0.5631	0.3309	0.49	51.2	60.00	31.29	0.5622	0.3315	0.47	51.16	60.08	31.26	0.5624	0.3313	0.47
20	69.33	-84.64	56.06	0.2690	0.6114	0.56	69.3	-84.3	55.92	0.2695	0.6106	0.53	69.36	-84.76	56.04	0.2688	0.6115	0.57
21	37.16	26.33	-65.25	0.2064	0.1545	0.66	37.22	27.01	-65.06	0.2083	0.1547	0.62	37.24	26.95	-64.98	0.2084	0.1549	0.59
22	66.70	-61.15	-9.54	0.2150	0.3922	0.48	66.7	-60.31	-9.49	0.2165	0.3916	0.36	66.79	-60.7	-9.28	0.2163	0.3925	0.53
23	50.10	68.41	-38.84	0.3809	0.2072	0.37	50.1	68.33	-38.78	0.3810	0.2073	0.36	50.09	68.18	-38.72	0.3808	0.2075	0.35
24	73.29	-12.96	69.64	0.4338	0.4986	0.66	73.25	-13.21	69.43	0.4331	0.4989	0.53	73.29	-13.72	69.53	0.4322	0.4998	0.47
25	63.13	105.32	-19.65	0.4916	0.2274	0.08	63.09	104.87	-19.66	0.4909	0.2277	0.14	63.02	104.9	-19.7	0.4910	0.2275	0.19
26	91.63	-51.87	104.51	0.3873	0.5733	0.64	91.58	-52.06	104.09	0.3867	0.5733	0.51	91.64	-52.66	104.22	0.3858	0.5743	0.34
27	67.87	-43.14	-52.22	0.1762	0.2675	0.81	67.91	-41.77	-52.06	0.1783	0.2673	0.52	68.01	-41.99	-51.8	0.1786	0.2681	0.66
28	85.80	-116.26	24.51	0.2007	0.5240	0.24	85.79	-115.23	24.49	0.2022	0.5230	0.36	85.9	-115.73	24.70	0.2018	0.5239	0.37
29	47.25	85.19	-86.53	0.2746	0.1260	0.15	47.32	85.42	-86.32	0.2756	0.1263	0.21	47.32	85.49	-86.24	0.2759	0.1264	0.24
30	82.17	28.71	101.34	0.5271	0.4490	0.16	82.1	28.14	100.96	0.5260	0.4497	0.30	82.1	27.74	101.03	0.5254	0.4503	0.51

2| 4 Display calibration device performance data

1.2 - Measured values

	Measured Values MR7						Measured Values MR8						Measured Values MR9					
Color	L*	a*	b*	x	y	ΔE_{00}	L*	a*	b*	x	y	ΔE_{00}	L*	a*	b*	x	y	ΔE_{00}
1	31.67	62.81	49.04	0.6730	0.3136	0.23	31.75	61.83	49.09	0.6703	0.3161	0.30	31.68	62.32	48.98	0.6717	0.3147	0.20
2	59.9	101.27	90.46	0.6789	0.3135	0.46	60.01	99.74	90.32	0.6762	0.3160	0.47	59.94	100.36	89.96	0.6772	0.3149	0.41
3	69.00	75.06	38.79	0.5595	0.3317	0.38	69.07	73.86	38.89	0.5575	0.3334	0.65	69.03	74.33	38.73	0.5581	0.3326	0.48
4	54.77	-97.18	64.47	0.2192	0.7186	0.27	54.71	-95.6	64.31	0.2229	0.7149	0.53	54.74	-96.32	64.26	0.2211	0.7163	0.38
5	84.13	-138.31	92.72	0.2186	0.7223	0.26	84.04	-135.98	92.55	0.2224	0.7186	0.57	84.09	-137.02	92.43	0.2206	0.7199	0.40
6	87.58	-94.43	65.27	0.2808	0.5940	0.26	87.51	-93.01	65.16	0.2831	0.5920	0.45	87.54	-93.68	65.11	0.2819	0.5928	0.32
7	16.48	42.86	-73.34	0.1614	0.0751	0.15	16.53	42.99	-73.27	0.1621	0.0753	0.16	16.53	43.13	-73.23	0.1625	0.0754	0.23
8	32.13	66.77	-111.8	0.1603	0.0720	0.25	32.23	66.84	-111.64	0.1609	0.0723	0.24	32.22	67.05	-111.62	0.1612	0.0723	0.32
9	52.59	31.71	-77.61	0.2161	0.1651	0.46	52.63	31.85	-77.53	0.2166	0.1653	0.55	52.63	31.93	-77.51	0.2167	0.1653	0.60
10	51.92	-63.18	-6.4	0.1911	0.4111	0.41	51.88	-61.91	-6.49	0.1935	0.4094	0.46	51.9	-62.39	-6.45	0.1926	0.4101	0.41
11	88.06	-90.28	-19.51	0.1878	0.3823	0.60	88.00	-88.42	-19.62	0.1900	0.3809	0.53	88.05	-89.11	-19.55	0.1893	0.3815	0.53
12	92.2	-50.98	-13.02	0.2532	0.3716	0.64	92.16	-49.96	-13.08	0.2544	0.3708	0.61	92.19	-50.37	-13.04	0.2540	0.3711	0.61
13	30.65	61.97	-38.8	0.3692	0.1711	0.24	30.72	61.34	-38.66	0.3682	0.1720	0.20	30.67	61.67	-38.74	0.3687	0.1715	0.21
14	65.73	110.35	-55.02	0.4043	0.1851	0.27	65.86	109.06	-54.83	0.4027	0.1862	0.21	65.79	109.68	-54.92	0.4035	0.1857	0.21
15	78.68	66.69	-33.87	0.3824	0.2519	0.30	78.74	65.94	-33.76	0.3815	0.2525	0.27	78.71	66.3	-33.82	0.3819	0.2522	0.27
16	59.75	-10.57	74.19	0.4503	0.5155	0.09	59.74	-10.58	74.04	0.4501	0.5153	0.07	59.73	-10.55	73.96	0.4501	0.5152	0.05
17	96.89	-15.86	112.23	0.4510	0.5166	0.18	96.87	-15.92	112.17	0.4509	0.5167	0.15	96.87	-16.00	111.93	0.4506	0.5167	0.09
18	98.02	-11.2	54.44	0.4068	0.4522	0.15	98.01	-11.2	54.4	0.4068	0.4521	0.14	98.01	-11.26	54.33	0.4066	0.4521	0.13
19	51.13	60.62	31.16	0.5634	0.3303	0.52	51.2	59.64	31.24	0.5613	0.3320	0.46	51.14	60.08	31.12	0.5622	0.3311	0.44
20	69.41	-85.21	56.11	0.2680	0.6123	0.61	69.35	-83.89	56.06	0.2706	0.6100	0.62	69.37	-84.47	55.98	0.2693	0.6108	0.57
21	37.22	27.04	-65.09	0.2083	0.1546	0.62	37.25	27.15	-65.03	0.2087	0.1548	0.64	37.24	27.25	-65.04	0.2089	0.1547	0.68
22	66.8	-61.09	-9.36	0.2155	0.3926	0.57	66.76	-59.85	-9.4	0.2175	0.3914	0.39	66.77	-60.3	-9.39	0.2168	0.3919	0.43
23	50.01	68.93	-38.95	0.3817	0.2065	0.53	50.09	68.12	-38.82	0.3804	0.2074	0.32	50.05	68.54	-38.87	0.3811	0.2069	0.43
24	73.29	-13.36	69.51	0.4329	0.4992	0.51	73.27	-13.34	69.5	0.4329	0.4991	0.51	73.26	-13.38	69.39	0.4327	0.4991	0.47
25	62.92	105.9	-19.95	0.4921	0.2264	0.26	63.03	104.54	-19.79	0.4901	0.2277	0.22	62.97	105.16	-19.9	0.4910	0.2270	0.22
26	91.65	-52.53	104.29	0.3861	0.5741	0.40	91.61	-52.00	104.22	0.3869	0.5733	0.55	91.63	-52.32	104.00	0.3862	0.5736	0.41
27	67.99	-42.5	-51.93	0.1777	0.2680	0.73	67.96	-41.23	-51.97	0.1793	0.2673	0.50	67.99	-41.57	-51.91	0.1790	0.2676	0.56
28	85.91	-116.51	24.66	0.2006	0.5245	0.28	85.84	-114.42	24.57	0.2035	0.5223	0.51	85.89	-115.29	24.60	0.2023	0.5232	0.40
29	47.22	86.09	-86.47	0.2762	0.1257	0.33	47.33	85.39	-86.3	0.2756	0.1263	0.21	47.28	85.86	-86.35	0.2762	0.1260	0.29
30	82.07	28.39	101.09	0.5265	0.4494	0.20	82.09	27.78	101.00	0.5255	0.4503	0.48	82.07	28.00	100.68	0.5257	0.4498	0.32

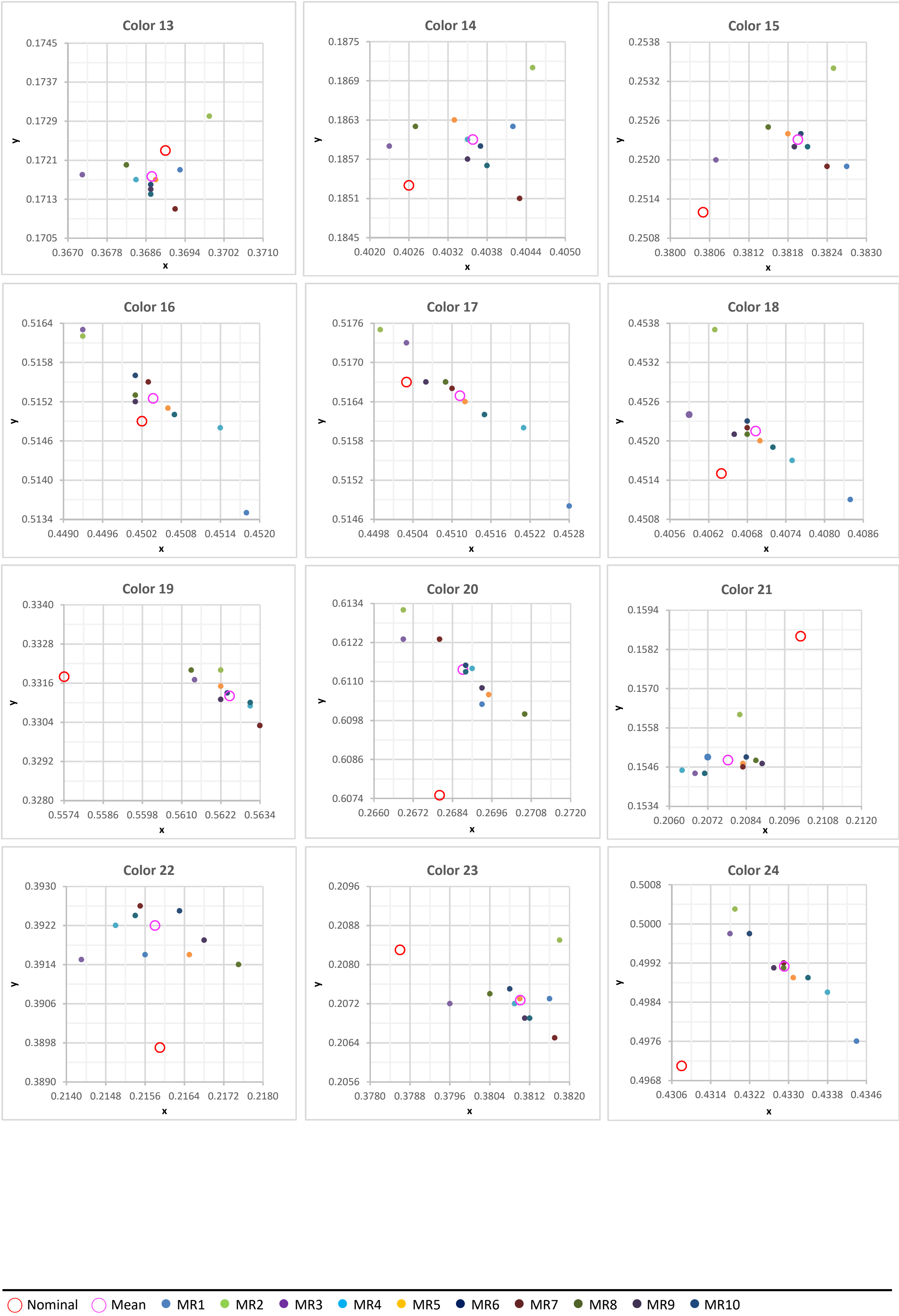
	Measured Values MR10					
Color	L*	a*	b*	x	y	ΔE_{00}
1	31.76	62.56	49.24	0.6723	0.3145	0.16
2	60.04	100.9	90.55	0.6780	0.3143	0.33
3	69.1	74.81	38.97	0.5591	0.3323	0.48
4	54.75	-96.65	64.39	0.2204	0.7173	0.34
5	84.09	-137.52	92.49	0.2197	0.7208	0.33
6	87.55	-93.93	65.16	0.2815	0.5932	0.29
7	16.39	42.52	-73.49	0.1599	0.0747	0.29
8	31.98	66.23	-112.07	0.1586	0.0715	0.40
9	52.54	31.2	-77.7	0.2150	0.1650	0.28
10	51.89	-63.18	-6.5	0.1909	0.4107	0.35
11	87.99	-90.27	-19.66	0.1876	0.3820	0.53
12	92.16	-50.95	-13.1	0.2531	0.3714	0.59
13	30.67	61.71	-38.77	0.3687	0.1714	0.21
14	65.8	109.84	-54.9	0.4038	0.1856	0.21
15	78.72	66.41	-33.79	0.3821	0.2522	0.29
16	59.77	-10.37	74.19	0.4507	0.5150	0.12
17	96.92	-15.56	112.24	0.4515	0.5162	0.30
18	98.04	-11.00	54.46	0.4072	0.4519	0.21
19	51.22	60.39	31.38	0.5631	0.3310	0.50
20	69.38	-84.75	56.03	0.2688	0.6113	0.58
21	37.15	26.62	-65.2	0.2071	0.1544	0.62
22	66.76	-61.05	-9.43	0.2154	0.3924	0.52
23	50.05	68.55	-38.86	0.3812	0.2069	0.43
24	73.3	-13.14	69.6	0.4334	0.4989	0.60
25	63.02	105.48	-19.77	0.4918	0.2270	0.16
26	91.65	-52.1	104.24	0.3868	0.5734	0.52
27	67.91	-42.8	-52.06	0.1769	0.2677	0.76
28	85.86	-116.15	24.56	0.2010	0.5240	0.27
29	47.19	85.57	-86.52	0.2752	0.1258	0.23
30	82.14	28.49	101.16	0.5267	0.4492	0.18

2| 4 Display calibration device performance data

1.3 - Visualization of the measured values in the CIE xy chromaticity diagram

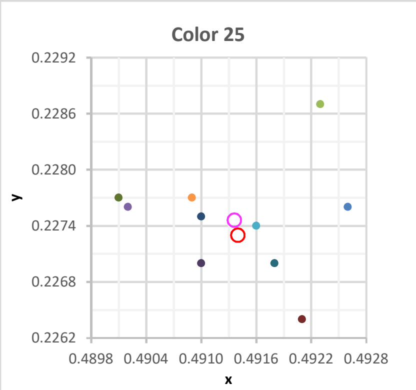
2| 4 Display calibration device performance data

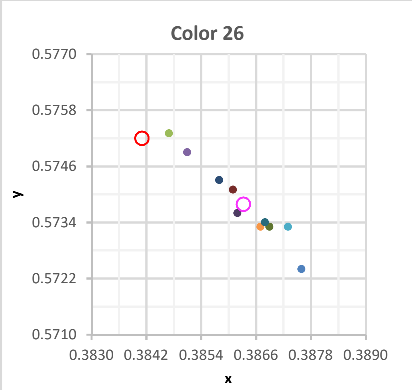
1.3 - Visualization of the measured values in the CIE xy chromaticity diagram

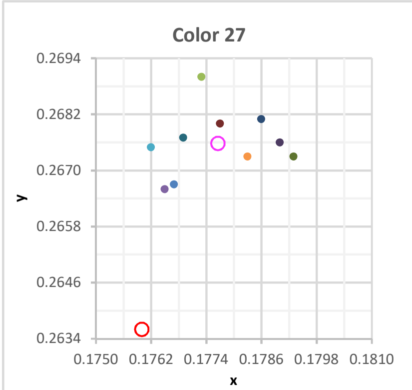


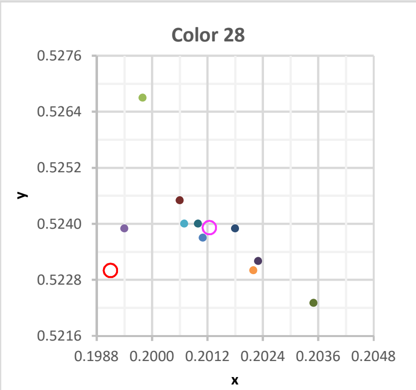
2| 4 Display calibration device performance data

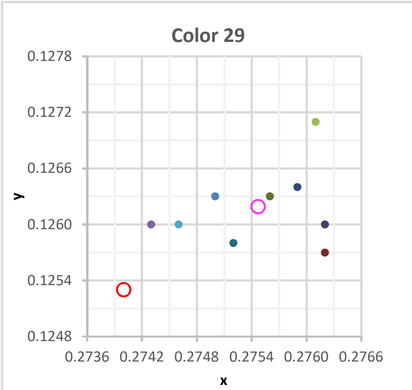
1.3 - Visualization of the measured values in the CIE xy chromaticity diagram

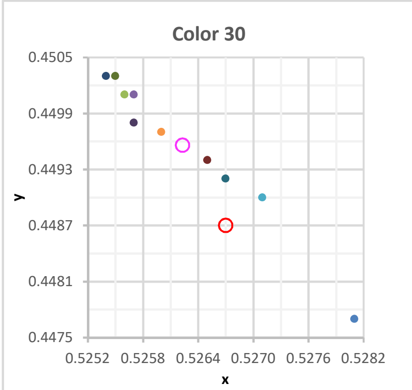


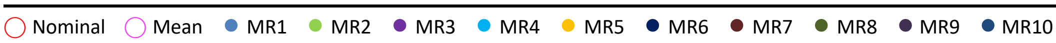












2| 4 Display calibration device performance data

1.4 - Color accuracy and repeatability of the measurements

Color		Device Values			Nominal Values					Accuracy (ΔE_{00} MR1 – MR10)				Repeatability (ΔE_{00} MR1 – MR10)			
		R	G	B	L*	a*	b*	x	y	Mean	Min	Max	SD	Mean	Min	Max	SD
	1	128	0	0	31.92	62.40	48.93	0.6705	0.3150	0.20	0.14	0.30	0.0500	0.11	0.02	0.25	0.0823
	2	255	0	0	60.40	100.64	90.13	0.6765	0.3153	0.36	0.24	0.47	0.0819	0.13	0.05	0.25	0.0762
	3	255	128	128	69.17	74.85	37.91	0.5572	0.3312	0.55	0.38	0.78	0.1127	0.14	0.03	0.25	0.0726
	4	0	128	0	54.64	-97.80	63.92	0.2170	0.7194	0.33	0.12	0.53	0.1161	0.13	0.04	0.22	0.0671
	5	0	255	0	83.99	-139.22	92.06	0.2164	0.7233	0.34	0.12	0.57	0.1312	0.13	0.04	0.25	0.0770
	6	128	255	128	87.43	-94.37	64.31	0.2799	0.5924	0.30	0.13	0.45	0.0799	0.12	0.04	0.23	0.0785
	7	0	0	128	16.67	42.61	-73.06	0.1623	0.0762	0.25	0.09	0.48	0.1144	0.16	0.11	0.35	0.0850
	8	0	0	255	32.40	66.30	-111.50	0.1608	0.0729	0.31	0.15	0.61	0.1465	0.22	0.13	0.46	0.1147
	9	128	128	255	52.80	31.38	-78.17	0.2148	0.1647	0.38	0.24	0.60	0.1231	0.24	0.15	0.39	0.0864
	10	0	128	128	51.82	-63.23	-7.16	0.1894	0.4082	0.38	0.23	0.59	0.0963	0.20	0.07	0.32	0.0783
	11	0	255	255	87.88	-90.09	-20.86	0.1862	0.3789	0.53	0.35	0.87	0.1393	0.17	0.08	0.42	0.1065
	12	170	255	255	92.03	-51.13	-14.19	0.2511	0.3692	0.60	0.37	1.02	0.1688	0.18	0.04	0.53	0.1464
	13	128	0	128	30.94	61.67	-38.67	0.3690	0.1723	0.22	0.19	0.26	0.0262	0.13	0.01	0.16	0.0510
	14	255	0	255	66.01	109.97	-55.40	0.4026	0.1853	0.21	0.16	0.30	0.0436	0.08	0.02	0.17	0.0514
	15	255	170	255	78.80	66.43	-34.55	0.3805	0.2512	0.29	0.19	0.46	0.0701	0.09	0.01	0.20	0.0708
	16	128	128	0	59.75	-10.47	73.81	0.4502	0.5149	0.17	0.05	0.40	0.1171	0.12	0.05	0.39	0.1224
	17	255	255	0	96.92	-16.14	111.74	0.4503	0.5167	0.25	0.09	0.69	0.1884	0.17	0.02	0.50	0.1561
	18	255	255	170	97.94	-11.14	53.94	0.4064	0.4515	0.27	0.13	0.63	0.1716	0.19	0.03	0.58	0.1991
	19	170	85	85	51.39	59.07	30.24	0.5574	0.3318	0.49	0.43	0.56	0.0390	0.16	0.03	0.21	0.0624
	20	85	170	85	68.88	-83.92	54.34	0.2680	0.6075	0.55	0.41	0.62	0.0687	0.12	0.04	0.22	0.0717
	21	85	85	170	37.81	25.92	-64.00	0.2101	0.1586	0.62	0.50	0.68	0.0497	0.17	0.15	0.35	0.0705
	22	85	170	170	66.52	-59.99	-10.04	0.2159	0.3897	0.48	0.33	0.81	0.1394	0.19	0.08	0.36	0.0877
	23	170	85	170	50.30	67.27	-38.84	0.3786	0.2083	0.39	0.31	0.53	0.0653	0.13	0.03	0.18	0.0543
	24	170	170	85	73.19	-13.43	67.62	0.4308	0.4971	0.54	0.40	0.76	0.1061	0.13	0.03	0.45	0.1453
	25	255	0	170	63.21	105.45	-19.76	0.4914	0.2273	0.18	0.08	0.26	0.0570	0.15	0.05	0.20	0.0523
	26	170	255	0	91.55	-53.44	103.67	0.3841	0.5752	0.44	0.15	0.68	0.1712	0.13	0.04	0.32	0.0953
	27	0	170	255	67.65	-41.57	-53.53	0.1760	0.2636	0.66	0.50	0.96	0.1503	0.18	0.10	0.37	0.0924
	28	0	255	170	85.71	-116.76	23.93	0.1991	0.5230	0.32	0.10	0.51	0.1107	0.18	0.05	0.26	0.0771
	29	170	0	255	47.34	85.65	-87.13	0.2740	0.1253	0.22	0.13	0.33	0.0666	0.12	0.04	0.18	0.0497
	30	255	170	0	82.05	28.63	100.64	0.5267	0.4487	0.33	0.16	0.51	0.1272	0.15	0.05	0.59	0.1554

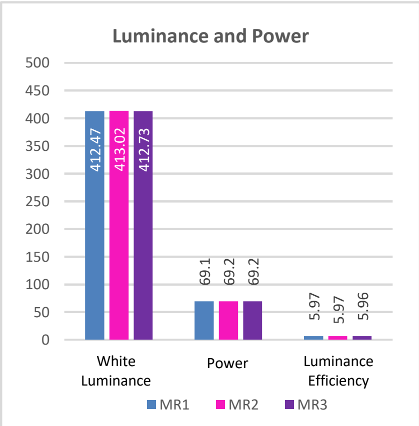
Mean	0.37	0.23	0.57	0.1043	0.15	0.05	0.32	0.0912

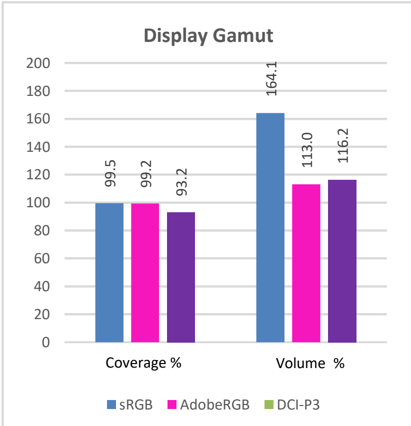
Annex 3 Display performance data

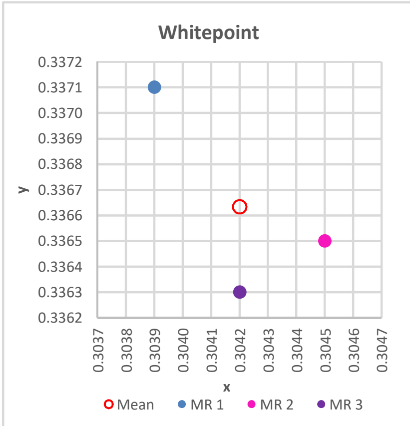
3| 1 Display performance data / Uncalibrated with maximum device settings

1.1 - Display performance data

	White Lum. (cd/m²)	Power (W)	Lum. Eff. (cd/W)	Black Lum. (cd/m²)	Whitepoint (CIE_xy)		Display Gamut					
							sRGB		AdobeRGB		DCI-P3	
					x	y	Cov. (%)	Vol. (%)	Cov. (%)	Vol. (%)	Cov. (%)	Vol. (%)
MR 1	412.47	69.1	5.97	0.3502	0.3039	0.3371	99.5	163.8	99.2	112.9	93.1	116.0
MR 2	413.02	69.2	5.97	0.3557	0.3045	0.3365	99.5	164.2	99.2	113.1	93.3	116.3
MR 3	412.73	69.2	5.96	0.3546	0.3042	0.3363	99.5	164.2	99.2	113.1	93.3	116.3
Mean	412.74	69.2	5.97	0.3535	0.3042	0.3366	99.5	164.1	99.2	113.0	93.2	116.2
Min	413.02	69.2	5.97	0.3557	0.3045	0.3371	99.5	164.2	99.2	113.1	93.3	116.3
Max	412.47	69.1	5.96	0.3502	0.3039	0.3363	99.5	163.8	99.2	112.9	93.1	116.0
SD	0.2246	0.0471	0.0022	0.0024	0.0002	0.0003	0.0000	0.1886	0.0000	0.0943	0.0943	0.1414

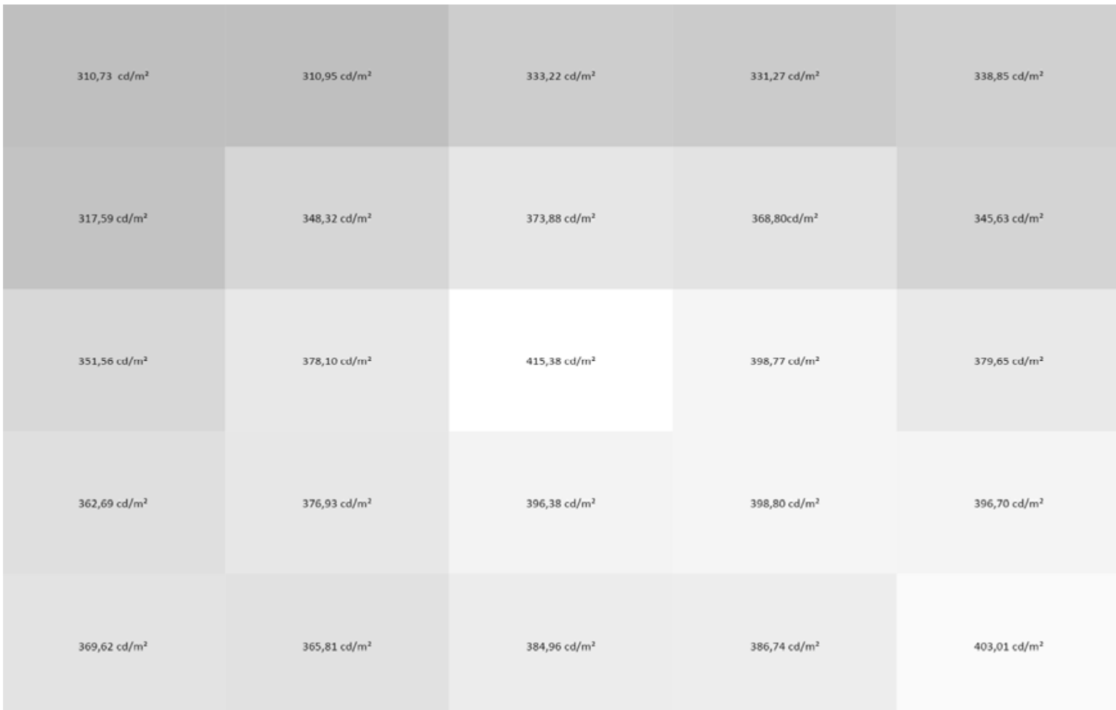






1.2 - Display uniformity - Visualization of the mean values in the 5x5 matrix

	Lum. cd/m²	Delta %	Lum. cd/m²	Delta %	Lum. cd/m²	Delta %	Lum. cd/m²	Delta %	Lum. cd/m²	Delta %
100%	310.73	-25.19	310.95	-25.14	333.22	-19.78	331.27	-20.25	338.85	-18.43
100%	317.59	-23.54	348.32	-16.15	373.88	-9.99	368.80	-11.21	345.63	-16.79
100%	351.56	-15.36	378.10	-8.97	415.38	0.00	398.77	-4.00	379.65	-8.60
100%	362.69	-12.68	376.93	-9.25	396.38	-4.57	398.80	-3.99	396.70	-4.50
100%	369.62	-11.02	365.81	-11.94	384.96	-7.32	386.74	-6.90	403.01	-2.10



3| 1 Display performance data / Uncalibrated with maximum device settings

1.2.1 - Display uniformity - Measured values from three control measurements (5x5 matrix)

	Lum. cd/m²	Delta %	ΔC^*_{00}	Lum. cd/m²	Delta %	ΔC^*_{00}	Lum. cd/m²	Delta %	ΔC^*_{00}	Lum. cd/m²	Delta %	ΔC^*_{00}	Lum. cd/m²	Delta %	ΔC^*_{00}
100%	309.45	-25.42	1.16	309.30	-25.46	0.72	331.75	-20.05	2.65	330.71	-20.30	0.44	337.30	-18.71	0.76
75%	309.46	-25.43	1.08	309.23	-25.49	0.63	331.60	-20.10	1.49	330.53	-20.35	0.39	337.05	-18.79	0.70
50%	182.14	-15.55	-0.62	184.54	-14.97	-1.41	197.53	-11.84	-1.91	196.13	-12.18	-0.11	197.27	-11.90	-0.97
25%	26.68	-2.64	-0.24	27.92	-2.34	-0.65	29.66	-1.92	-1.18	29.42	-1.98	0.03	29.22	-2.03	-0.73
100%	317.29	-23.54	1.84	347.16	-16.34	0.50	372.85	-10.15	0.55	368.20	-11.27	0.48	345.04	-16.85	1.62
75%	317.32	-23.54	1.81	347.16	-16.35	0.45	372.85	-10.16	0.49	368.20	-11.28	0.42	345.04	-16.86	1.57
50%	187.23	-14.32	-0.20	206.68	-9.63	-0.66	221.49	-6.07	-0.72	217.58	-7.01	0.01	201.17	-10.96	-1.18
25%	27.92	-2.34	-0.07	31.49	-1.48	-0.60	33.63	-0.97	-0.39	32.66	-1.20	-0.08	29.75	-1.90	-0.94
100%	351.62	-15.26	1.69	378.00	-8.90	0.65	**414.95**			398.10	-4.06	1.46	379.49	-8.55	1.88
75%	351.62	-15.27	1.63	378.08	-8.90	0.60	**415.00**			398.14	-4.06	1.43	379.49	-8.56	1.82
50%	208.03	-9.31	-0.24	225.48	-5.10	-0.42	**246.65**			235.36	-2.72	0.44	221.41	-6.08	-0.77
25%	31.57	-1.46	-0.03	34.87	-0.67	-0.21	**37.64**			35.81	-0.44	0.15	33.05	-1.11	-0.56
100%	363.03	-12.51	2.18	376.80	-9.19	1.73	396.68	-4.40	1.90	398.81	-3.89	3.24	397.45	-4.22	2.14
75%	363.03	-12.52	2.12	376.83	-9.20	1.70	396.65	-4.42	1.81	398.76	-3.91	3.23	397.47	-4.22	2.03
50%	215.06	-7.61	0.55	224.39	-5.37	0.18	235.59	-2.67	0.47	233.93	-3.07	1.63	230.50	-3.89	0.37
25%	32.92	-1.14	0.43	34.99	-0.64	0.22	36.02	-0.39	0.23	35.58	-0.50	0.90	34.17	-0.84	0.11
100%	369.62	-10.92	3.11	364.66	-12.12	3.02	385.18	-7.17	2.75	386.22	-6.92	3.56	403.85	-0.03	1.92
75%	369.67	-10.92	2.99	364.66	-12.13	2.94	385.14	-7.20	2.75	386.22	-6.94	3.50	403.85	-0.03	1.88
50%	218.54	-6.77	2.09	214.97	-7.64	1.75	224.16	-5.42	1.93	221.49	-6.06	2.13	229.55	-4.12	0.27
25%	33.59	-0.98	1.39	33.31	-1.04	1.16	33.50	-1.00	1.31	32.59	-1.22	1.44	32.88	-1.15	0.14

100%	311.53	-25.05	1.24	311.72	-25.00	0.61	334.14	-19.61	1.49	332.00	-20.12	0.54	341.46	-17.85	0.69
75%	311.56	-25.05	1.23	311.72	-25.01	0.58	334.22	-19.60	1.48	331.97	-20.14	0.46	341.46	-17.85	0.62
50%	184.25	-15.41	-0.70	186.78	-14.81	-1.46	200.28	-11.56	-1.92	198.00	-12.11	-0.20	200.28	-11.56	-0.96
25%	27.14	-2.63	-0.30	28.38	-2.33	-0.61	30.22	-1.89	-0.92	29.77	-1.99	-0.02	29.60	-2.03	-0.67
100%	318.13	-23.46	2.17	349.00	-16.03	0.27	374.50	-9.90	0.50	369.49	-11.10	0.34	346.14	-16.72	1.81
75%	318.15	-23.46	2.07	349.04	-16.03	0.26	374.47	-9.91	0.49	369.44	-11.12	0.35	346.19	-16.72	1.60
50%	188.03	-14.50	-0.20	208.87	-9.49	-0.70	223.64	-5.94	-0.72	219.44	-6.95	-0.07	202.61	-11.00	-1.20
25%	28.11	-2.40	0.35	31.90	-1.48	-0.08	34.05	-0.96	-0.35	33.01	-1.22	-0.03	30.02	-1.93	-0.95
100%	351.79	-15.36	1.78	378.10	-9.03	0.60	**415.63**			399.44	-3.90	1.49	380.25	-8.51	2.00
75%	351.74	-15.38	1.77	378.10	-9.04	0.56	**415.66**			399.44	-3.90	1.46	380.25	-8.52	1.97
50%	208.83	-9.50	-0.40	226.75	-5.19	-0.57	**248.32**			237.28	-2.65	0.32	222.88	-6.12	-0.87
25%	31.87	-1.49	0.05	35.25	-0.68	0.06	**38.06**			36.22	-0.44	0.58	33.43	-1.11	-0.46
100%	362.77	-12.72	2.35	377.04	-9.28	2.01	396.41	-4.63	2.01	398.95	-4.01	3.35	396.34	-4.64	2.05
75%	362.77	-12.72	2.31	377.04	-9.29	1.97	396.41	-4.63	1.98	398.99	-4.01	3.27	396.38	-4.64	1.98
50%	215.51	-7.89	0.45	225.33	-5.53	0.10	236.21	-2.91	0.42	234.88	-3.23	1.61	231.00	-4.17	0.22
25%	33.07	-1.20	0.68	35.29	-0.67	0.37	36.17	-0.46	0.56	35.73	-0.56	1.32	34.37	-0.89	0.22
100%	369.23	-11.17	3.21	365.81	-11.99	3.31	384.80	-7.42	2.94	386.47	-7.02	3.75	402.22	-3.23	2.02
75%	369.26	-11.17	3.21	365.81	-11.99	3.29	384.77	-7.43	2.89	386.47	-7.02	3.71	402.22	-3.23	1.98
50%	218.75	-7.11	2.12	216.10	-7.75	1.76	224.72	-5.68	1.89	222.38	-6.24	2.05	229.55	-4.52	0.14
25%	33.66	-1.06	1.67	33.57	-1.08	1.48	33.72	-1.04	1.47	32.81	-1.26	1.59	32.93	-1.23	0.31

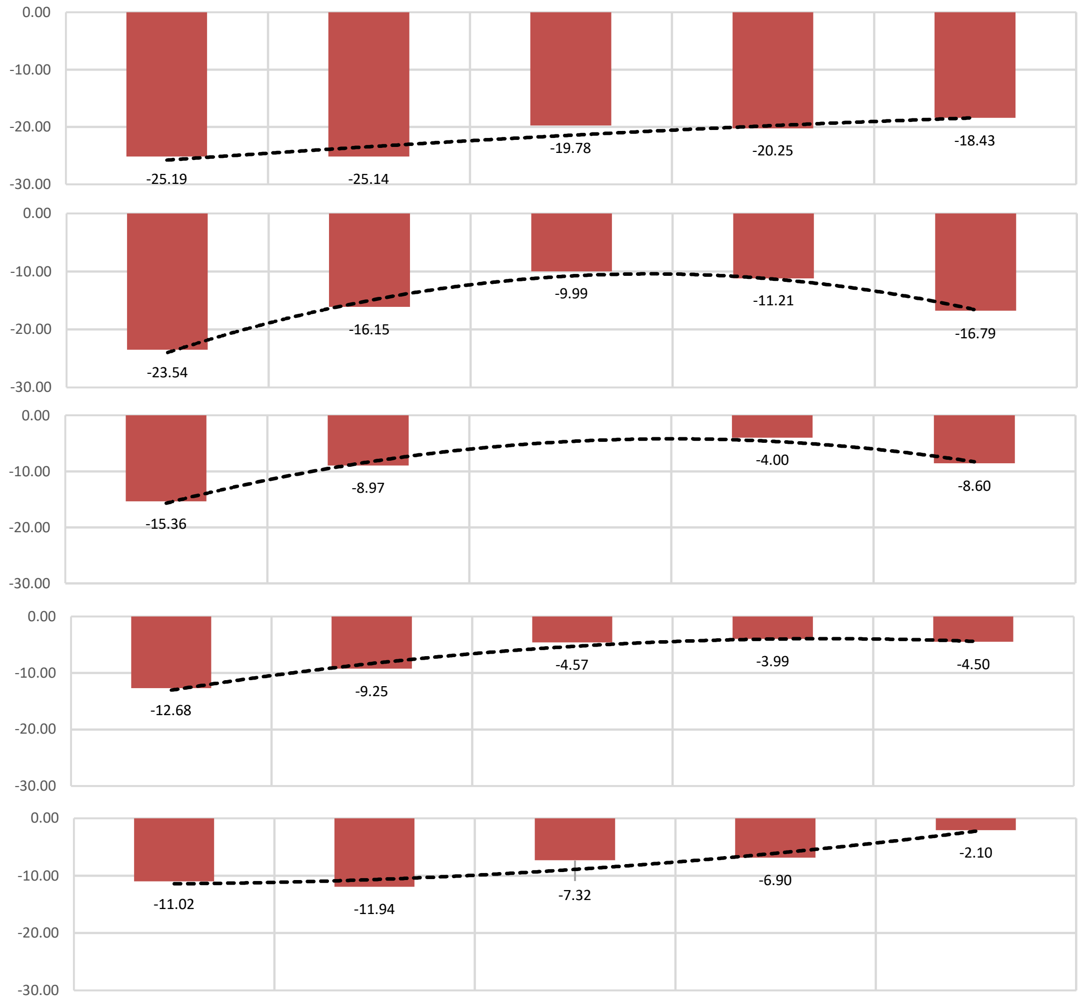
100%	311.20	-25.11	1.13	311.83	-24.96	0.67	333.76	-19.68	1.44	331.11	-20.32	0.48	337.78	-18.72	0.68
75%	311.20	-25.11	1.09	311.86	-24.95	0.55	333.81	-19.66	1.47	331.08	-20.32	0.40	337.74	-18.72	0.68
50%	184.39	-15.47	-0.68	187.20	-14.79	-1.52	200.05	-11.70	-2.05	197.70	-12.27	-0.45	198.65	-12.04	-1.02
25%	27.06	-2.71	-0.16	28.42	-2.38	-0.98	30.11	-1.97	-1.13	29.74	-2.06	-0.36	29.39	-2.15	-1.09
100%	317.36	-23.63	2.09	348.79	-16.07	0.33	374.30	-9.93	0.46	368.71	-11.27	0.39	345.72	-16.81	1.71
75%	317.32	-23.63	2.09	348.79	-16.06	0.29	374.30	-9.92	0.42	368.75	-11.26	0.30	345.69	-16.81	1.67
50%	188.02	-14.59	-0.26	208.81	-9.59	-0.78	223.80	-5.98	-0.74	219.14	-7.11	-0.15	202.58	-11.09	-1.27
25%	28.12	-2.45	-0.21	31.87	-1.55	-0.39	34.13	-1.01	-0.46	32.93	-1.30	0.00	30.02	-2.00	-1.05
100%	351.27	-15.47	1.70	378.20	-8.99	0.57	**415.56**			398.77	-4.04	1.48	379.20	-8.75	2.05
75%	351.27	-15.46	1.66	378.17	-8.99	0.52	**415.53**			398.76	-4.04	1.52	379.23	-8.73	2.02
50%	208.89	-9.57	-0.34	227.07	-5.20	-0.62	**248.67**			236.97	-2.82	0.37	222.56	-6.28	-0.96
25%	31.87	-1.55	0.09	35.32	-0.72	-0.01	**38.32**			36.18	-0.51	0.32	33.47	-1.17	-0.86
100%	362.26	-12.82	2.31	376.95	-9.29	1.88	396.06	-4.69	1.89	398.64	-4.07	3.38	396.32	-4.63	2.33
75%	362.34	-12.80	2.27	377.03	-9.26	1.84	396.06	-4.68	1.88	398.61	-4.07	3.30	396.29	-4.63	2.27
50%	215.72	-7.93	0.42	225.69	-5.53	0.06	236.54	-2.92	0.38	234.76	-3.35	1.51	230.95	-4.26	0.08
25%	33.19	-1.23	0.32	35.37	-0.71	0.29	36.40	-0.46	0.39	35.78	-0.61	0.93	34.40	-0.94	0.21
100%	370.00	-10.96	3.25	366.95	-11.70	3.31	384.89	-7.38	2.84	387.52	-6.75	3.86	402.96	-3.03	2.16
75%	370.04	-10.95	3.16	366.95	-11.69	3.28	384.86	-7.38	2.76	387.55	-6.73	3.86	402.96	-3.02	2.13
50%	219.53	-7.01	1.98	216.97	-7.63	1.72	225.34	-5.61	1.70	223.38	-6.09	2.07	229.98	-4.50	0.10
25%	33.81	-1.08	1.49	33.72	-1.11	1.27	33.77	-1.10	1.22	32.99	-1.28	1.60	33.01	-1.28	0.10

3| 1 Display performance data / Uncalibrated with maximum device settings

1.2.2 - Display uniformity - Mean measured values (5x5 matrix)

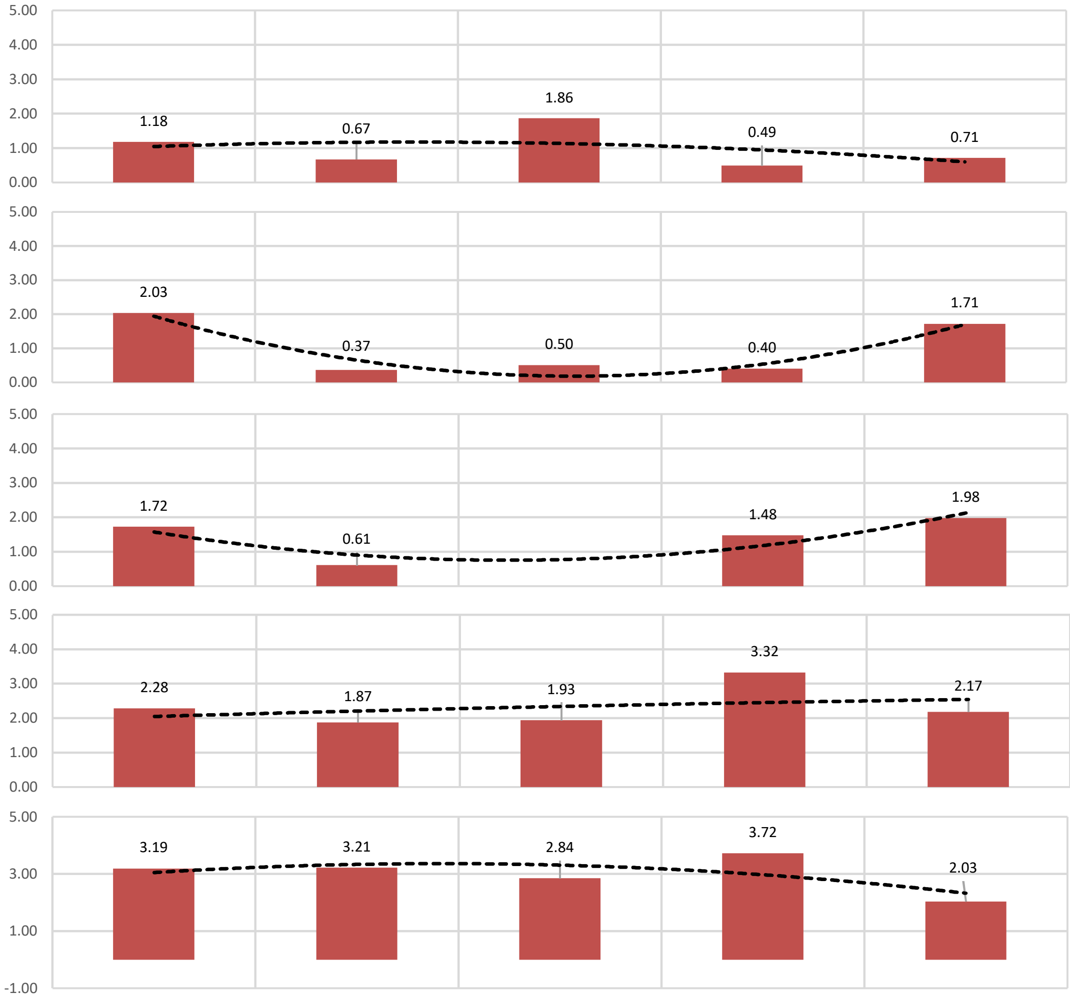
	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00
100%	310.73	-25.19	1.18	310.95	-25.14	0.67	333.22	-19.78	1.86	331.27	-20.25	0.49	338.85	-18.43	0.71
75%	310.74	-25.20	1.13	310.94	-25.15	0.59	333.21	-19.79	1.48	331.19	-20.27	0.42	338.75	-18.45	0.67
50%	183.59	-15.48	-0.67	186.17	-14.86	-1.46	199.29	-11.70	-1.96	197.28	-12.19	-0.25	198.73	-11.83	-0.98
25%	26.96	-2.66	-0.23	28.24	-2.35	-0.75	30.00	-1.93	-1.08	29.64	-2.01	-0.12	29.40	-2.07	-0.83
100%	317.59	-23.54	2.03	348.32	-16.15	0.37	373.88	-9.99	0.50	368.80	-11.21	0.40	345.63	-16.79	1.71
75%	317.60	-23.54	1.99	348.33	-16.15	0.33	373.87	-10.00	0.47	368.80	-11.22	0.36	345.64	-16.80	1.61
50%	187.76	-14.47	-0.22	208.12	-9.57	-0.71	222.98	-6.00	-0.73	218.72	-7.02	-0.07	202.12	-11.02	-1.22
25%	28.05	-2.40	0.02	31.75	-1.50	-0.36	33.94	-0.98	-0.40	32.87	-1.24	-0.04	29.93	-1.94	-0.98
100%	351.56	-15.36	1.72	378.10	-8.97	0.61	**415.38**			398.77	-4.00	1.48	379.65	-8.60	1.98
75%	351.54	-15.37	1.69	378.12	-8.98	0.56	**415.40**			398.78	-4.00	1.47	379.66	-8.60	1.94
50%	208.58	-9.46	-0.33	226.43	-5.16	-0.54	**247.88**			236.54	-2.73	0.38	222.28	-6.16	-0.87
25%	31.77	-1.50	0.04	35.15	-0.69	-0.05	**38.01**			36.07	-0.46	0.35	33.32	-1.13	-0.63
100%	362.69	-12.68	2.28	376.93	-9.25	1.87	396.38	-4.57	1.93	398.80	-3.99	3.32	396.70	-4.50	2.17
75%	362.71	-12.68	2.23	376.97	-9.25	1.84	396.37	-4.58	1.89	398.79	-4.00	3.27	396.71	-4.50	2.09
50%	215.43	-7.81	0.47	225.14	-5.48	0.11	236.11	-2.83	0.42	234.52	-3.22	1.58	230.82	-4.11	0.22
25%	33.06	-1.19	0.48	35.22	-0.67	0.29	36.20	-0.44	0.39	35.70	-0.56	1.05	34.31	-0.89	0.18
100%	369.62	-11.02	3.19	365.81	-11.94	3.21	384.96	-7.32	2.84	386.74	-6.90	3.72	403.01	-2.10	2.03
75%	369.66	-11.01	3.12	365.81	-11.94	3.17	384.92	-7.34	2.80	386.75	-6.90	3.69	403.01	-2.09	2.00
50%	218.94	-6.96	2.06	216.01	-7.67	1.74	224.74	-5.57	1.84	222.42	-6.13	2.08	229.69	-4.38	0.17
25%	33.69	-1.04	1.52	33.53	-1.08	1.30	33.66	-1.05	1.33	32.80	-1.25	1.54	32.94	-1.22	0.18

1.2.3 - Display uniformity - Visualization of the mean luminance differences (%)



3| 1 Display performance data / Uncalibrated with maximum device settings

1.2.4 - Display uniformity - Visualization of the mean chromaticity difference ΔC^*_{00}



3| 1 Display performance data / Calibrated and profiled (Display1_MD1_AdobeRGB_160_V1.icm)

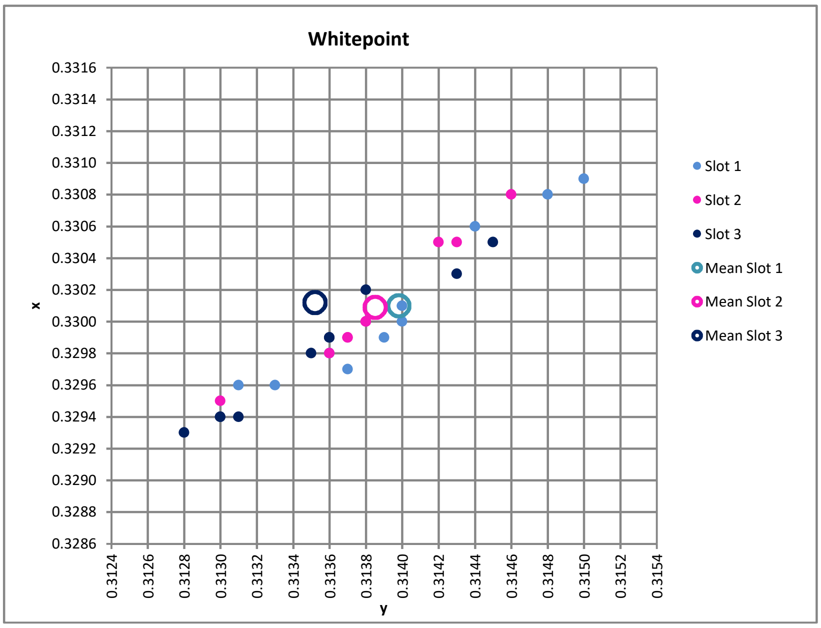
1.3 - Performance data (test period of 5 days)

Day	Slot	White Lum. (cd/m²)	Black Lum. (cd/m²)	CCT (K)	Whitepoint X	Whitepoint Y	Whitepoint Z	Whitepoint x	Whitepoint y
Day 1	Slot 1	159.50	0.2337	6452	95.16	100.00	107.91	0.3140	0.3300
		159.50	0.2339	6432	95.15	100.00	107.24	0.3139	0.3299
	Slot 2	159.60	0.2340	6436	95.10	100.00	107.95	0.3138	0.3300
		159.70	0.2341	6441	95.10	100.00	108.18	0.3137	0.3299
	Slot 3	159.60	0.2345	6441	95.07	100.00	107.60	0.3135	0.3298
		159.70	0.2343	6441	95.10	100.00	108.02	0.3136	0.3299
Day 2	Slot 1	159.60	0.2337	6452	95.07	100.00	108.04	0.3136	0.3298
		159.70	0.2342	6446	95.07	100.00	108.14	0.3137	0.3297
	Slot 2	159.60	0.2342	6451	95.09	100.00	108.13	0.3136	0.3298
		159.90	0.2337	6439	95.09	100.00	107.97	0.3138	0.3300
	Slot 3	160.20	0.2350	6480	95.03	100.00	108.51	0.3131	0.3294
		160.30	0.2356	6494	95.00	100.00	108.67	0.3128	0.3293
Day 3	Slot 1	160.00	0.2336	6379	95.19	100.00	108.13	0.3150	0.3309
		159.50	0.2342	6379	95.16	100.00	107.15	0.3148	0.3308
	Slot 2	159.60	0.2347	6388	95.11	100.00	107.19	0.3146	0.3308
		159.70	0.2350	6406	95.11	100.00	107.47	0.3143	0.3305
	Slot 3	159.40	0.2330	6399	95.15	100.00	107.43	0.3145	0.3305
		159.30	0.2334	6449	95.04	100.00	108.04	0.3136	0.3299
Day 4	Slot 1	159.30	0.2337	6400	95.11	100.00	107.38	0.3144	0.3306
		159.50	0.2341	6423	95.13	100.00	107.79	0.3140	0.3301
	Slot 2	159.70	0.2343	6441	95.10	100.00	108.02	0.3137	0.3299
		160.20	0.2349	6436	95.09	100.00	107.92	0.3138	0.3300
	Slot 3	160.50	0.2354	6483	95.04	100.00	108.58	0.3130	0.3294
		160.50	0.2355	6483	95.04	100.00	108.58	0.3130	0.3294
Day 5	Slot 1	159.90	0.2350	6468	95.05	100.00	108.35	0.3133	0.3296
		160.00	0.2351	6477	94.99	100.00	108.39	0.3131	0.3296
	Slot 2	160.10	0.2352	6481	94.99	100.00	108.46	0.3130	0.3295
		159.70	0.2349	6411	95.07	100.00	107.49	0.3142	0.3305
	Slot 3	159.90	0.2350	6419	95.08	100.00	107.64	0.3143	0.3303
		160.00	0.2353	6433	95.05	100.00	107.80	0.3138	0.3302

	White Lum.	Black Lum.	CCT	X	Y	Z	x	y
Mean	159.8	0.2344	6439	95.08	100.00	107.94	0.3138	0.3300
Min	159.3	0.2330	6379	94.99	100.00	107.15	0.3128	0.3293
Max	160.5	0.2356	6494	95.19	100.00	108.67	0.3150	0.3309
SD	0.3197	0.0007	31	0.0494	0.0000	0.4260	0.0006	0.0004

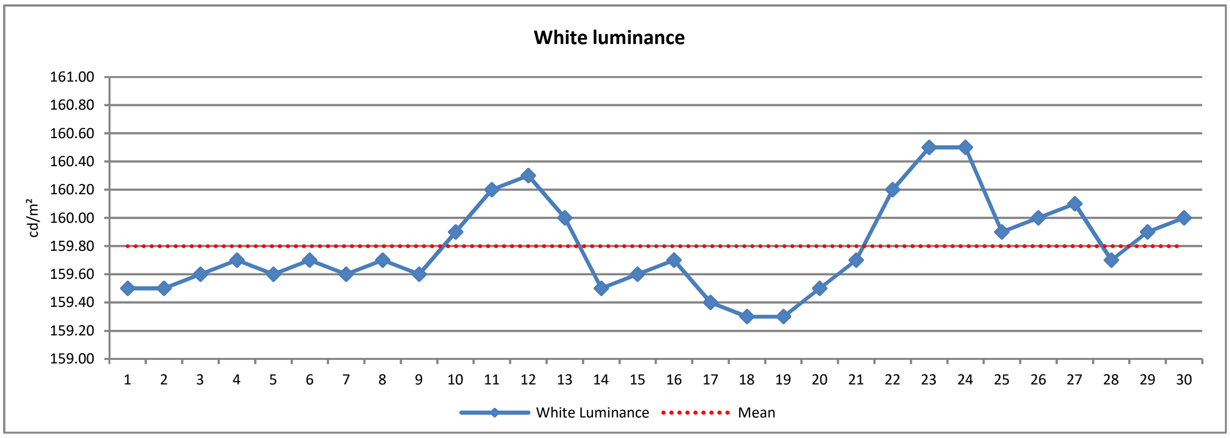
Group	Statistic	White Lum. (cd/m²)	Black Lum. (cd/m²)	CCT (K)	Whitepoint X	Whitepoint Y	Whitepoint Z	Whitepoint x	Whitepoint y
Slot 1	Mean	159.65	0.2341	6431	95.11	100.00	107.85	0.3140	0.3301
	Min	159.30	0.2336	6379	94.99	100.00	107.15	0.3131	0.3296
	Max	160.00	0.2351	6477	95.19	100.00	108.39	0.3150	0.3309
	SD	0.2291	0.0005	33	0.0588	0.0000	0.4278	0.0006	0.0005
Slot 2	Mean	159.78	0.2345	6433	95.09	100.00	107.88	0.3139	0.3301
	Min	159.60	0.2337	6388	94.99	100.00	107.19	0.3130	0.3295
	Max	160.20	0.2352	6481	95.11	100.00	108.46	0.3146	0.3308
	SD	0.2040	0.0005	25	0.0335	0.0000	0.3632	0.0004	0.0004
Slot 3	Mean	159.94	0.2347	6452	95.06	100.00	108.09	0.3135	0.3301
	Min	159.30	0.2330	6399	95.00	100.00	107.43	0.3128	0.3293
	Max	160.50	0.2356	6494	95.15	100.00	108.67	0.3145	0.3309
	SD	0.4128	0.0009	30	0.0400	0.0000	0.4430	0.0005	0.0005
Day 1	Mean	159.60	0.2341	6441	95.11	100.00	107.82	0.3138	0.3299
	Min	159.50	0.2337	6432	95.07	100.00	107.24	0.3135	0.3298
	Max	159.70	0.2345	6452	95.16	100.00	108.18	0.3140	0.3300
	SD	0.0816	0.0003	6	0.0314	0.0000	0.3107	0.0002	0.0001
Day 2	Mean	159.88	0.2344	6460	95.06	100.00	108.24	0.3134	0.3297
	Min	159.60	0.2337	6439	95.00	100.00	107.97	0.3128	0.3293
	Max	160.30	0.2356	6494	95.09	100.00	108.67	0.3138	0.3300
	SD	0.2794	0.0007	20	0.0329	0.0000	0.2558	0.0004	0.0002
Day 3	Mean	159.58	0.2340	6400	95.13	100.00	107.57	0.3145	0.3306
	Min	159.30	0.2330	6379	95.04	100.00	107.15	0.3136	0.3299
	Max	160.00	0.2350	6449	95.19	100.00	108.13	0.3150	0.3309
	SD	0.2267	0.0007	24	0.0478	0.0000	0.3840	0.0004	0.0003
Day 4	Mean	159.95	0.2347	6444	95.09	100.00	108.05	0.3137	0.3299
	Min	159.30	0.2337	6400	95.04	100.00	107.38	0.3130	0.3294
	Max	160.50	0.2355	6483	95.13	100.00	108.58	0.3144	0.3306
	SD	0.4752	0.0007	30	0.0340	0.0000	0.4274	0.0005	0.0004
Day 5	Mean	159.93	0.2351	6448	95.04	100.00	108.02	0.3136	0.3300
	Min	159.70	0.2349	6411	94.99	100.00	107.49	0.3130	0.3295
	Max	160.10	0.2353	6481	95.08	100.00	108.46	0.3143	0.3305
	SD	0.1247	0.0001	28	0.0358	0.0000	0.3901	0.0005	0.0004

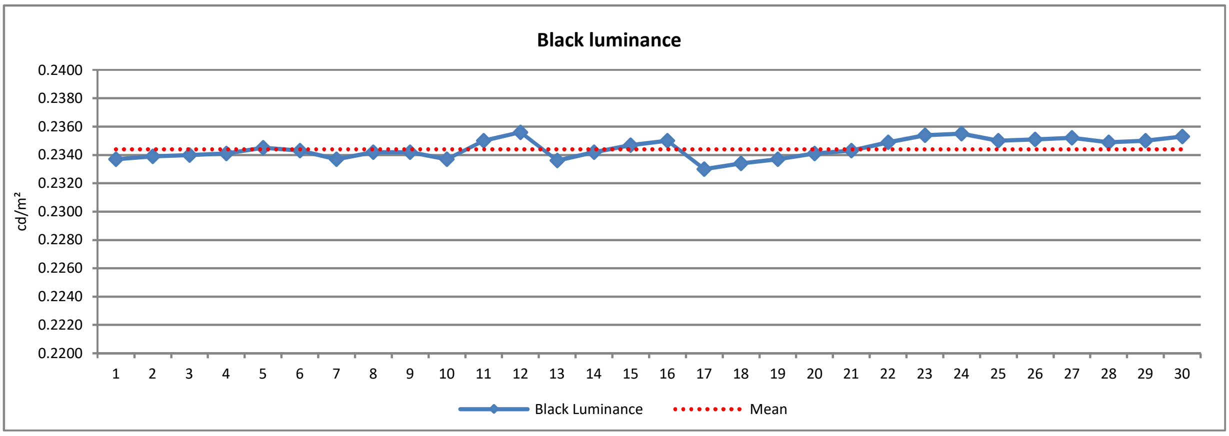
1.4 - Performance data - visualization of the measured whitepoints in the CIE xy chromaticity diagram

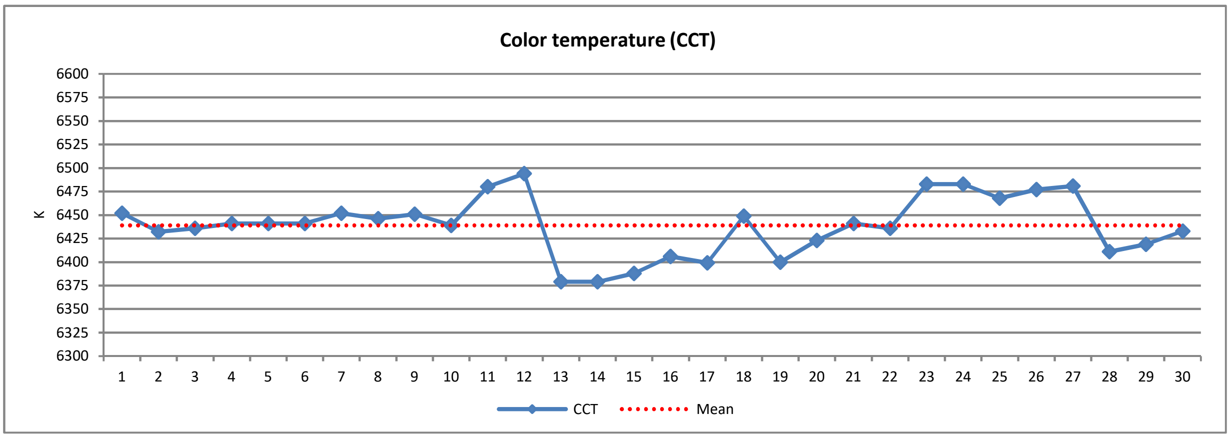


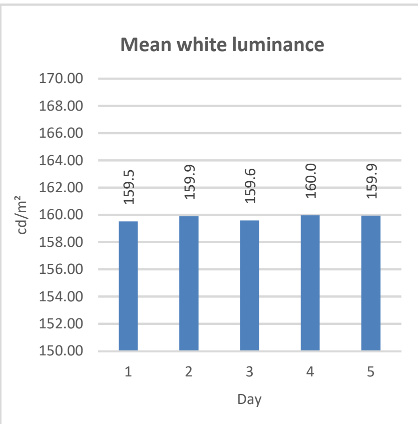
3| 1 Display performance data / Calibrated and profiled (Display1_MD1_AdobeRGB_160_V1.icm)

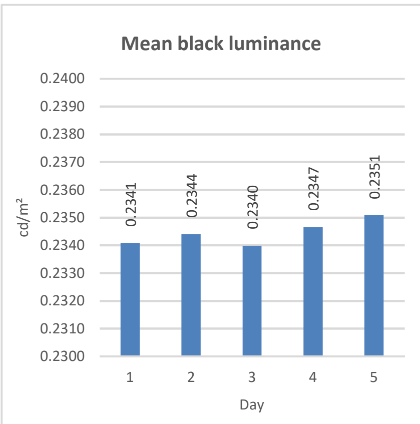
1.5 - Performance data - visualization of the measured values

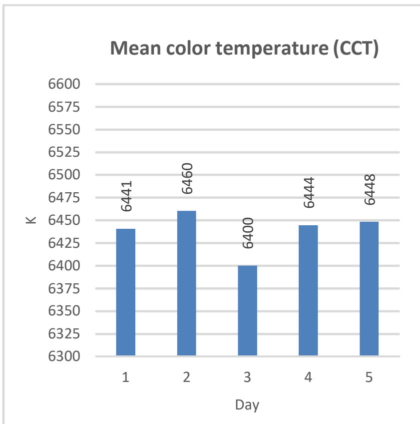






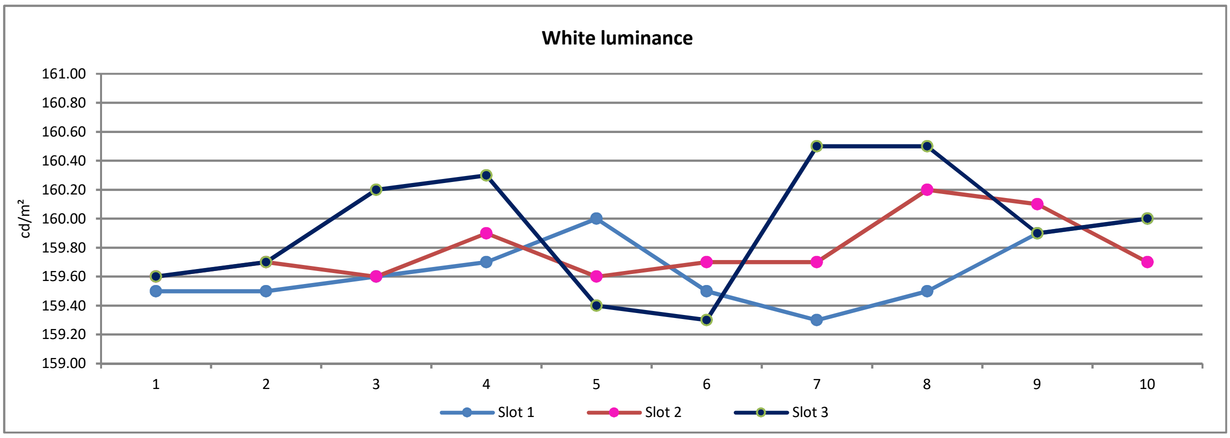


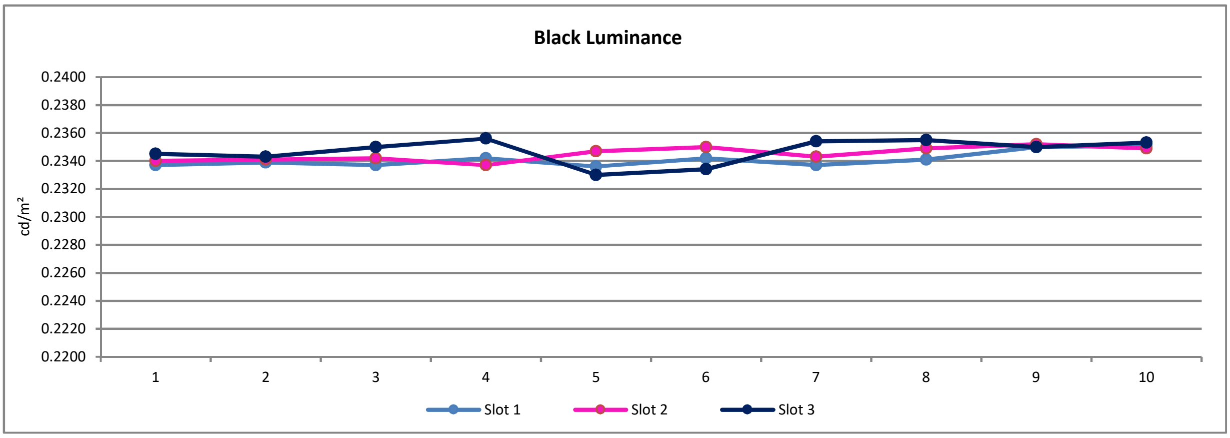


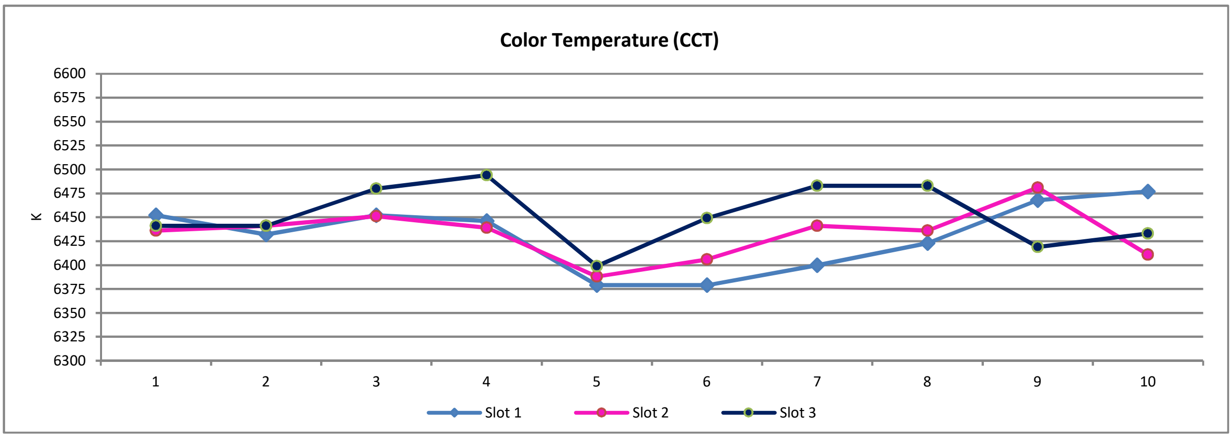


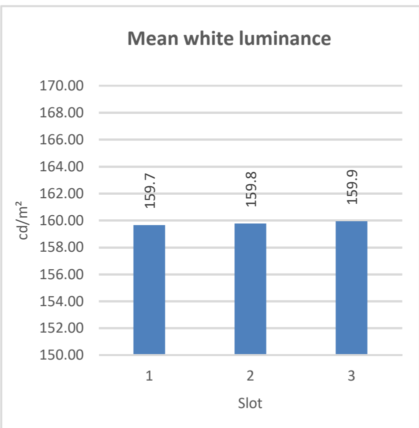
3| 1 Display performance data / Calibrated and profiled (Display1_MD1_AdobeRGB_160_V1.icm)

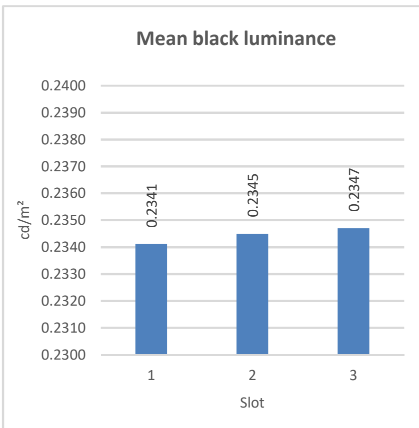
1.5 - Performance data - visualization of the measured values

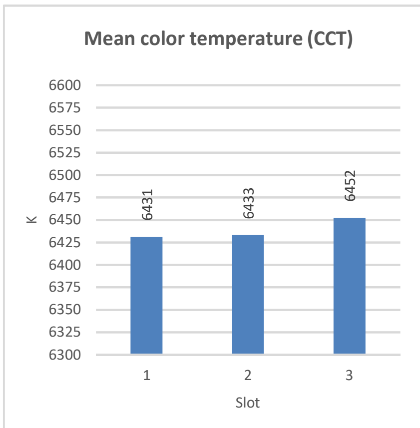












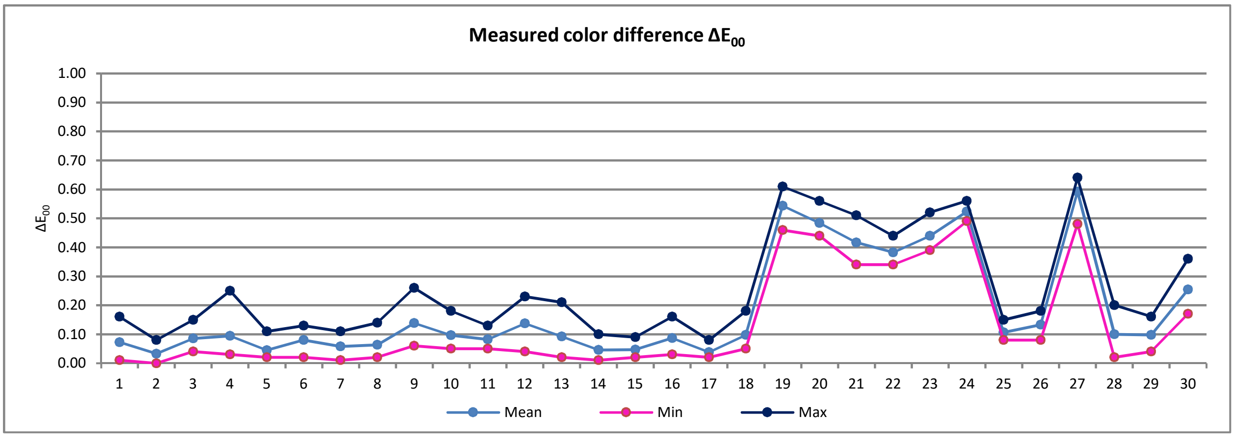
3| 1 Display performance data / Calibrated and profiled (Display1_MD1_AdobeRGB_160_V1.icm)

1.6 - Color accuracy - measured color difference ΔE_{00}

	Device Values			Nominal Values			Day 1		Day 2		Day 3		Day 4		Day 5		ΔE_{00}			
Color	R	G	B	L*	a*	b*	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	Mean	Min	Max	SD
1	128	0	0	30.73	64.64	48.49	0.02	0.03	0.03	0.05	0.01	0.01	0.13	0.13	0.16	0.15	0.07	0.01	0.16	0.0591
2	255	0	0	58.82	104.87	93.98	0.01	0.01	0.00	0.02	0.08	0.05	0.02	0.07	0.04	0.03	0.03	0.00	0.08	0.0253
3	255	128	128	68.38	77.12	37.49	0.06	0.05	0.06	0.04	0.09	0.06	0.10	0.12	0.15	0.12	0.09	0.04	0.15	0.0347
4	0	128	0	55.46	-97.26	64.06	0.05	0.04	0.05	0.08	0.07	0.03	0.17	0.25	0.09	0.11	0.09	0.03	0.25	0.0648
5	0	255	0	84.76	-137.79	91.88	0.03	0.02	0.02	0.05	0.11	0.04	0.05	0.08	0.03	0.02	0.05	0.02	0.11	0.0280
6	128	255	128	88.01	-95.27	64.37	0.03	0.02	0.05	0.08	0.09	0.04	0.13	0.13	0.12	0.11	0.08	0.02	0.13	0.0402
7	0	0	128	16.63	43.55	-74.76	0.01	0.09	0.07	0.02	0.11	0.05	0.05	0.10	0.06	0.02	0.06	0.01	0.11	0.0331
8	0	0	255	31.70	66.67	-112.36	0.04	0.08	0.08	0.05	0.14	0.08	0.05	0.05	0.05	0.02	0.06	0.02	0.14	0.0314
9	128	128	255	52.23	30.77	-78.08	0.06	0.06	0.06	0.08	0.24	0.08	0.26	0.19	0.17	0.19	0.14	0.06	0.26	0.0753
10	0	128	128	52.42	-63.49	-6.60	0.06	0.07	0.05	0.12	0.08	0.08	0.10	0.18	0.07	0.16	0.10	0.05	0.18	0.0412
11	0	255	255	88.57	-91.25	-18.75	0.09	0.05	0.11	0.08	0.13	0.11	0.07	0.06	0.07	0.05	0.08	0.05	0.13	0.0260
12	170	255	255	92.32	-53.30	-12.88	0.10	0.13	0.11	0.15	0.04	0.10	0.20	0.23	0.17	0.14	0.14	0.04	0.23	0.0518
13	128	0	128	29.70	63.13	-41.21	0.03	0.03	0.03	0.06	0.04	0.02	0.21	0.15	0.18	0.17	0.09	0.02	0.21	0.0718
14	255	0	255	64.65	113.43	-56.57	0.03	0.02	0.01	0.05	0.10	0.05	0.04	0.05	0.06	0.05	0.05	0.01	0.10	0.0233
15	255	170	255	78.06	68.31	-34.66	0.02	0.05	0.04	0.09	0.03	0.04	0.08	0.05	0.04	0.03	0.05	0.02	0.09	0.0210
16	128	128	0	59.79	-11.50	73.79	0.03	0.05	0.10	0.04	0.09	0.06	0.13	0.16	0.09	0.12	0.09	0.03	0.16	0.0400
17	255	255	0	96.92	-15.49	111.96	0.06	0.02	0.02	0.08	0.02	0.02	0.05	0.04	0.03	0.04	0.04	0.02	0.08	0.0194
18	255	255	170	98.03	-10.96	54.52	0.08	0.08	0.11	0.18	0.08	0.07	0.13	0.11	0.05	0.09	0.10	0.05	0.18	0.0349
19	170	85	85	50.38	59.69	28.73	0.51	0.49	0.52	0.46	0.52	0.51	0.60	0.61	0.61	0.60	0.54	0.46	0.61	0.0533
20	85	170	85	69.25	-83.59	54.31	0.47	0.46	0.46	0.48	0.45	0.44	0.53	0.56	0.51	0.48	0.48	0.44	0.56	0.0361
21	85	85	170	37.77	25.27	-63.60	0.34	0.36	0.34	0.41	0.34	0.36	0.51	0.49	0.50	0.51	0.42	0.34	0.51	0.0734
22	85	170	170	66.79	-60.36	-9.17	0.38	0.36	0.42	0.41	0.44	0.37	0.36	0.38	0.36	0.34	0.38	0.34	0.44	0.0299
23	170	85	170	49.37	68.10	-40.04	0.42	0.43	0.42	0.42	0.39	0.39	0.47	0.52	0.46	0.48	0.44	0.39	0.52	0.0395
24	170	170	85	72.91	-14.02	66.66	0.53	0.51	0.52	0.53	0.49	0.51	0.52	0.56	0.53	0.53	0.52	0.49	0.56	0.0173
25	255	0	170	61.82	109.31	-21.62	0.09	0.09	0.08	0.14	0.12	0.08	0.15	0.12	0.10	0.09	0.11	0.08	0.15	0.0237
26	170	255	0	91.74	-54.11	103.44	0.14	0.11	0.10	0.10	0.08	0.12	0.18	0.18	0.14	0.18	0.13	0.08	0.18	0.0352
27	0	170	255	67.78	-42.55	-52.16	0.60	0.55	0.61	0.48	0.60	0.64	0.59	0.62	0.63	0.60	0.59	0.48	0.64	0.0440
28	0	255	170	86.51	-116.69	25.04	0.06	0.03	0.02	0.09	0.11	0.04	0.20	0.16	0.16	0.13	0.10	0.02	0.20	0.0590
29	170	0	255	45.97	87.19	-88.38	0.06	0.06	0.05	0.12	0.13	0.04	0.12	0.10	0.16	0.14	0.10	0.04	0.16	0.0402
30	255	170	0	81.67	29.87	101.25	0.24	0.20	0.29	0.28	0.17	0.21	0.34	0.36	0.21	0.24	0.25	0.17	0.36	0.0590

	Mean	Min	Max	SD
Mean	0.18	0.13	0.25	0.0411

1.6.1 - Color accuracy - visualization of the measured color difference ΔE_{00}

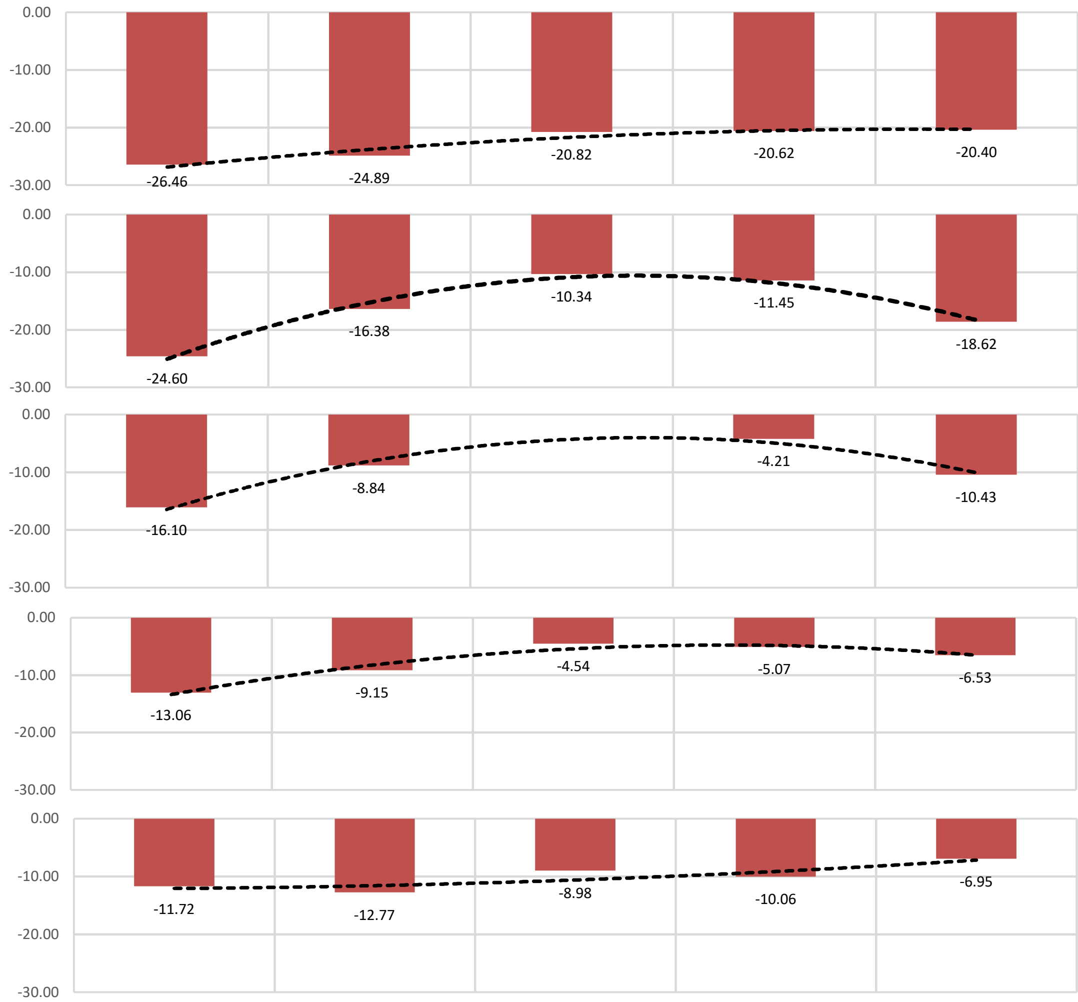


3| 1 Display performance data / Calibrated and profiled (Display1_MD1_AdobeRGB_160_V1.icm)

1.7 - Display uniformity - measured values (5x5 matrix)

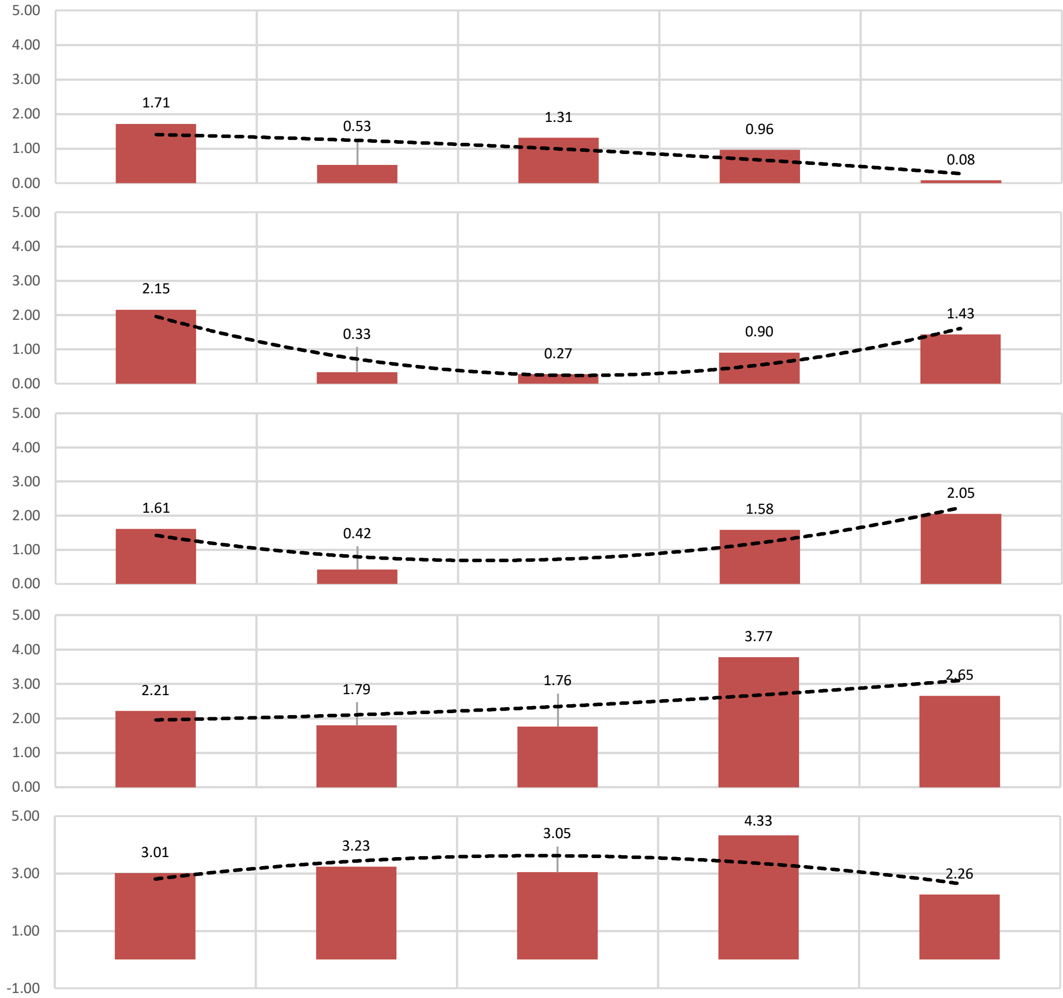
	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00
100%	117.87	-26.46	1.71	120.39	-24.89	0.53	126.92	-20.82	1.31	127.24	-20.62	0.96	127.58	-20.40	0.08
75%	61.42	-14.69	0.92	63.46	-13.42	0.24	66.66	-11.42	0.85	66.72	-11.39	0.20	66.15	-11.74	-0.03
50%	24.74	-6.37	0.78	25.93	-5.62	0.19	27.08	-4.91	0.75	27.17	-4.85	0.33	26.75	-5.11	-0.12
25%	3.69	-1.55	-0.04	5.94	-1.31	-0.09	6.19	-1.15	0.31	6.30	-1.09	-0.26	6.25	-1.11	0.39
100%	120.85	-24.60	2.15	134.02	-16.38	0.33	143.70	-10.34	0.27	141.92	-11.45	0.90	130.43	-18.62	1.43
75%	63.39	-13.47	1.28	70.84	-8.81	-0.20	75.89	-5.66	0.24	74.50	-6.53	0.04	67.87	-10.67	0.75
50%	25.75	-5.74	1.30	29.09	-3.65	0.03	32.12	-2.39	0.19	30.41	-2.83	0.11	27.50	-4.64	0.56
25%	3.25	-1.36	0.00	6.69	-0.84	-0.18	7.13	-0.56	0.04	7.04	-0.62	-0.26	6.38	-1.04	0.06
100%	134.48	-16.10	1.61	146.11	-8.84	0.42	**160.28**			153.54	-4.21	1.58	143.57	-10.43	2.05
75%	71.08	-8.66	0.82	77.75	-4.50	0.10	**84.97**			81.11	-2.41	0.74	75.13	-6.14	1.25
50%	29.18	-3.60	0.64	32.18	-1.73	0.04	**34.95**			33.33	-1.01	0.75	30.69	-2.65	0.98
25%	1.97	-0.84	-0.21	7.45	-0.37	-0.09	**8.04**			7.75	-0.18	-0.27	7.11	-0.58	0.23
100%	139.35	-13.06	2.21	145.62	-9.15	1.79	153.01	-4.54	1.76	152.15	-5.07	3.77	149.81	-6.53	2.65
75%	73.96	-6.87	1.32	77.72	-4.52	0.94	81.10	-2.42	1.01	80.13	-3.02	2.65	78.10	-4.29	1.48
50%	30.49	-2.78	1.33	32.33	-1.63	0.98	33.33	-1.01	0.77	32.92	-1.26	2.15	31.77	-1.98	1.32
25%	6.95	-0.68	-0.02	7.54	-0.31	-0.20	7.64	-0.25	-0.15	7.67	-0.23	0.57	7.38	-0.41	0.04
100%	141.50	-11.72	3.01	139.81	-12.77	3.23	145.90	-8.98	3.05	144.15	-10.06	4.33	149.15	-6.95	2.26
75%	75.12	-6.14	2.25	74.25	-6.69	2.47	76.43	-5.33	2.35	74.72	-6.39	3.14	76.45	-5.31	1.33
50%	30.98	-2.48	1.84	30.84	-2.56	2.25	31.19	-2.35	1.57	30.31	-2.89	2.64	30.64	-2.69	1.16
25%	0.57	-0.55	0.57	7.25	-0.49	0.48	7.22	-0.51	0.46	7.11	-0.58	0.86	7.12	-0.57	-0.04

1.7.1 - Display uniformity - Visualization of the luminance difference (%)



3| 1 Display performance data / Calibrated and profiled (Display1_MD1_AdobeRGB_160_V1.icm)

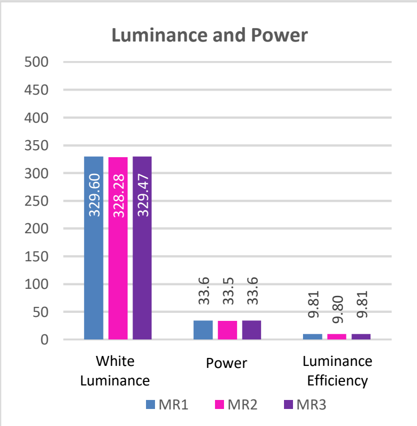
1.7.2 - Display uniformity - Visualization of the chromaticity difference ΔC^*_{00}

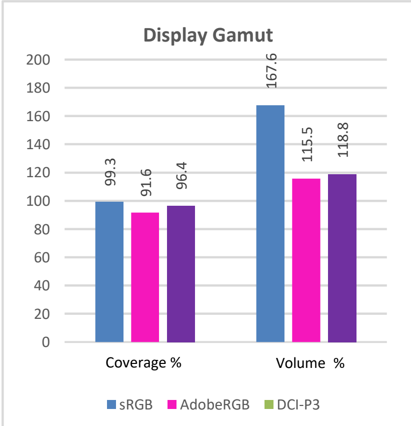


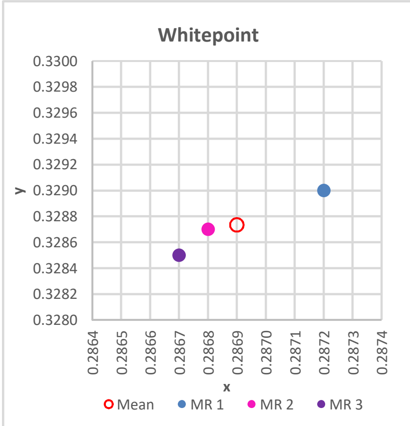
3| 2 Display performance data / Uncalibrated with maximum device settings

1.1 - Display performance data

	White Lum. (cd/m²)	Power (W)	Lum. Eff. (cd/W)	Black Lum. (cd/m²)	Whitepoint (CIE_xy) x	Whitepoint (CIE_xy) y	Display Gamut sRGB Cov. (%)	sRGB Vol. (%)	AdobeRGB Cov. (%)	AdobeRGB Vol. (%)	DCI-P3 Cov. (%)	DCI-P3 Vol. (%)
MR 1	329.60	33.6	9.81	0.2381	0.2872	0.3290	99.4	168.5	92.2	116.1	96.5	119.4
MR 2	328.28	33.5	9.80	0.2312	0.2868	0.3287	99.2	166.3	90.7	114.6	96.3	117.8
MR 3	329.47	33.6	9.81	0.2330	0.2867	0.3285	99.3	168.1	91.9	115.8	96.5	119.1
Mean	329.12	33.6	9.80	0.2341	0.2869	0.3287	99.3	167.6	91.6	115.5	96.4	118.8
Min	329.6	33.6	9.81	0.2381	0.2872	0.329	99.4	168.5	92.2	116.1	96.5	119.4
Max	328.28	33.5	9.80	0.2312	0.2867	0.3285	99.2	166.3	90.7	114.6	96.3	117.8
SD	0.5940	0.0471	0.0042	0.3296	94.9300	0.0002	0.0816	0.9568	0.6481	0.6481	0.0943	0.6944

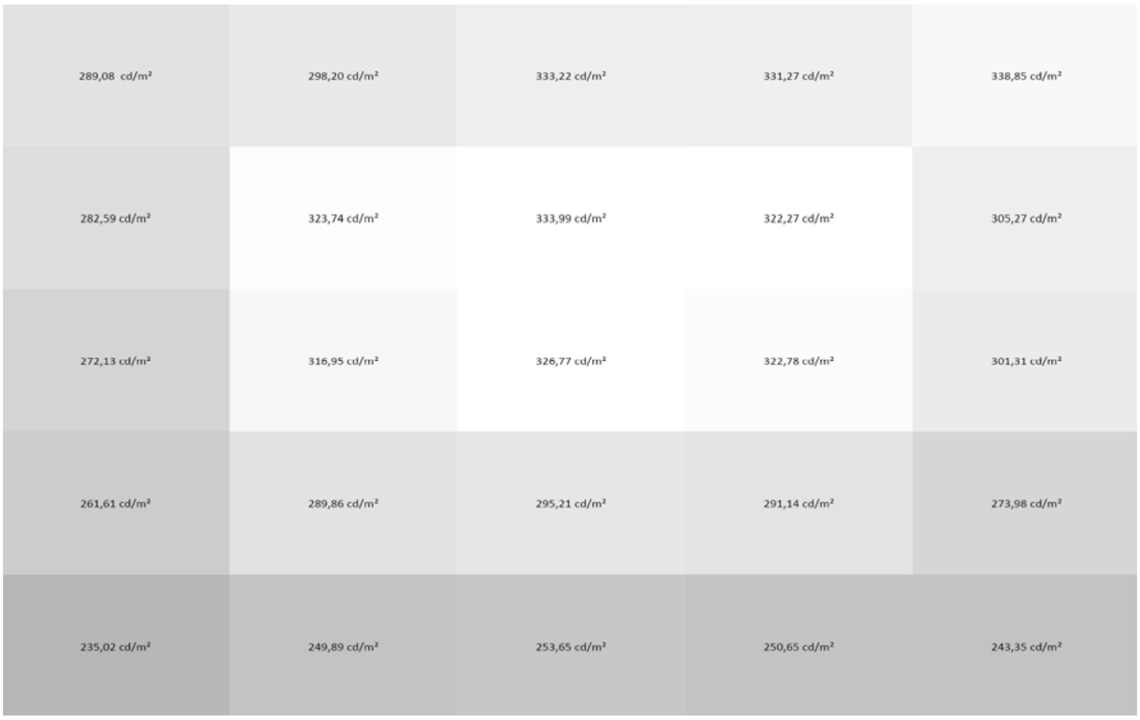






1.2 - Display uniformity - Visualization of the mean values in the 5x5 matrix

	Lum. cd/m²	Delta %	Lum. cd/m²	Delta %	Lum. cd/m²	Delta %	Lum. cd/m²	Delta %	Lum. cd/m²	Delta %
100%	289.08	-11.53	298.20	-8.74	304.46	-6.83	305.90	-6.39	313.45	-4.07
100%	282.59	-13.52	323.74	-0.93	333.39	2.03	332.27	1.68	305.27	-6.58
100%	272.13	-16.72	316.95	-3.00	326.77	0.00	322.78	-1.22	301.31	-7.79
100%	261.61	-19.94	289.86	-11.30	295.21	-9.66	291.14	-10.90	273.98	-16.16
100%	235.02	-28.08	249.89	-23.53	253.65	-22.38	250.65	-23.30	243.35	-25.53



3| 2 Display performance data / Uncalibrated with maximum device settings

1.2.1 - Display uniformity - Measured values from three control measurements (5x5 matrix)

	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00
100%	288.90	-11.78	3.48	296.97	-9.32	0.98	302.98	-7.48	1.07	305.40	-6.74	2.10	313.16	-4.37	2.45
75%	221.21	-9.77	1.69	232.08	-6.45	0.76	237.41	-4.83	0.14	239.38	-4.22	1.54	244.39	-2.69	0.96
50%	88.35	-4.95	1.08	97.01	-2.31	0.64	99.36	-1.59	0.30	100.27	-1.31	1.33	101.52	-0.93	0.59
25%	18.67	-1.21	1.17	20.93	-0.52	0.48	21.35	-0.39	0.10	21.62	-0.31	0.90	21.93	-0.22	0.48
100%	283.08	-13.56	2.29	322.83	-1.42	0.88	332.47	1.52	0.73	331.37	1.19	1.60	303.46	-7.33	1.74
75%	215.09	-11.64	0.60	250.53	-0.82	0.69	258.52	1.62	0.19	257.85	1.41	1.09	235.38	-5.45	0.73
50%	85.12	-5.94	0.13	104.04	-0.16	0.54	107.46	0.89	0.18	107.61	0.93	0.89	97.10	-2.28	0.45
25%	17.77	-1.49	0.25	22.49	-0.05	0.55	23.21	0.18	0.51	23.33	0.21	1.07	20.96	-0.51	0.55
100%	272.86	-16.68	2.98	317.82	-2.95	1.10	**327.48**			322.82	-1.42	1.12	301.21	-8.02	1.18
75%	207.00	-14.11	1.08	244.17	-2.76	0.77	**253.22**			250.93	-0.70	0.05	232.92	-6.20	0.10
50%	81.64	-7.00	0.50	99.94	-1.41	0.66	**104.56**			104.23	-0.10	0.17	96.05	-2.60	-0.09
25%	16.99	-1.73	0.99	21.47	-0.36	0.50	**22.64**			22.55	-0.03	0.24	20.77	-0.57	0.10
100%	262.53	-19.83	1.98	290.08	-11.42	2.82	295.03	-9.91	2.64	291.61	-10.95	0.59	273.95	-16.35	1.34
75%	199.28	-16.47	0.21	223.44	-9.09	2.69	227.91	-7.73	2.52	227.02	-8.00	0.19	212.99	-12.28	0.95
50%	79.03	-7.79	-0.31	93.01	-3.53	2.35	94.80	-2.98	2.25	95.11	-2.89	0.63	88.67	-4.85	0.92
25%	16.62	-1.84	-0.04	20.28	-0.72	1.66	20.62	-0.62	1.58	20.72	-0.59	0.38	19.28	-1.03	0.79
100%	236.51	-27.78	2.88	250.83	-23.41	2.77	254.56	-22.27	1.64	251.01	-23.35	0.20	244.36	-25.38	1.83
75%	179.93	-22.38	1.07	193.31	-18.29	2.39	196.81	-17.23	1.45	195.78	-17.54	0.13	190.60	-19.12	-0.25
50%	71.61	-10.06	0.41	80.09	-7.47	1.95	81.42	-7.07	1.18	81.85	-6.93	0.37	79.13	-7.77	-0.28
25%	15.01	-2.33	0.42	17.34	-1.62	1.45	17.47	-1.58	0.74	17.71	-1.51	0.51	17.02	-1.72	0.11

100%	289.47	-11.36	3.98	299.53	-8.28	0.61	305.44	-6.47	1.13	305.87	-6.34	1.99	313.32	-4.05	2.73
75%	221.97	-9.33	2.09	234.75	-5.42	0.37	240.05	-3.79	0.18	240.57	-3.64	1.23	245.46	-2.14	1.05
50%	88.64	-4.85	1.02	98.45	-1.84	0.37	100.93	-1.08	0.10	101.08	-1.04	0.78	102.36	-0.64	0.60
25%	18.49	-1.26	0.91	21.23	-0.42	0.37	21.73	-0.27	0.29	21.78	-0.25	0.54	22.05	-0.17	0.56
100%	281.77	-13.71	2.65	324.34	-0.68	0.65	333.68	2.18	0.78	332.43	1.80	1.56	305.62	-6.41	1.94
75%	214.70	-11.56	0.73	252.44	0.00	0.44	260.20	2.38	0.04	259.12	2.04	0.93	237.64	-4.53	0.64
50%	85.03	-5.95	0.11	105.25	0.24	0.38	108.64	1.28	0.17	108.30	1.17	0.89	98.28	-1.90	0.34
25%	17.70	-1.50	0.52	22.79	0.06	0.43	23.47	0.26	0.04	23.48	0.27	0.79	21.19	-0.43	0.38
100%	272.25	-16.63	3.25	316.62	-3.04	0.99	**326.56**			322.58	-1.22	1.27	301.31	-7.73	1.39
75%	207.01	-13.91	1.08	243.80	-2.65	0.59	**252.44**			251.09	-0.41	0.03	233.50	-5.80	0.05
50%	81.81	-6.94	0.30	100.14	-1.32	0.34	**104.47**			104.40	-0.02	-0.04	96.49	-2.44	-0.02
25%	17.03	-1.71	0.58	21.59	-0.31	0.37	**22.61**			22.59	0.00	0.37	20.84	-0.54	-0.14
100%	260.49	-20.23	2.03	289.90	-11.23	2.74	295.17	-9.61	2.68	290.76	-10.96	0.63	273.90	-16.13	1.25
75%	197.79	-16.74	0.22	223.52	-8.86	2.61	227.93	-7.51	2.56	226.35	-7.99	0.17	212.96	-12.09	0.80
50%	78.49	-7.96	-0.51	93.10	-3.48	2.18	95.00	-2.90	2.23	94.82	-2.95	0.38	88.61	-4.86	0.78
25%	16.47	-1.88	0.10	20.35	-0.69	1.57	20.70	-0.58	1.56	20.69	-0.59	0.52	19.28	-1.02	0.62
100%	234.53	-28.18	2.91	249.23	-23.68	2.76	253.33	-22.42	1.70	250.42	-23.32	0.15	242.54	-25.73	1.69
75%	178.46	-22.65	1.01	192.25	-18.43	2.30	196.08	-17.26	1.50	195.25	-17.51	0.05	189.21	-19.36	-0.50
50%	71.14	-10.20	0.09	79.69	-7.59	1.76	81.13	-7.15	1.29	81.71	-6.97	0.27	78.61	-7.92	-0.50
25%	14.91	-2.36	0.00	17.27	-1.64	1.31	17.44	-1.58	0.93	17.71	-1.50	0.37	17.02	-1.71	-0.03

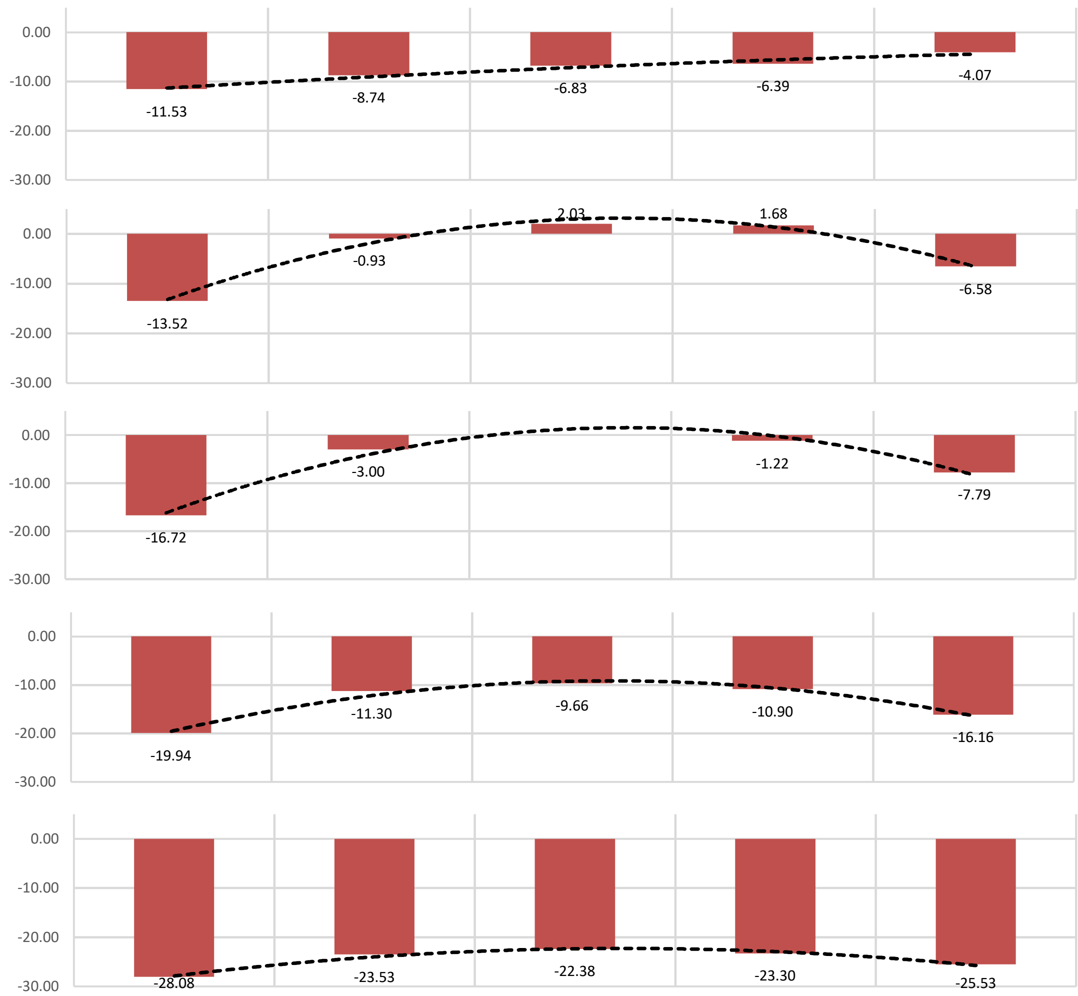
100%	288.88	-11.46	3.91	298.11	-8.63	0.50	304.97	-6.53	1.12	306.42	-6.08	2.04	313.87	-3.80	2.85
75%	221.83	-9.34	1.90	233.95	-5.63	0.22	239.80	-3.83	0.15	240.98	-3.47	1.27	246.03	-1.92	1.06
50%	88.71	-4.80	0.91	98.12	-1.91	0.18	100.90	-1.06	0.17	101.31	-0.94	0.94	102.41	-0.60	0.64
25%	18.53	-1.25	0.51	21.16	-0.45	0.22	21.73	-0.27	0.20	21.85	-0.23	0.63	21.98	-0.19	0.48
100%	282.92	-13.29	2.67	324.06	-0.68	0.55	334.03	2.38	0.80	333.01	2.06	1.57	306.74	-5.99	1.92
75%	215.64	-11.24	0.55	252.23	-0.02	0.19	260.48	2.50	-0.07	259.92	2.33	0.95	238.64	-4.19	0.50
50%	85.51	-5.78	0.08	105.07	0.22	0.21	108.69	1.33	0.12	108.76	1.35	0.87	98.84	-1.69	0.35
25%	17.85	-1.46	0.28	22.71	0.03	0.27	23.47	0.26	-0.03	23.56	0.29	0.78	21.34	-0.39	0.46
100%	271.28	-16.86	3.25	316.41	-3.02	0.98	**326.27**			322.93	-1.02	1.30	301.40	-7.62	1.40
75%	206.23	-14.12	1.06	243.78	-2.61	0.49	**252.31**			251.55	-0.23	-0.05	233.69	-5.70	0.04
50%	81.48	-7.01	0.36	100.11	-1.30	0.27	**104.36**			104.63	0.08	-0.05	96.64	-2.37	-0.09
25%	16.96	-1.73	0.65	21.56	-0.32	0.43	**22.61**			22.62	0.00	-0.01	20.84	-0.54	-0.19
100%	261.81	-19.76	1.91	289.59	-11.24	2.69	295.44	-9.45	2.69	291.05	-10.80	0.52	274.08	-16.00	1.20
75%	198.93	-16.36	0.09	223.34	-8.88	2.50	228.12	-7.41	2.54	226.61	-7.88	0.13	213.07	-12.03	0.72
50%	79.08	-7.75	-0.45	93.02	-3.48	2.04	95.08	-2.85	2.18	94.97	-2.88	0.50	88.76	-4.78	0.80
25%	16.62	-1.83	-0.08	20.28	-0.71	1.41	20.70	-0.59	1.52	20.69	-0.59	0.46	19.28	-1.02	0.55
100%	234.01	-28.28	2.83	249.61	-23.50	2.85	253.06	-22.44	1.77	250.53	-23.22	0.24	243.16	-25.47	1.62
75%	177.99	-22.78	0.82	192.40	-18.36	2.39	195.75	-17.34	1.44	195.33	-17.46	0.12	189.66	-19.20	-0.54
50%	70.96	-10.24	0.01	79.77	-7.54	1.95	80.98	-7.17	1.18	81.79	-6.92	0.34	78.84	-7.82	-0.50
25%	14.89	-2.37	0.18	17.27	-1.64	1.34	17.44	-1.59	0.97	17.71	-1.50	0.37	17.02	-1.71	-0.13

3| 2 Display performance data / Uncalibrated with maximum device settings

1.2.2 - Display uniformity - Mean measured values (5x5 matrix)

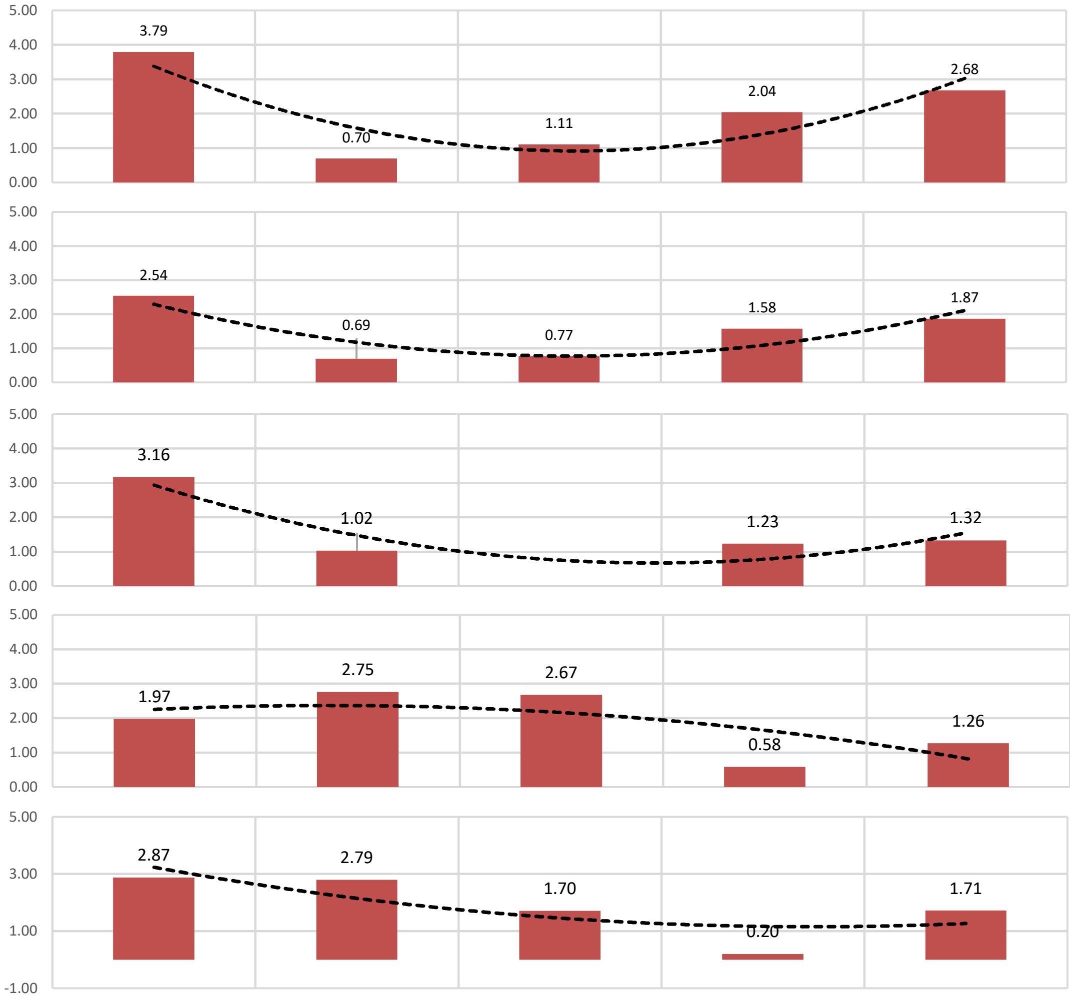
Mean	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00
100%	289.08	-11.53	3.79	298.20	-8.74	0.70	304.46	-6.83	1.11	305.90	-6.39	2.04	313.45	-4.07	2.68
75%	221.67	-9.48	1.89	233.59	-5.83	0.45	239.09	-4.15	0.16	240.31	-3.78	1.35	245.29	-2.25	1.02
50%	88.57	-4.87	1.00	97.86	-2.02	0.40	100.40	-1.24	0.19	100.89	-1.10	1.02	102.10	-0.72	0.61
25%	18.56	-1.24	0.86	21.11	-0.46	0.36	21.60	-0.31	0.20	21.75	-0.26	0.69	21.99	-0.19	0.51
100%	282.59	-13.52	2.54	323.74	-0.93	0.69	333.39	2.03	0.77	332.27	1.68	1.58	305.27	-6.58	1.87
75%	215.14	-11.48	0.63	251.73	-0.28	0.44	259.73	2.17	0.05	258.96	1.93	0.99	237.22	-4.72	0.62
50%	85.22	-5.89	0.11	104.79	0.10	0.38	108.26	1.17	0.16	108.22	1.15	0.88	98.07	-1.96	0.38
25%	17.77	-1.48	0.35	22.66	0.01	0.42	23.38	0.23	0.17	23.46	0.26	0.88	21.16	-0.44	0.46
100%	272.13	-16.72	3.16	316.95	-3.00	1.02	**326.77**			322.78	-1.22	1.23	301.31	-7.79	1.32
75%	206.75	-14.05	1.07	243.92	-2.67	0.62	**252.66**			251.19	-0.45	0.01	233.37	-5.90	0.06
50%	81.64	-6.98	0.39	100.06	-1.34	0.42	**104.46**			104.42	-0.01	0.03	96.39	-2.47	-0.07
25%	16.99	-1.72	0.74	21.54	-0.33	0.43	**22.62**			22.59	-0.01	0.20	20.82	-0.55	-0.08
100%	261.61	-19.94	1.97	289.86	-11.30	2.75	295.21	-9.66	2.67	291.14	-10.90	0.58	273.98	-16.16	1.26
75%	198.67	-16.52	0.17	223.43	-8.94	2.60	227.99	-7.55	2.54	226.66	-7.96	0.16	213.01	-12.13	0.82
50%	78.87	-7.83	-0.42	93.04	-3.50	2.19	94.96	-2.91	2.22	94.97	-2.91	0.50	88.68	-4.83	0.83
25%	16.57	-1.85	-0.01	20.30	-0.71	1.55	20.67	-0.60	1.55	20.70	-0.59	0.45	19.28	-1.02	0.65
100%	235.02	-28.08	2.87	249.89	-23.53	2.79	253.65	-22.38	1.70	250.65	-23.30	0.20	243.35	-25.53	1.71
75%	178.79	-22.60	0.97	192.65	-18.36	2.36	196.21	-17.28	1.46	195.45	-17.50	0.10	189.82	-19.23	-0.43
50%	71.24	-10.17	0.17	79.85	-7.53	1.89	81.18	-7.13	1.22	81.78	-6.94	0.33	78.86	-7.84	-0.43
25%	14.94	-2.35	0.20	17.29	-1.63	1.37	17.45	-1.58	0.88	17.71	-1.50	0.42	17.02	-1.71	-0.02

1.2.3 - Display uniformity - Visualization of the mean luminance differences (%) in the 5 x 5 matrix



3| 2 Display performance data / Uncalibrated with maximum device settings

1.2.4 - Display uniformity - Visualization of the mean chromaticity difference ΔC^*_{00}



3| 2 Display performance data / Calibrated and profiled (Display2_MD1_AdobeRGB_160_V1.icm)

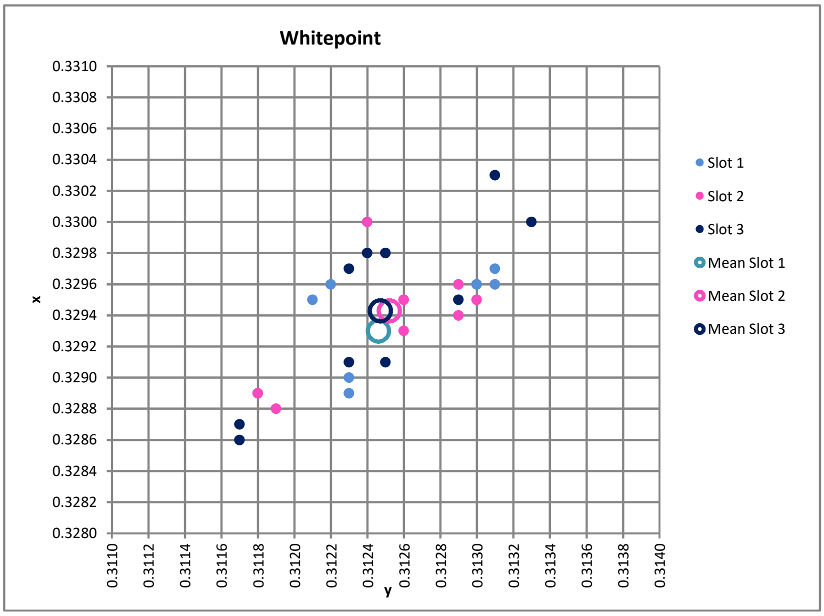
1.3 - Performance data (test period of 5 days)

		White Lum. (cd/m²)	Black Lum. (cd/m²)	CCT (K)	Whitepoint X	Y	Z	x	y
Day 1	Slot 1	159.80	0.2000	6479	95.00	100.00	108.44	0.3131	0.3296
		159.70	0.2003	6484	95.03	100.00	108.39	0.3130	0.3296
	Slot 2	159.80	0.2007	6483	95.00	100.00	108.51	0.3130	0.3295
		159.70	0.2006	6489	94.99	100.00	108.58	0.3129	0.3294
	Slot 3	159.80	0.2006	6488	94.97	100.00	108.53	0.3129	0.3295
		159.50	0.2024	6466	94.94	100.00	108.13	0.3133	0.3300
Day 2	Slot 1	159.60	0.2026	6476	94.96	100.00	108.32	0.3131	0.3297
		159.70	0.2027	6489	94.93	100.00	108.48	0.3130	0.3296
	Slot 2	159.70	0.2029	6489	94.93	100.00	108.48	0.3129	0.3296
		159.80	0.2032	6508	94.93	100.00	108.76	0.3126	0.3293
	Slot 3	159.80	0.2007	6513	94.95	100.00	108.89	0.3125	0.3291
		159.90	0.2009	6523	94.92	100.00	108.98	0.3123	0.3291
Day 3	Slot 1	159.90	0.2009	6528	94.95	100.00	109.10	0.3123	0.3289
		159.90	0.2009	6527	94.92	100.00	109.05	0.3123	0.3290
	Slot 2	159.50	0.1991	6506	94.88	100.00	108.64	0.3126	0.3295
		159.50	0.1994	6506	94.85	100.00	108.59	0.3126	0.3295
	Slot 3	160.00	0.2002	6561	94.82	100.00	109.30	0.3117	0.3287
		159.90	0.2001	6562	94.84	100.00	109.44	0.3117	0.3286
Day 4	Slot 1	159.90	0.2001	6562	94.84	100.00	109.44	0.3117	0.3286
		160.00	0.1963	6556	94.79	100.00	109.27	0.3118	0.3289
	Slot 2	159.90	0.1965	6552	94.85	100.00	109.30	0.3119	0.3288
		160.00	0.1965	6556	94.79	100.00	109.27	0.3118	0.3289
	Slot 3	159.70	0.1937	6474	94.78	100.00	107.97	0.3131	0.3303
		160.20	0.1940	6514	94.73	100.00	108.50	0.3124	0.3298
Day 5	Slot 1	160.30	0.1945	6529	94.72	100.00	108.72	0.3122	0.3296
		160.30	0.1946	6533	94.72	100.00	108.79	0.3121	0.3295
	Slot 2	160.00	0.1953	6511	94.69	100.00	108.38	0.3124	0.3300
		160.10	0.1954	6511	94.75	100.00	108.48	0.3125	0.3298
	Slot 3	160.10	0.1955	6520	94.72	100.00	108.58	0.3123	0.3297
		159.70	0.1960	6509	94.75	100.00	108.46	0.3125	0.3298

	White Lum.	Black Lum.	CCT	X	Y	Z	x	y
Mean	159.9	0.1989	6513	94.86	100.00	108.73	0.3125	0.3294
Min	159.5	0.1937	6466	94.69	100.00	107.97	0.3117	0.3286
Max	160.3	0.2032	6562	95.03	100.00	109.44	0.3133	0.3303
SD	0.2108	0.0029	28	0.0998	0.0000	0.3862	0.0005	0.0004

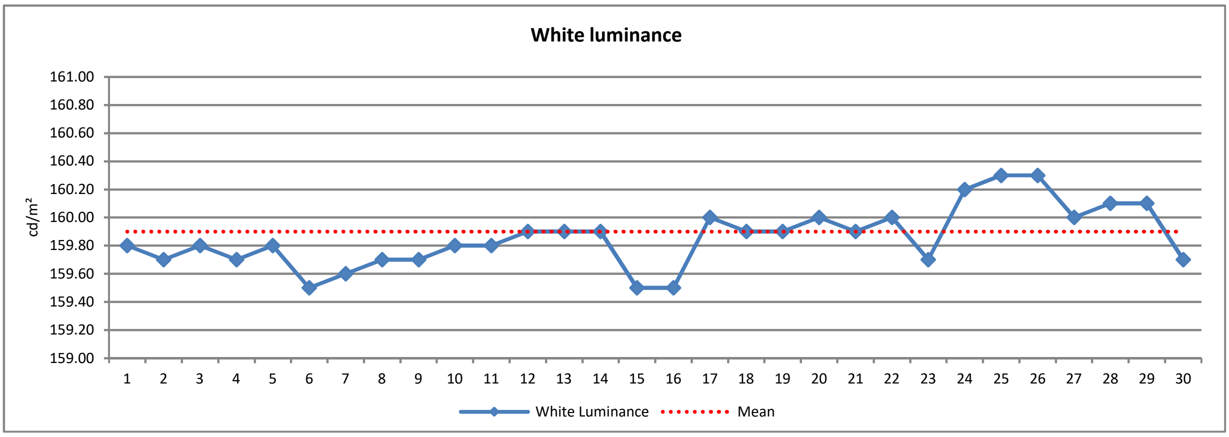
		White Lum. (cd/m²)	Black Lum. (cd/m²)	CCT (K)	Whitepoint X	Y	Z	x	y
Slot 1	Mean	159.91	0.1993	6516	94.89	100.00	108.80	0.3125	0.3293
	Min	159.60	0.1945	6476	94.72	100.00	108.32	0.3117	0.3286
	Max	160.30	0.2027	6562	95.03	100.00	109.44	0.3131	0.3297
	SD	0.2256	0.0029	30	0.1062	0.0000	0.3768	0.0005	0.0004
Slot 2	Mean	159.80	0.1990	6511	94.87	100.00	108.70	0.3125	0.3294
	Min	159.50	0.1953	6483	94.69	100.00	108.38	0.3118	0.3288
	Max	160.10	0.2032	6556	95.00	100.00	109.30	0.3130	0.3300
	SD	0.1949	0.0028	23	0.0961	0.0000	0.3089	0.0004	0.0003
Slot 3	Mean	159.86	0.1984	6513	94.84	100.00	108.68	0.3125	0.3294
	Min	159.50	0.1937	6466	94.72	100.00	107.97	0.3117	0.3286
	Max	160.20	0.2024	6562	94.97	100.00	109.44	0.3133	0.3303
	SD	0.1960	0.0031	30	0.0916	0.0000	0.4490	0.0005	0.0005
Day 1	Mean	159.72	0.2008	6482	94.99	100.00	108.43	0.3130	0.3296
	Min	159.50	0.2000	6466	94.94	100.00	108.13	0.3129	0.3294
	Max	159.80	0.2024	6489	95.03	100.00	108.58	0.3133	0.3300
	SD	0.1067	0.0008	8	0.0279	0.0000	0.1475	0.0001	0.0002
Day 2	Mean	159.75	0.2022	6500	94.94	100.00	108.65	0.3127	0.3294
	Min	159.60	0.2007	6476	94.92	100.00	108.32	0.3123	0.3291
	Max	159.90	0.2032	6523	94.96	100.00	108.98	0.3131	0.3297
	SD	0.0957	0.0010	16	0.0137	0.0000	0.2399	0.0003	0.0002
Day 3	Mean	159.78	0.2001	6532	94.88	100.00	109.02	0.3122	0.3290
	Min	159.50	0.1991	6506	94.82	100.00	108.59	0.3117	0.3286
	Max	160.00	0.2009	6562	94.95	100.00	109.44	0.3126	0.3295
	SD	0.2034	0.0007	23	0.0457	0.0000	0.3140	0.0004	0.0004
Day 4	Mean	159.95	0.1962	6536	94.80	100.00	108.96	0.3121	0.3292
	Min	159.70	0.1937	6474	94.73	100.00	107.97	0.3117	0.3286
	Max	160.20	0.2001	6562	94.85	100.00	109.44	0.3131	0.3303
	SD	0.1500	0.0021	32	0.0399	0.0000	0.5369	0.0005	0.0006
Day 5	Mean	160.08	0.1952	6519	94.73	100.00	108.57	0.3123	0.3297
	Min	159.70	0.1945	6509	94.69	100.00	108.38	0.3121	0.3295
	Max	160.30	0.1960	6533	94.75	100.00	108.79	0.3125	0.3300
	SD	0.2034	0.0005	9	0.0206	0.0000	0.1456	0.0001	0.0002

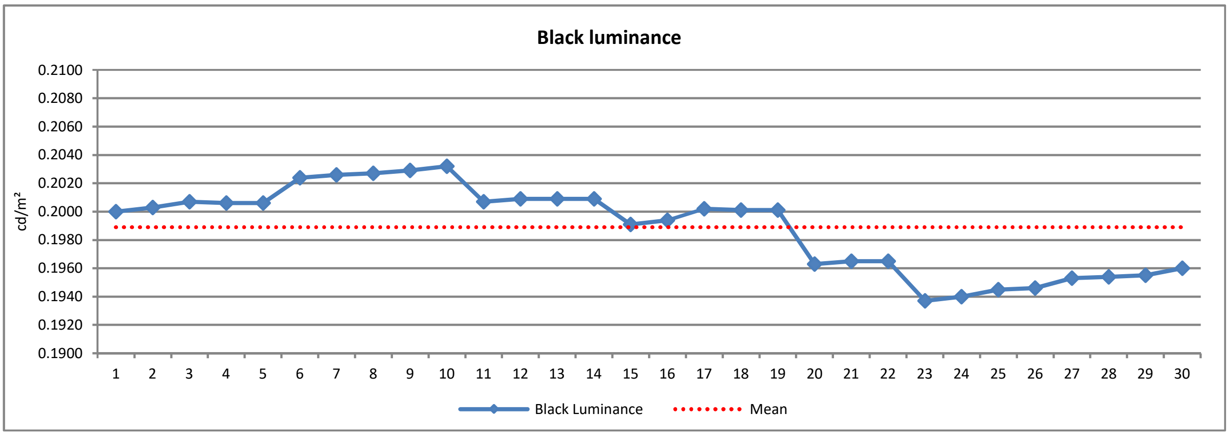
1.4 - Performance data - visualization of the measured whitepoints in the CIE xy chromaticity diagram

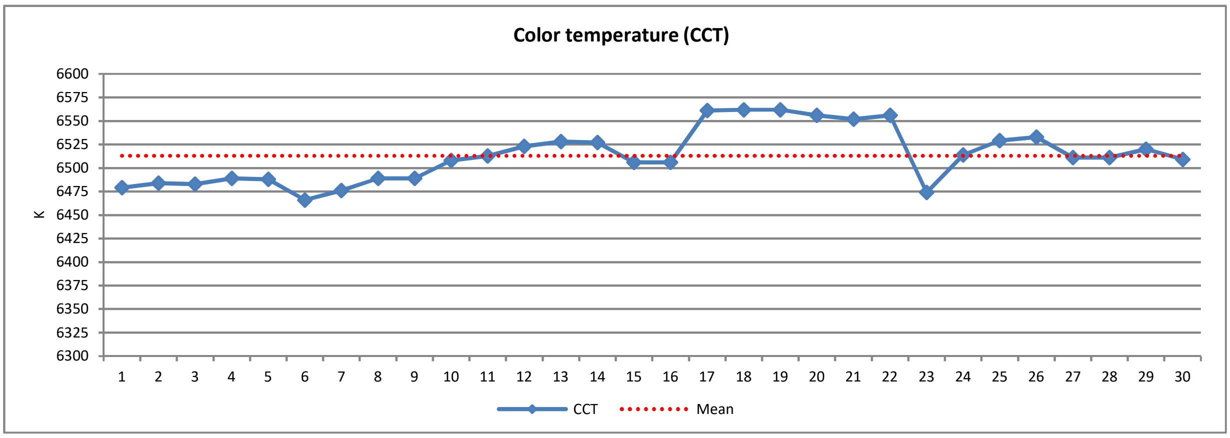


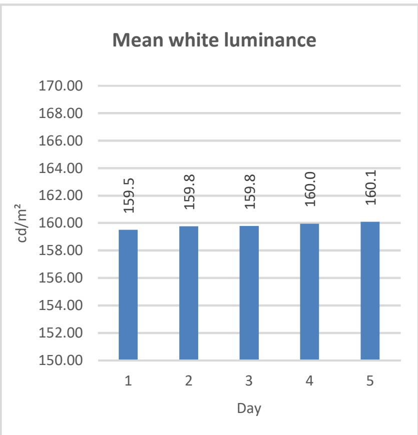
3| 2 Display performance data / Calibrated and profiled (Display2_MD1_AdobeRGB_160_V1.icm)

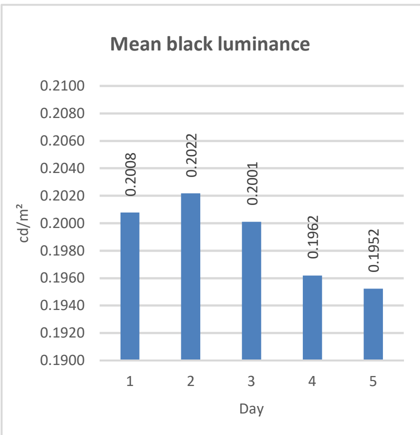
1.5 - Performance data - visualization of the measured values

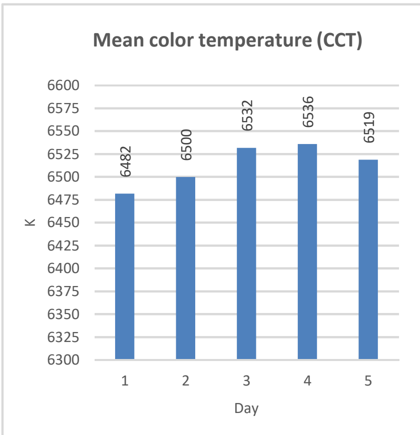






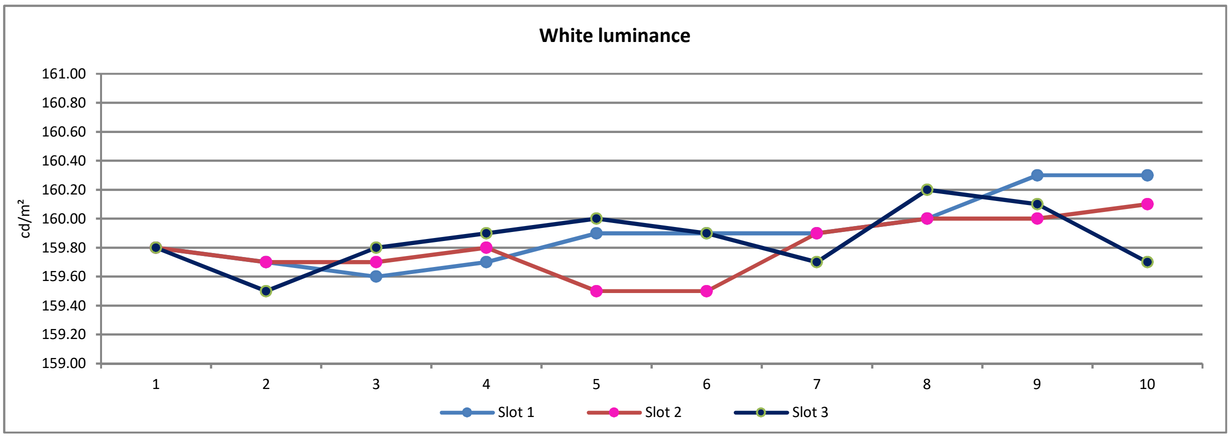


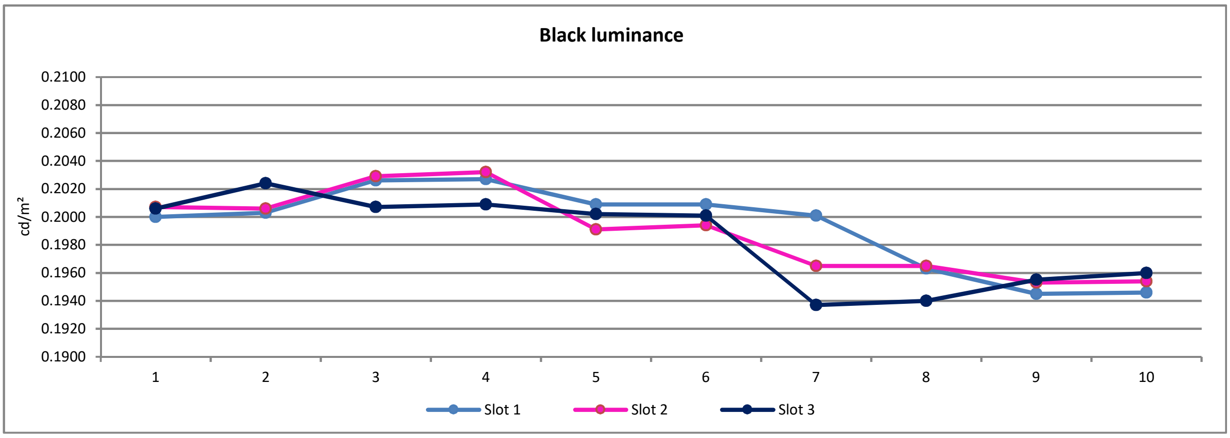


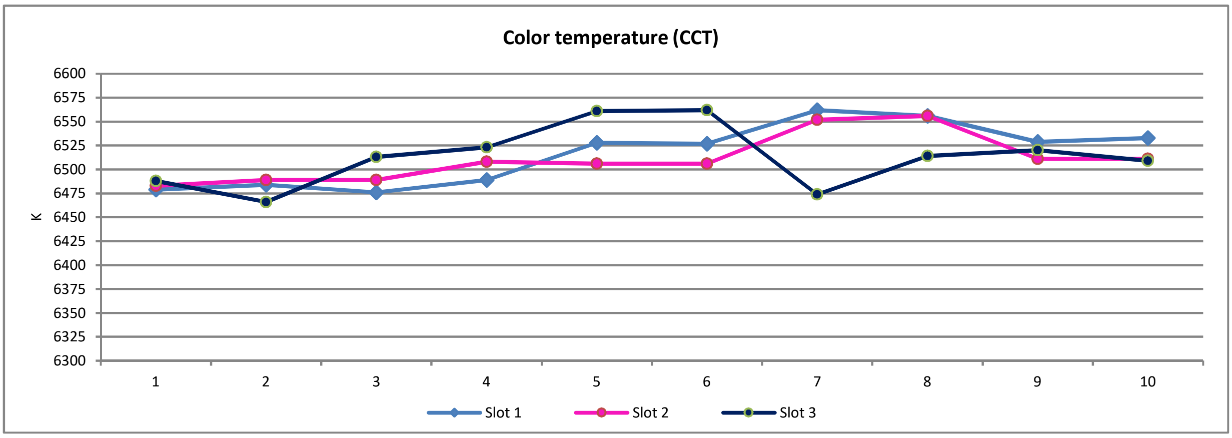


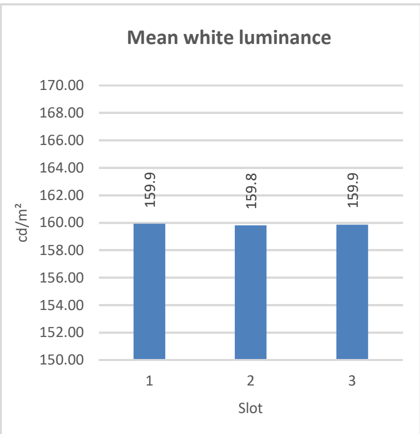
3| 2 Display performance data / Calibrated and profiled (Display2_MD1_AdobeRGB_160_V1.icm)

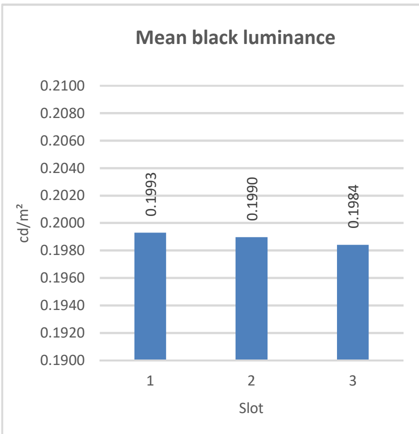
1.5 - Performance data - visualization of the measured values

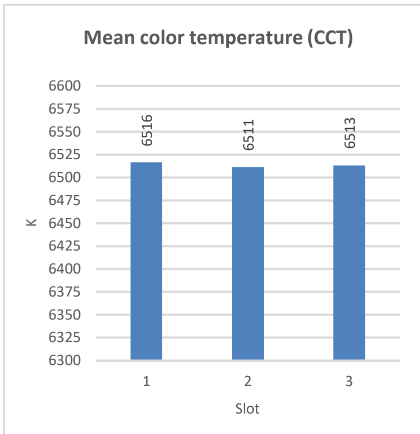












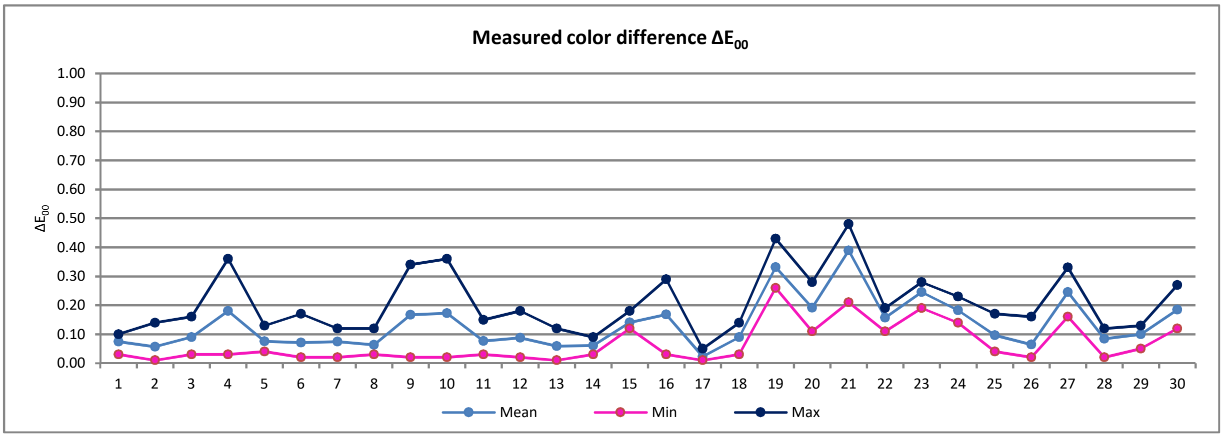
3| 2 Display performance data / Calibrated and profiled (Display2_MD1_AdobeRGB_160_V1.icm)

1.6 - Color accuracy - measured color difference ΔE_{00}

	Device Values			Nominal Values			Day 1		Day 2		Day 3		Day 4		Day 5		ΔE_{00}			
Color	R	G	B	L*	a*	b*	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	Mean	Min	Max	SD
1	128	0	0	29.34	60.59	45.46	0.03	0.07	0.08	0.09	0.09	0.07	0.05	0.07	0.10	0.09	0.07	0.03	0.10	0.0201
2	255	0	0	59.53	102.24	90.99	0.02	0.07	0.01	0.04	0.03	0.05	0.09	0.01	0.14	0.11	0.06	0.01	0.14	0.0422
3	255	128	128	70.46	67.74	29.78	0.04	0.05	0.03	0.15	0.15	0.16	0.14	0.04	0.09	0.05	0.09	0.03	0.16	0.0514
4	0	128	0	47.27	-74.73	61.58	0.03	0.07	0.14	0.34	0.31	0.30	0.36	0.11	0.06	0.08	0.18	0.03	0.36	0.1244
5	0	255	0	89.92	-126.58	106.51	0.04	0.09	0.06	0.05	0.06	0.06	0.13	0.04	0.12	0.11	0.08	0.04	0.13	0.0320
6	128	255	128	91.47	-88.02	61.68	0.02	0.02	0.03	0.10	0.10	0.08	0.17	0.02	0.09	0.08	0.07	0.02	0.17	0.0464
7	0	0	128	10.26	61.84	-78.29	0.02	0.09	0.05	0.08	0.07	0.08	0.12	0.09	0.11	0.04	0.08	0.02	0.12	0.0294
8	0	0	255	26.58	106.90	-132.71	0.04	0.07	0.03	0.06	0.05	0.09	0.07	0.12	0.06	0.04	0.06	0.03	0.12	0.0253
9	128	128	255	56.99	40.50	-76.33	0.06	0.06	0.04	0.30	0.34	0.33	0.33	0.02	0.11	0.08	0.17	0.02	0.34	0.1312
10	0	128	128	48.60	-46.68	-9.93	0.02	0.06	0.03	0.34	0.32	0.34	0.36	0.02	0.15	0.09	0.17	0.02	0.36	0.1414
11	0	255	255	91.56	-77.65	-17.31	0.06	0.05	0.03	0.07	0.05	0.04	0.15	0.05	0.15	0.12	0.08	0.03	0.15	0.0431
12	170	255	255	94.42	-40.29	-10.55	0.05	0.05	0.02	0.09	0.11	0.07	0.18	0.07	0.15	0.09	0.09	0.02	0.18	0.0458
13	128	0	128	31.42	73.32	-40.75	0.03	0.01	0.02	0.10	0.09	0.10	0.12	0.01	0.07	0.04	0.06	0.01	0.12	0.0396
14	255	0	255	63.06	123.39	-67.23	0.08	0.09	0.05	0.05	0.03	0.06	0.05	0.06	0.08	0.06	0.06	0.03	0.09	0.0170
15	255	170	255	80.48	59.44	-33.97	0.14	0.13	0.12	0.12	0.14	0.16	0.13	0.13	0.16	0.18	0.14	0.12	0.18	0.0187
16	128	128	0	52.70	-12.51	70.47	0.03	0.14	0.08	0.28	0.27	0.26	0.29	0.17	0.13	0.03	0.17	0.03	0.29	0.0971
17	255	255	0	98.85	-22.22	121.07	0.02	0.05	0.01	0.02	0.02	0.04	0.01	0.01	0.02	0.03	0.02	0.01	0.05	0.0127
18	255	255	170	99.17	-13.78	49.74	0.09	0.08	0.14	0.07	0.07	0.03	0.10	0.08	0.11	0.13	0.09	0.03	0.14	0.0303
19	170	85	85	48.37	49.08	21.97	0.26	0.28	0.29	0.42	0.40	0.40	0.43	0.28	0.28	0.28	0.33	0.26	0.43	0.0666
20	85	170	85	63.49	-64.19	44.60	0.23	0.20	0.18	0.11	0.14	0.14	0.19	0.18	0.28	0.26	0.19	0.11	0.28	0.0513
21	85	85	170	38.63	29.04	-55.69	0.37	0.39	0.44	0.38	0.40	0.21	0.33	0.48	0.47	0.42	0.39	0.21	0.48	0.0738
22	85	170	170	64.48	-41.53	-10.49	0.16	0.16	0.15	0.15	0.11	0.15	0.19	0.13	0.19	0.18	0.16	0.11	0.19	0.0241
23	170	85	170	49.91	62.81	-35.31	0.25	0.26	0.28	0.23	0.23	0.23	0.25	0.19	0.28	0.26	0.25	0.19	0.28	0.0258
24	170	170	85	69.04	-13.11	55.03	0.19	0.17	0.19	0.16	0.18	0.15	0.21	0.14	0.21	0.23	0.18	0.14	0.23	0.0272
25	255	0	170	60.84	111.09	-17.98	0.10	0.11	0.09	0.04	0.04	0.06	0.10	0.09	0.17	0.17	0.10	0.04	0.17	0.0434
26	170	255	0	93.11	-73.07	112.03	0.03	0.04	0.02	0.07	0.05	0.03	0.16	0.02	0.12	0.11	0.07	0.02	0.16	0.0463
27	0	170	255	65.75	-18.42	-62.10	0.30	0.23	0.33	0.20	0.16	0.21	0.19	0.28	0.27	0.28	0.25	0.16	0.33	0.0520
28	0	255	170	90.52	-105.73	32.53	0.11	0.10	0.08	0.02	0.04	0.04	0.12	0.10	0.12	0.11	0.08	0.02	0.12	0.0353
29	170	0	255	46.28	109.93	-96.97	0.11	0.12	0.06	0.12	0.12	0.13	0.11	0.12	0.06	0.05	0.10	0.05	0.13	0.0290
30	255	170	0	78.35	36.62	103.09	0.15	0.15	0.12	0.14	0.19	0.18	0.25	0.13	0.27	0.27	0.19	0.12	0.27	0.0552

Mean	0.13	0.07	0.21	0.0493

1.6.1 - Color accuracy - visualization of the measured color difference ΔE_{00}

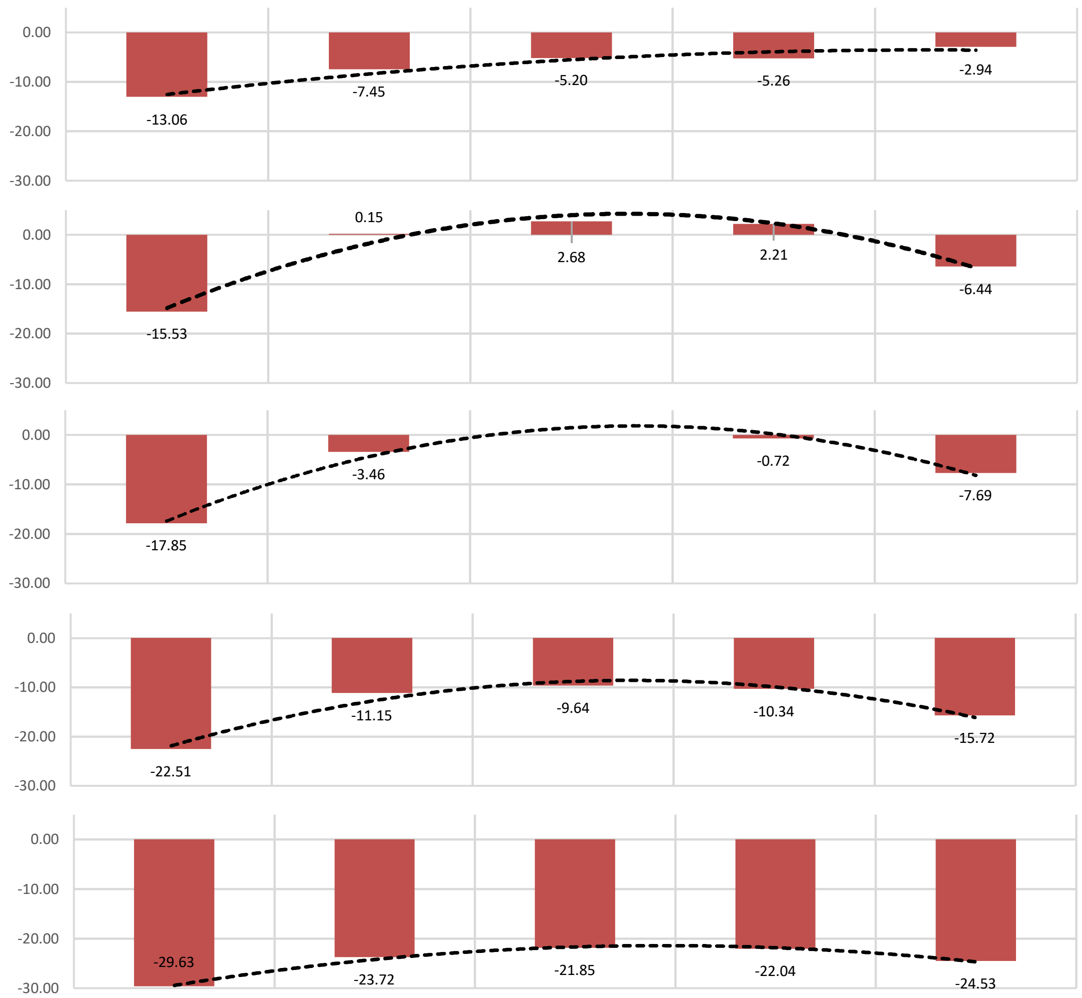


3| 2 Display performance data / Calibrated and profiled (Display2_MD1_AdobeRGB_160_V1.icm)

1.7 - Display uniformity - measured values (5x5 matrix)

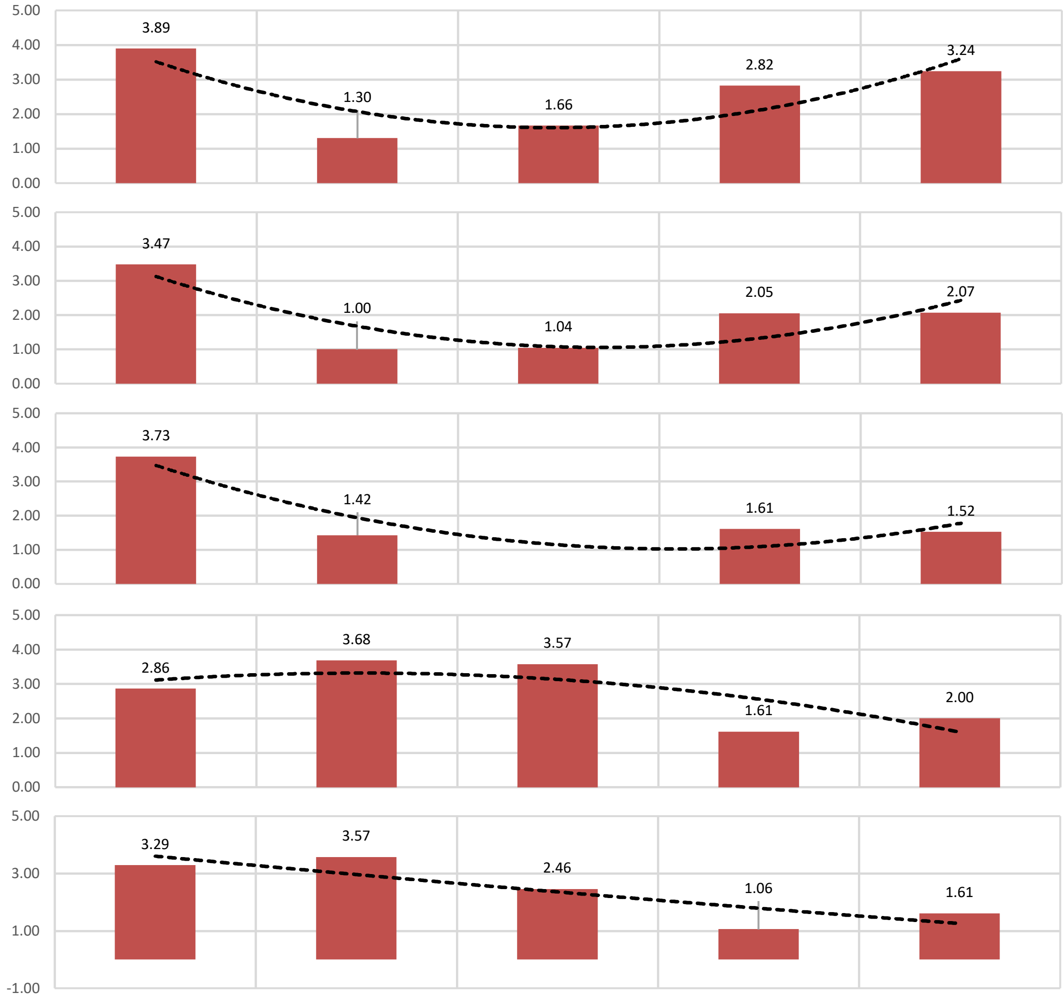
	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00
100%	138.69	-13.06	3.89	147.63	-7.45	1.30	151.23	-5.20	1.66	151.13	-5.26	2.82	154.84	-2.94	3.24
75%	71.02	-8.09	3.24	78.01	-3.70	0.16	80.18	-2.34	0.55	80.07	-2.41	1.50	81.70	-1.39	2.15
50%	28.20	-3.84	2.41	31.91	-1.51	0.32	32.79	-0.96	0.55	32.77	-0.97	1.44	33.38	-0.59	1.86
25%	1.13	-0.86	1.13	6.90	-0.45	0.02	7.13	-0.31	0.22	7.18	-0.27	0.55	7.41	-0.13	1.04
100%	134.75	-15.53	3.47	159.75	0.15	1.00	163.80	2.68	1.04	163.05	2.21	2.05	149.25	-6.44	2.07
75%	68.67	-9.56	2.71	84.25	0.21	0.25	86.38	1.55	0.35	86.27	1.48	1.05	78.38	-3.47	1.34
50%	27.20	-4.46	1.71	34.51	0.12	0.38	35.36	0.65	0.44	35.34	0.64	1.27	32.00	-1.45	1.32
25%	6.00	-1.02	0.89	7.54	-0.05	0.07	7.77	0.09	0.14	7.81	0.12	0.51	7.13	-0.31	0.70
100%	131.05	-17.85	3.73	153.99	-3.46	1.42	**159.52**			158.37	-0.72	1.61	147.25	-7.69	1.52
75%	66.79	-10.74	2.99	80.44	-2.18	0.67	**83.92**			83.54	-0.24	0.99	77.33	-4.13	0.99
50%	26.46	-4.93	2.24	32.74	-0.99	0.53	**34.32**			34.20	-0.08	0.88	31.55	-1.73	0.99
25%	5.84	-1.12	1.05	7.22	-0.25	0.10	**7.62**			7.60	-0.01	0.46	7.01	-0.38	0.54
100%	123.61	-22.51	2.86	141.73	-11.15	3.68	144.14	-9.64	3.57	143.03	-10.34	1.61	134.45	-15.72	2.00
75%	63.01	-13.11	2.03	74.87	-5.67	2.40	76.28	-4.79	2.25	75.91	-5.02	0.64	70.92	-8.15	0.88
50%	25.06	-5.80	1.28	30.85	-2.18	2.07	31.34	-1.86	1.99	31.24	-1.93	0.78	29.00	-3.33	0.91
25%	5.63	-1.25	0.27	7.22	-0.50	0.10	6.94	-0.43	0.96	6.94	-0.43	0.36	6.45	-0.74	0.50
100%	112.25	-29.63	3.29	121.68	-23.72	3.57	124.67	-21.85	2.46	124.36	-22.04	1.06	120.39	-24.53	1.61
75%	57.44	-16.60	2.28	64.03	-12.47	2.30	65.54	-11.52	1.32	65.84	-11.34	0.20	63.35	-12.89	1.21
50%	22.85	-7.19	1.18	26.22	-5.08	1.92	26.75	-4.74	1.24	26.96	-4.61	0.42	25.80	-5.34	0.94
25%	5.11	-1.58	0.40	5.78	-1.16	1.06	5.87	-1.10	0.56	5.93	-1.06	0.01	5.68	-1.22	0.49

1.7.1 - Display uniformity - Visualization of the luminance difference (%)



3| 2 Display performance data / Calibrated and profiled (Display2_MD1_AdobeRGB_160_V1.icm)

1.7.2 - Display uniformity - Visualization of the chromaticity difference ΔC*$_{00}$

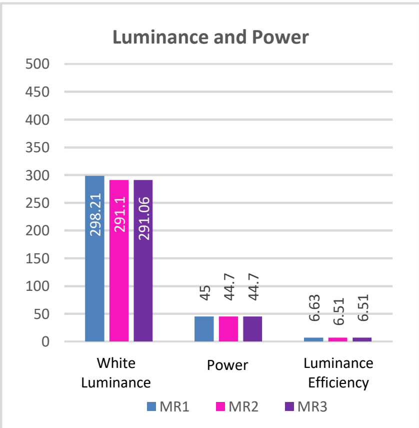


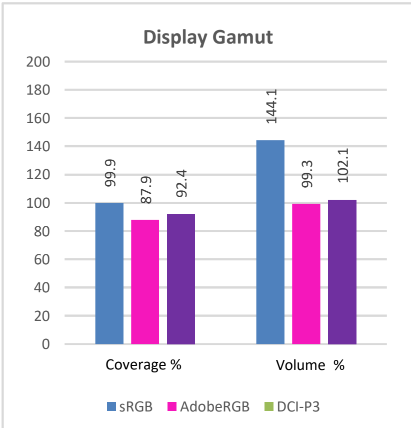
3| 3 Display performance data / Uncalibrated with maximum device settings

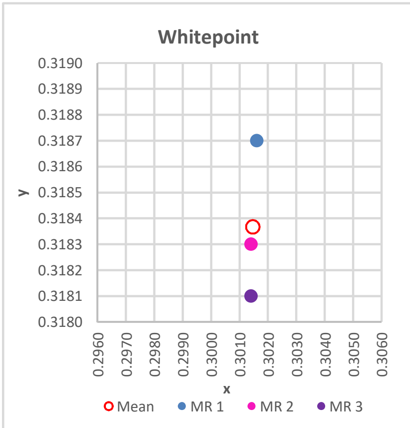
1.1 - Display performance data

	White Lum. (cd/m²)	Power (W)	Lum. Eff. (cd/W)	Black Lum. (cd/m²)	Whitepoint (CIE_xy)		Display Gamut					
							sRGB		AdobeRGB		DCI-P3	
					x	y	Cov. (%)	Vol. (%)	Cov. (%)	Vol. (%)	Cov. (%)	Vol. (%)
MR 1	298.21	45	6.63	0.1062	0.3016	0.3187	99.9	144.5	88.1	99.6	92.5	102.4
MR 2	291.1	44.7	6.51	0.1049	0.3014	0.3183	99.9	143.9	87.8	99.2	92.4	102
MR 3	291.06	44.7	6.51	0.1044	0.3014	0.3181	99.9	143.9	87.8	99.2	92.4	102

Mean	293.4567	44.8	6.55	0.1052	0.3015	0.3184	99.9	144.1	87.9	99.3	92.4	102.1
Min	298.21	45.0	6.63	0.1062	0.3016	0.3187	99.9	144.5	88.1	99.6	92.5	102.4
Max	291.06	44.7	6.51	0.1044	0.3014	0.3181	99.9	143.9	87.8	99.2	92.4	102
SD	3.3612	0.1414	0.0542	0.3296	94.9300	0.0002	0.0000	0.2828	0.1414	0.1886	0.0471	0.1886

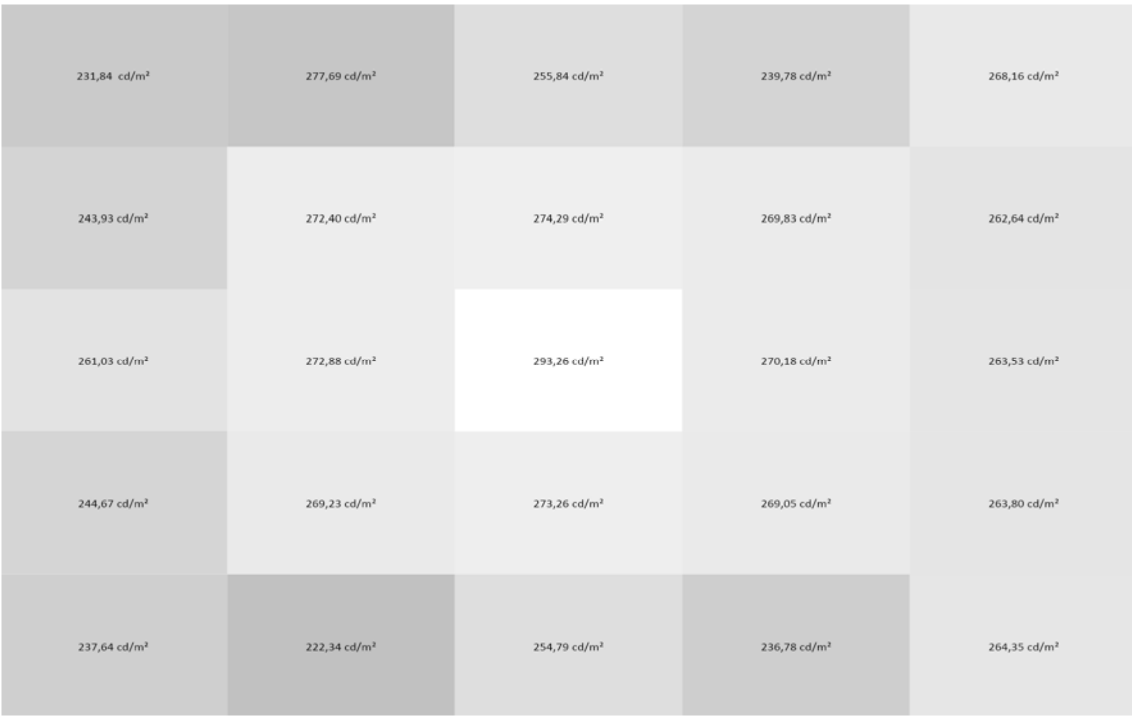






1.2 - Display uniformity - Visualization of the mean values in the 5x5 matrix

	Lum. cd/m²	Delta %	Lum. cd/m²	Delta %	Lum. cd/m²	Delta %	Lum. cd/m²	Delta %	Lum. cd/m²	Delta %
100%	231.84	-20.94	227.69	-22.35	255.84	-12.75	239.78	-18.22	268.16	-8.55
100%	243.93	-16.82	272.40	-7.10	274.29	-6.46	269.83	-7.98	262.46	-10.50
100%	261.03	-10.99	272.88	-6.95	293.26	0.00	270.18	-7.86	263.53	-10.13
100%	244.67	-16.57	269.23	-8.19	273.26	-6.82	269.05	-8.25	263.80	-10.03
100%	237.64	-18.96	222.34	-24.18	254.79	-13.11	236.78	-19.25	264.35	-9.85



3| 3 Display performance data / Uncalibrated with maximum device settings

1.2.1 - Display uniformity - Measured values from three control measurements (5x5 matrix)

	Lum. cd/m²	Delta %	ΔC^*_{00}	Lum. cd/m²	Delta %	ΔC^*_{00}	Lum. cd/m²	Delta %	ΔC^*_{00}	Lum. cd/m²	Delta %	ΔC^*_{00}	Lum. cd/m²	Delta %	ΔC^*_{00}
100%	234.24	-21.42	1.76	228.26	-23.43	1.02	256.92	-13.82	1.06	236.97	-20.51	1.12	269.54	-9.58	1.19
75%	226.38	-21.00	1.06	220.91	-22.84	0.67	249.00	-13.41	1.03	229.52	-19.95	1.17	260.91	-9.42	1.28
50%	85.95	-7.18	1.82	81.94	-8.53	1.53	93.73	-4.57	1.30	86.48	-7.00	2.64	96.81	-3.54	4.33
25%	17.80	-0.97	1.46	16.07	-1.55	0.80	18.19	-0.84	0.65	16.69	-1.34	1.81	18.81	-0.63	3.62
100%	246.62	-17.27	1.35	274.50	-7.92	1.22	276.79	-7.15	0.35	272.37	-8.63	0.48	265.01	-11.10	0.52
75%	238.66	-16.88	0.54	265.65	-7.82	0.65	268.32	-6.93	0.15	264.01	-8.38	0.52	256.63	-10.85	0.59
50%	90.76	-5.57	1.50	97.09	-3.44	1.79	99.73	-2.56	0.58	98.16	-3.08	2.18	95.73	-3.90	3.43
25%	18.88	-0.61	1.05	18.08	-0.63	1.17	19.00	-0.57	0.30	18.55	-0.72	1.84	18.62	-0.69	2.57
100%	264.19	-11.38	1.36	276.49	-7.25	0.82	**298.10**			272.38	-8.63	0.49	264.52	-11.26	0.43
75%	255.71	-11.16	0.71	267.92	-7.07	0.25	**288.98**			263.98	-8.39	0.33	256.30	-10.96	0.28
50%	97.45	-3.32	1.37	99.01	-2.80	1.32	**107.35**			98.54	-2.96	0.70	96.25	-3.73	1.86
25%	20.01	-0.23	1.36	19.21	-0.50	0.72	**20.69**			18.74	-0.65	0.55	18.74	-0.65	1.52
100%	247.64	-16.93	1.05	273.10	-8.39	0.77	276.26	-7.33	0.38	270.59	-9.23	0.62	264.29	-11.34	0.76
75%	240.02	-16.42	0.54	264.80	-8.11	0.25	268.24	-6.96	-0.18	262.61	-8.85	0.49	256.04	-11.05	0.49
50%	92.16	-5.10	1.74	97.69	-3.24	1.47	100.65	-2.25	0.29	99.05	-2.78	0.99	96.96	-3.49	1.65
25%	18.70	-0.67	1.09	18.44	-0.76	0.80	19.07	-0.54	0.05	18.97	-0.58	0.37	19.07	-0.54	1.16
100%	239.65	-19.61	1.82	224.39	-24.73	2.00	257.12	-13.75	1.88	237.83	-20.22	1.00	265.09	-11.08	0.88
75%	233.05	-18.76	1.17	218.19	-23.75	1.39	250.35	-12.96	1.35	231.15	-19.40	0.47	256.91	-10.76	0.80
50%	91.80	-5.22	2.04	83.52	-7.99	2.38	97.63	-3.26	2.19	90.40	-5.69	1.18	99.17	-2.74	2.26
25%	18.74	-0.65	1.34	16.10	-1.54	1.71	19.07	-0.54	1.23	17.94	-0.92	-0.01	19.97	-0.24	0.91

100%	231.48	-20.47	1.54	227.45	-21.85	1.04	255.84	-12.10	1.08	241.21	-17.12	1.06	268.72	-7.67	1.42
75%	223.41	-20.18	0.87	219.82	-21.41	0.70	247.72	-11.83	1.02	233.51	-16.71	1.18	259.95	-7.63	1.49
50%	84.10	-6.91	1.80	80.89	-8.01	1.65	92.38	-4.06	1.27	87.31	-5.80	2.67	96.25	-2.73	4.44
25%	17.80	-0.80	1.80	16.09	-1.39	1.62	18.04	-0.72	1.10	16.85	-1.13	2.44	18.81	-0.46	4.16
100%	242.17	-16.80	1.12	271.48	-6.72	1.21	273.00	-6.20	0.45	268.79	-7.65	0.55	261.31	-10.22	0.78
75%	233.82	-16.60	0.49	262.21	-6.85	0.74	264.50	-6.06	0.24	260.21	-7.54	0.61	253.02	-10.01	0.78
50%	88.40	-5.43	1.56	95.24	-3.08	1.84	97.76	-2.21	0.73	96.67	-2.59	2.28	94.55	-3.32	3.55
25%	18.73	-0.49	1.91	18.70	-0.50	1.62	18.84	-0.45	1.00	18.41	-0.60	1.95	18.55	-0.55	3.36
100%	259.96	-10.68	1.03	269.92	-7.26	0.72	**291.06**			269.22	-7.50	0.54	263.16	-9.59	0.35
75%	251.18	-10.64	0.58	261.29	-7.16	0.20	**282.15**			260.71	-7.37	0.41	254.87	-9.37	0.40
50%	95.24	-3.08	1.25	96.02	-2.81	1.07	**104.20**			97.16	-2.42	0.88	95.96	-2.83	1.86
25%	19.83	-0.11	1.81	18.73	-0.49	1.55	**20.14**			18.63	-0.52	0.83	18.89	-0.43	1.91
100%	243.47	-16.35	0.92	266.50	-8.44	0.81	272.36	-6.43	0.29	268.42	-7.78	0.60	263.79	-9.37	0.72
75%	235.65	-15.97	0.59	258.43	-8.15	0.29	264.23	-6.15	-0.11	260.21	-7.54	0.53	255.53	-9.14	0.59
50%	90.02	-4.87	1.57	95.33	-3.05	1.42	98.99	-1.79	0.42	98.06	-2.11	1.08	97.00	-2.47	1.71
25%	18.44	-0.59	1.61	18.18	-0.67	1.39	18.92	-0.42	0.79	18.85	-0.45	1.46	19.18	-0.33	1.99
100%	236.77	-18.65	1.73	221.53	-23.89	1.94	253.48	-12.91	1.90	236.07	-18.89	1.00	262.81	-9.71	0.97
75%	230.01	-17.91	1.17	215.34	-22.95	1.37	246.59	-12.22	1.53	229.34	-18.14	0.62	254.74	-9.42	0.95
50%	90.51	-4.70	1.94	82.39	-7.50	2.35	95.96	-2.83	2.26	89.45	-5.07	1.14	98.25	-2.05	2.29
25%	18.64	-0.52	1.67	16.01	-1.42	1.97	18.74	-0.48	1.80	17.68	-0.85	0.48	19.74	-0.14	1.66

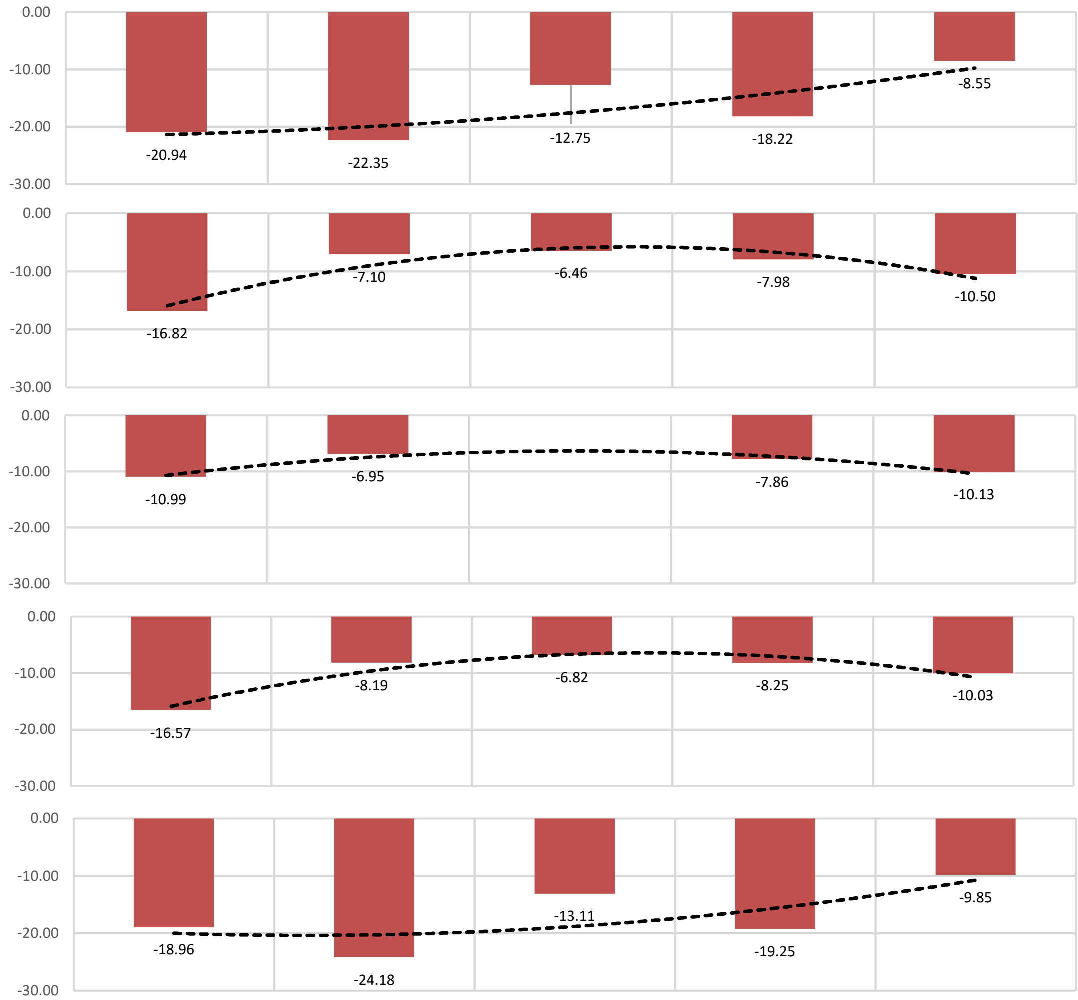
100%	229.81	-20.92	1.35	227.37	-21.76	1.07	254.76	-12.34	1.12	241.17	-17.02	1.02	266.22	-8.40	1.41
75%	221.66	-20.66	0.81	219.72	-21.33	0.67	246.90	-11.98	1.03	233.43	-16.61	1.15	257.56	-8.31	1.47
50%	83.33	-7.16	1.79	80.79	-8.03	1.46	92.13	-4.13	1.14	87.38	-5.76	2.51	95.45	-2.98	4.46
25%	17.62	-0.87	1.71	16.08	-1.40	1.58	18.01	-0.73	0.69	16.92	-1.11	2.29	18.66	-0.51	4.39
100%	242.99	-16.39	1.02	271.23	-6.67	1.12	273.09	-6.03	0.33	268.33	-7.67	0.55	261.07	-10.17	0.70
75%	234.59	-16.21	0.47	262.00	-6.78	0.60	264.42	-5.95	0.20	259.66	-7.59	0.61	252.74	-9.97	0.69
50%	88.73	-5.30	1.46	95.09	-3.11	1.83	97.66	-2.23	0.56	96.34	-2.68	2.34	94.34	-3.37	3.37
25%	18.83	-0.45	1.98	18.65	-0.51	1.97	18.81	-0.46	0.61	18.36	-0.61	2.26	18.50	-0.56	3.62
100%	258.94	-10.90	1.02	272.22	-6.33	0.67	**290.62**			268.93	-7.46	0.57	262.92	-9.53	0.43
75%	250.16	-10.86	0.45	263.37	-6.31	0.24	**281.71**			260.46	-7.31	0.51	254.59	-9.33	0.43
50%	94.76	-3.22	1.27	96.69	-2.56	1.12	**104.13**			97.10	-2.42	0.64	95.70	-2.90	1.83
25%	19.88	-0.09	1.31	18.91	-0.43	1.70	**20.14**			18.63	-0.52	0.83	18.82	-0.46	1.94
100%	242.89	-16.42	0.84	268.10	-7.75	0.68	271.15	-6.70	0.26	268.13	-7.74	0.63	263.32	-9.39	0.77
75%	235.00	-16.07	0.47	259.86	-7.52	0.28	263.10	-6.40	-0.11	260.00	-7.47	0.57	254.99	-9.19	0.63
50%	89.69	-4.97	1.53	95.51	-2.96	1.47	98.40	-1.97	0.23	97.98	-2.11	1.18	96.64	-2.58	1.49
25%	18.39	-0.60	1.91	18.21	-0.67	1.47	18.74	-0.48	0.53	18.89	-0.43	1.03	19.07	-0.37	1.65
100%	236.50	-18.62	1.55	221.10	-23.92	1.90	253.78	-12.68	1.80	236.45	-18.64	0.95	265.15	-8.76	0.86
75%	229.69	-17.90	1.06	215.00	-22.95	1.34	247.01	-11.94	1.36	229.66	-17.91	0.49	256.95	-8.52	0.89
50%	90.26	-4.77	1.92	82.13	-7.57	2.22	95.93	-2.82	2.00	89.45	-5.05	1.06	98.99	-1.77	2.28
25%	18.56	-0.55	1.69	15.94	-1.45	1.84	18.67	-0.51	1.00	17.63	-0.86	0.82	19.79	-0.12	1.29

3| 3 Display performance data / Uncalibrated with maximum device settings

1.2.2 - Display uniformity - Mean measured values (5x5 matrix)

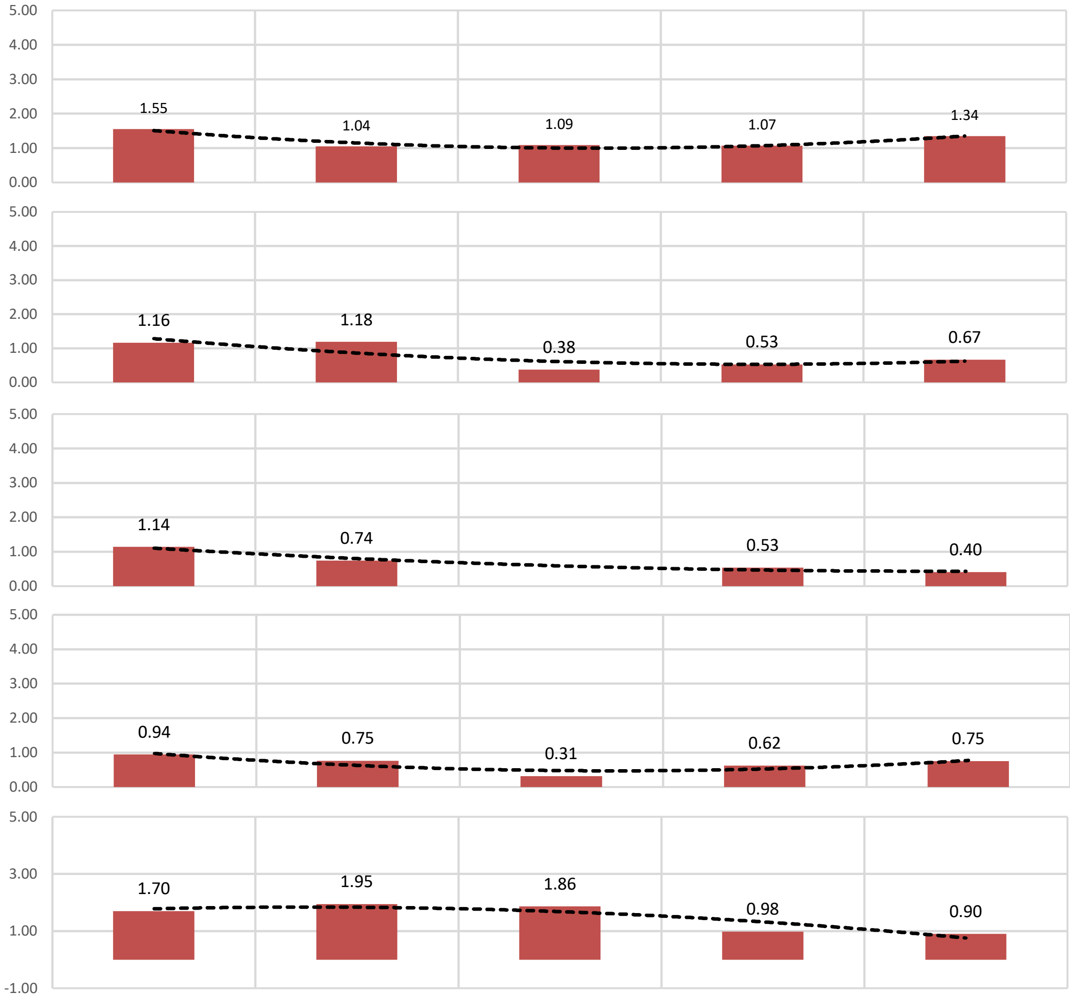
	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00
100%	231.84	-20.94	1.55	227.69	-22.35	1.04	255.84	-12.75	1.09	239.78	-18.22	1.07	268.16	-8.55	1.34
75%	223.82	-20.61	0.91	220.15	-21.86	0.68	247.87	-12.41	1.03	232.15	-17.76	1.17	259.47	-8.45	1.41
50%	84.46	-7.08	1.80	81.21	-8.19	1.55	92.75	-4.25	1.24	87.06	-6.19	2.61	96.17	-3.08	4.41
25%	17.74	-0.88	1.66	16.08	-1.45	1.33	18.08	-0.76	0.81	16.82	-1.19	2.18	18.76	-0.53	4.06
100%	243.93	-16.82	1.16	272.40	-7.10	1.18	274.29	-6.46	0.38	269.83	-7.98	0.53	262.46	-10.50	0.67
75%	235.69	-16.56	0.50	263.29	-7.15	0.66	265.75	-6.31	0.20	261.29	-7.84	0.58	254.13	-10.28	0.69
50%	89.30	-5.43	1.51	95.81	-3.21	1.82	98.38	-2.33	0.62	97.06	-2.78	2.27	94.87	-3.53	3.45
25%	18.81	-0.52	1.65	18.48	-0.55	1.59	18.88	-0.49	0.64	18.44	-0.64	2.02	18.56	-0.60	3.18
100%	261.03	-10.99	1.14	272.88	-6.95	0.74	**293.26**			270.18	-7.86	0.53	263.53	-10.13	0.40
75%	252.35	-10.89	0.58	264.19	-6.85	0.23	**284.28**			261.72	-7.69	0.42	255.25	-9.89	0.37
50%	95.82	-3.21	1.30	97.24	-2.72	1.17	**105.23**			97.60	-2.60	0.74	95.97	-3.15	1.85
25%	19.91	-0.14	1.49	18.95	-0.47	1.32	**20.32**			18.67	-0.56	0.74	18.82	-0.51	1.79
100%	244.67	-16.57	0.94	269.23	-8.19	0.75	273.26	-6.82	0.31	269.05	-8.25	0.62	263.80	-10.03	0.75
75%	236.89	-16.15	0.53	261.03	-7.93	0.27	265.19	-6.50	-0.13	260.94	-7.95	0.53	255.52	-9.79	0.57
50%	90.62	-4.98	1.61	96.18	-3.08	1.45	99.35	-2.00	0.31	98.36	-2.33	1.08	96.87	-2.85	1.62
25%	18.51	-0.62	1.54	18.28	-0.70	1.22	18.91	-0.48	0.46	18.90	-0.49	0.95	19.11	-0.41	1.60
100%	237.64	-18.96	1.70	222.34	-24.18	1.95	254.79	-13.11	1.86	236.78	-19.25	0.98	264.35	-9.85	0.90
75%	230.92	-18.19	1.13	216.18	-23.22	1.37	247.98	-12.37	1.41	230.05	-18.48	0.53	256.20	-9.57	0.88
50%	90.86	-4.90	1.97	82.68	-7.69	2.32	96.51	-2.97	2.15	89.77	-5.27	1.13	98.80	-2.19	2.28
25%	18.65	-0.57	1.57	16.02	-1.47	1.84	18.83	-0.51	1.34	17.75	-0.88	0.43	19.83	-0.17	1.29

1.2.3 - Display uniformity - Visualization of the mean luminance differences (%) in the 5 x 5 matrix



3| 3 Display performance data / Uncalibrated with maximum device settings

1.2.4 - Display uniformity - Visualization of the mean chromaticity difference ΔC^*_{00}



3| 3 Display performance data / Calibrated and profiled (Display3_MD1_sRGB_80_V1.icm)

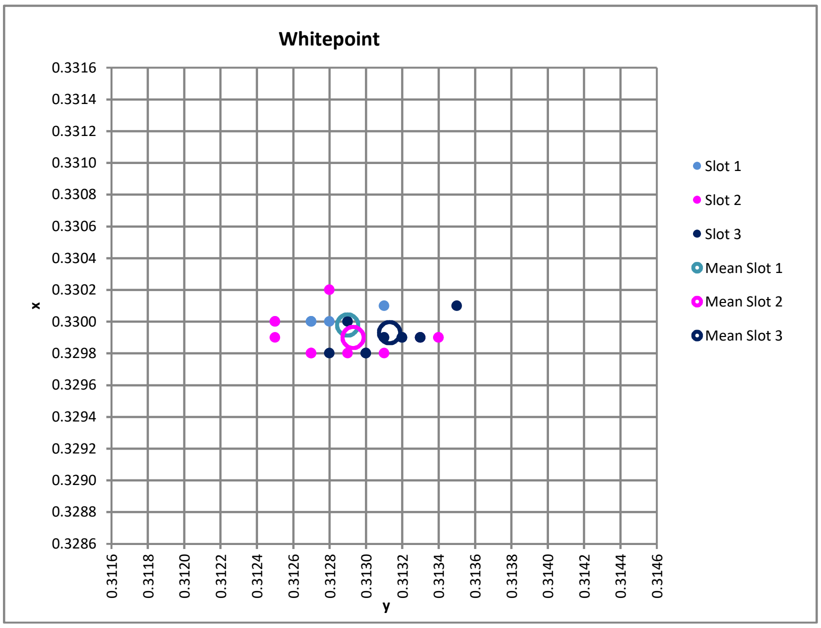
1.3 - Performance data (test period of 5 days)

		White Lum. (cd/m^2)	Black Lum. (cd/m^2)	CCT (K)	Whitepoint X	Whitepoint Y	Whitepoint Z	Whitepoint x	Whitepoint y
Day 1	Slot 1	79.90	0.0373	6505	94.71	100.00	108.33	0.3125	0.3300
		80.00	0.0374	6495	94.78	100.00	108.29	0.3127	0.3300
	Slot 2	79.90	0.0370	6476	94.95	100.00	108.30	0.3131	0.3298
		79.70	0.0369	6460	94.99	100.00	108.12	0.3134	0.3299
	Slot 3	79.70	0.0369	6470	94.92	100.00	108.16	0.3132	0.3299
		79.90	0.0369	6467	94.95	100.00	108.16	0.3133	0.3299
Day 2	Slot 1	80.00	0.0376	6474	94.91	100.00	108.20	0.3131	0.3299
		79.70	0.0375	6470	94.92	100.00	108.16	0.3132	0.3299
	Slot 2	79.90	0.0373	6505	94.71	100.00	108.33	0.3125	0.3300
		79.70	0.0373	6489	94.74	100.00	108.14	0.3128	0.3302
	Slot 3	79.70	0.0372	6470	94.92	100.00	108.16	0.3132	0.3299
		79.50	0.0370	6454	94.96	100.00	107.98	0.3135	0.3301
Day 3	Slot 1	79.80	0.0375	6488	94.82	100.00	108.24	0.3129	0.3300
		80.00	0.0375	6495	94.78	100.00	108.29	0.3127	0.3300
	Slot 2	79.90	0.0371	6496	94.82	100.00	108.39	0.3127	0.3298
		79.70	0.0370	6510	94.73	100.00	108.43	0.3125	0.3299
	Slot 3	79.50	0.0371	6492	94.83	100.00	108.35	0.3128	0.3298
		79.60	0.0370	6482	94.90	100.00	108.30	0.3130	0.3298
Day 4	Slot 1	79.60	0.0370	6491	94.79	100.00	108.24	0.3128	0.3300
		79.80	0.0378	6498	94.75	100.00	108.29	0.3127	0.3300
	Slot 2	79.70	0.0379	6489	94.86	100.00	108.34	0.3129	0.3298
		79.90	0.0378	6496	94.82	100.00	108.39	0.3127	0.3298
	Slot 3	79.80	0.0379	6488	94.82	100.00	108.24	0.3129	0.3300
		79.60	0.0377	6482	94.90	100.00	108.30	0.3130	0.3298
Day 5	Slot 1	80.00	0.0379	6464	94.98	100.00	108.16	0.3133	0.3299
		80.10	0.0379	6473	94.87	100.00	108.10	0.3131	0.3301
	Slot 2	79.90	0.0378	6467	94.95	100.00	108.16	0.3133	0.3299
		79.90	0.0379	6457	95.02	100.00	108.12	0.3134	0.3299
	Slot 3	79.90	0.0378	6467	94.95	100.00	108.16	0.3133	0.3299
		80.00	0.0378	6474	94.91	100.00	108.20	0.3131	0.3299

Mean	79.8	0.0374	6481	94.87	100.00	108.23	0.3130	0.3299
Min	79.5	0.0369	6454	94.71	100.00	107.98	0.3125	0.3298
Max	80.1	0.0379	6510	95.02	100.00	108.43	0.3135	0.3302
SD	0.1578	0.0004	15	0.0877	0.0000	0.1018	0.0003	0.0001

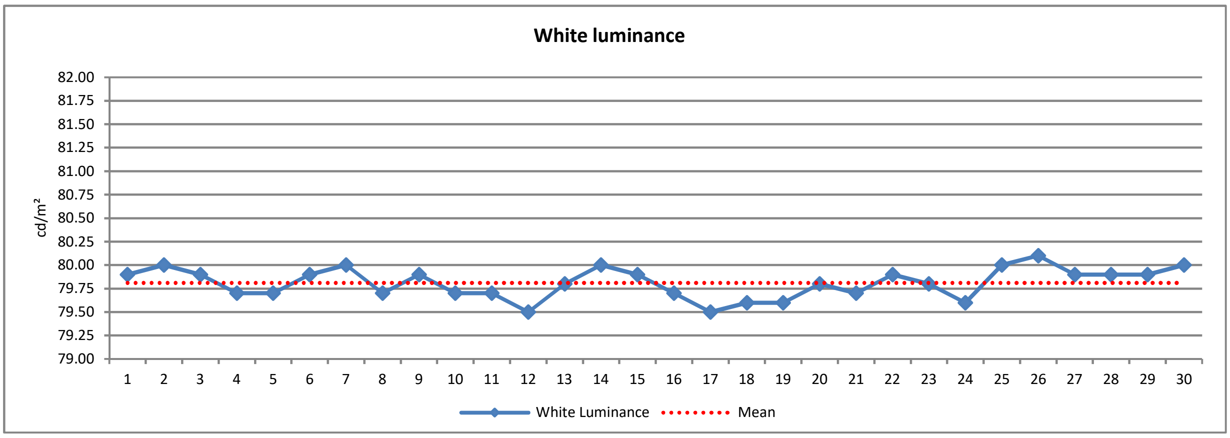
		White Lum. (cd/m^2)	Black Lum. (cd/m^2)	CCT (K)	Whitepoint X	Whitepoint Y	Whitepoint Z	Whitepoint x	Whitepoint y
Slot 1	Mean	79.89	0.0375	6485	94.83	100.00	108.23	0.3129	0.3300
	Min	79.60	0.0370	6464	94.71	100.00	108.10	0.3125	0.3299
	Max	80.10	0.0379	6505	94.98	100.00	108.33	0.3133	0.3301
	SD	0.1513	0.0003	13	0.0813	0.0000	0.0697	0.0002	0.0001
Slot 2	Mean	79.82	0.0374	6485	94.86	100.00	108.27	0.3129	0.3299
	Min	79.70	0.0369	6457	94.71	100.00	108.12	0.3125	0.3298
	Max	79.90	0.0379	6510	95.02	100.00	108.43	0.3134	0.3302
	SD	0.0980	0.0004	18	0.1076	0.0000	0.1174	0.0003	0.0001
Slot 3	Mean	79.72	0.0373	6475	94.91	100.00	108.20	0.3131	0.3299
	Min	79.50	0.0369	6454	94.82	100.00	107.98	0.3128	0.3298
	Max	80.00	0.0379	6492	94.96	100.00	108.35	0.3135	0.3302
	SD	0.1661	0.0004	11	0.0452	0.0000	0.0994	0.0002	0.0001
Day 1	Mean	79.85	0.0371	6479	94.88	100.00	108.23	0.3130	0.3299
	Min	79.70	0.0369	6460	94.71	100.00	108.12	0.3125	0.3298
	Max	80.00	0.0374	6505	94.99	100.00	108.33	0.3134	0.3300
	SD	0.1118	0.0002	16	0.1019	0.0000	0.0820	0.0003	0.0001
Day 2	Mean	79.75	0.0373	6477	94.86	100.00	108.16	0.3131	0.3300
	Min	79.50	0.0370	6454	94.71	100.00	107.98	0.3125	0.3299
	Max	80.00	0.0376	6505	94.96	100.00	108.33	0.3135	0.3302
	SD	0.1607	0.0002	16	0.0971	0.0000	0.1027	0.0003	0.0001
Day 3	Mean	79.75	0.0372	6494	94.81	100.00	108.33	0.3128	0.3299
	Min	79.50	0.0370	6482	94.73	100.00	108.24	0.3125	0.3298
	Max	80.00	0.0375	6510	94.90	100.00	108.43	0.3130	0.3300
	SD	0.1708	0.0002	9	0.0515	0.0000	0.0639	0.0002	0.0001
Day 4	Mean	79.73	0.0377	6491	94.82	100.00	108.30	0.3128	0.3299
	Min	79.60	0.0370	6482	94.75	100.00	108.24	0.3127	0.3298
	Max	79.90	0.0379	6498	94.90	100.00	108.39	0.3130	0.3300
	SD	0.1106	0.0003	5	0.0478	0.0000	0.0532	0.0001	0.0001
Day 5	Mean	79.97	0.0379	6467	94.95	100.00	108.15	0.3133	0.3299
	Min	79.90	0.0378	6457	94.87	100.00	108.10	0.3131	0.3299
	Max	80.10	0.0379	6474	95.02	100.00	108.20	0.3134	0.3301
	SD	0.0745	0.0001	6	0.0478	0.0000	0.0321	0.0001	0.0001

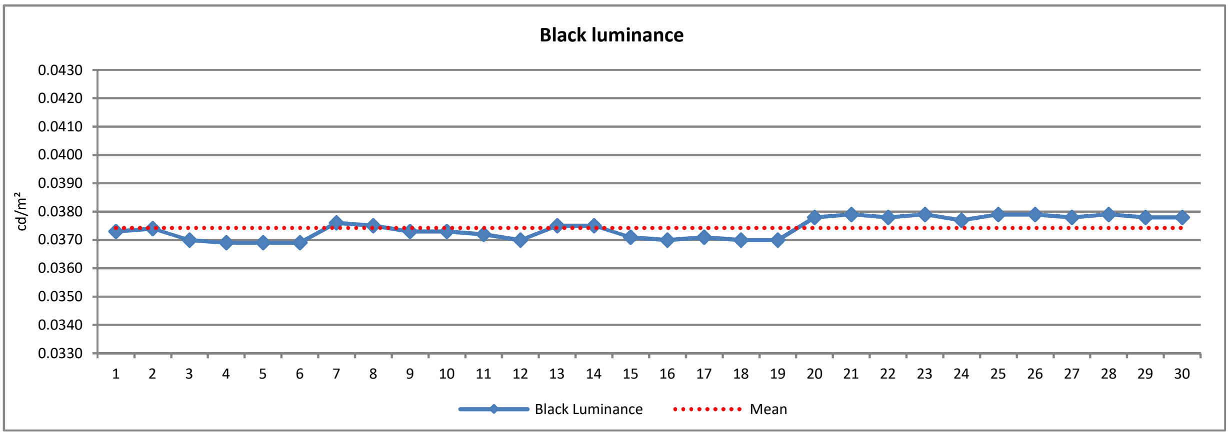
1.4 - Performance data - visualization of the measured whitepoints in the CIE xy chromaticity diagram

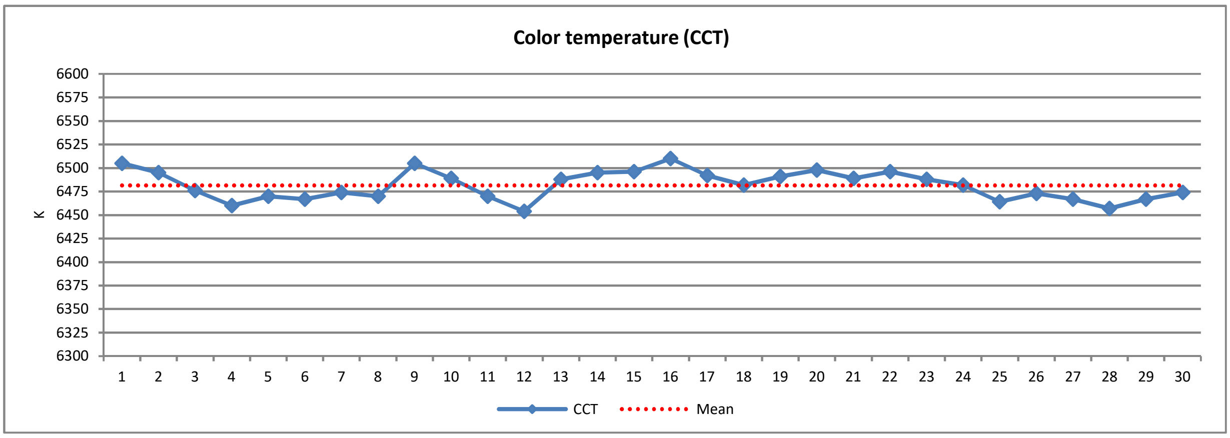


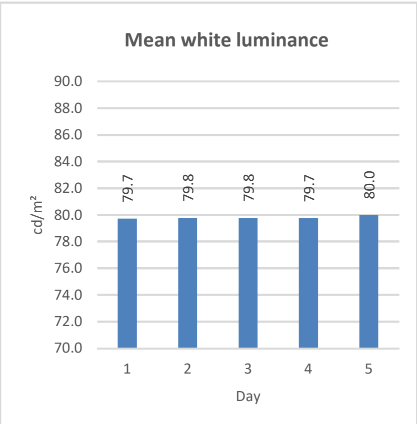
3| 3 Display performance data / Calibrated and profiled (Display3_MD1_sRGB_80_V1.icm)

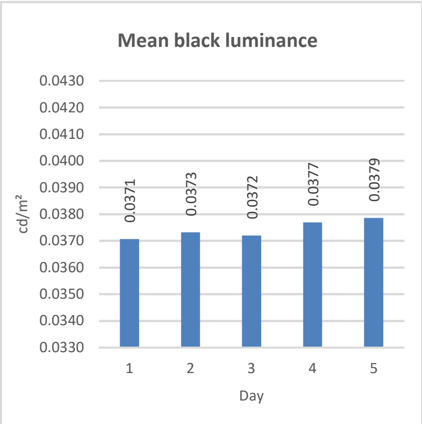
1.5 - Performance data - visualization of the measured values

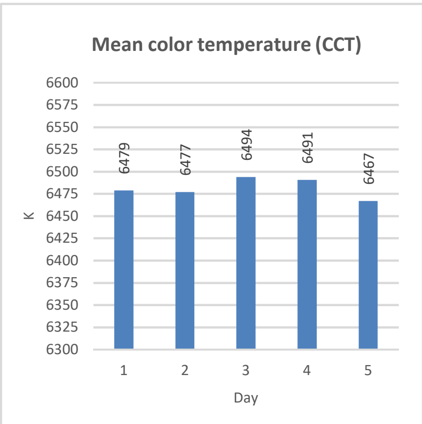






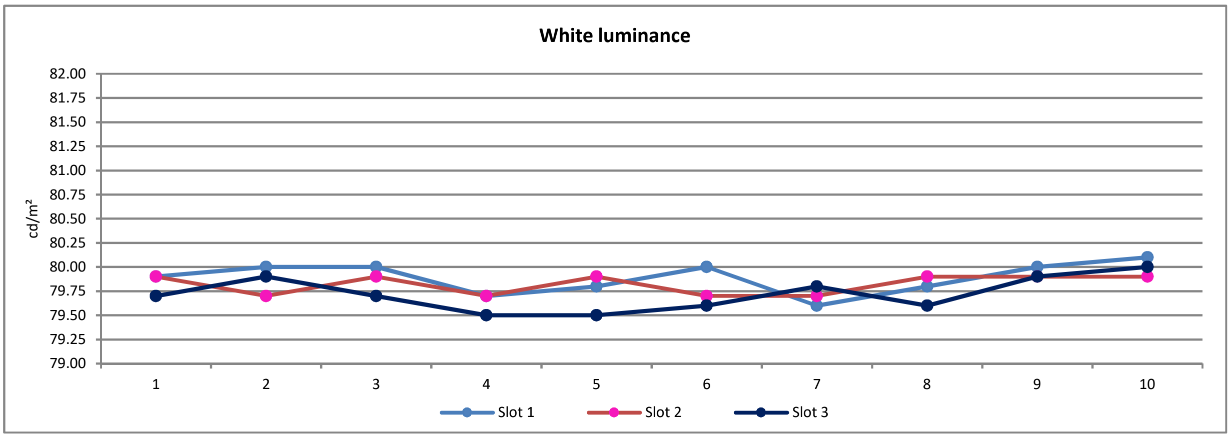


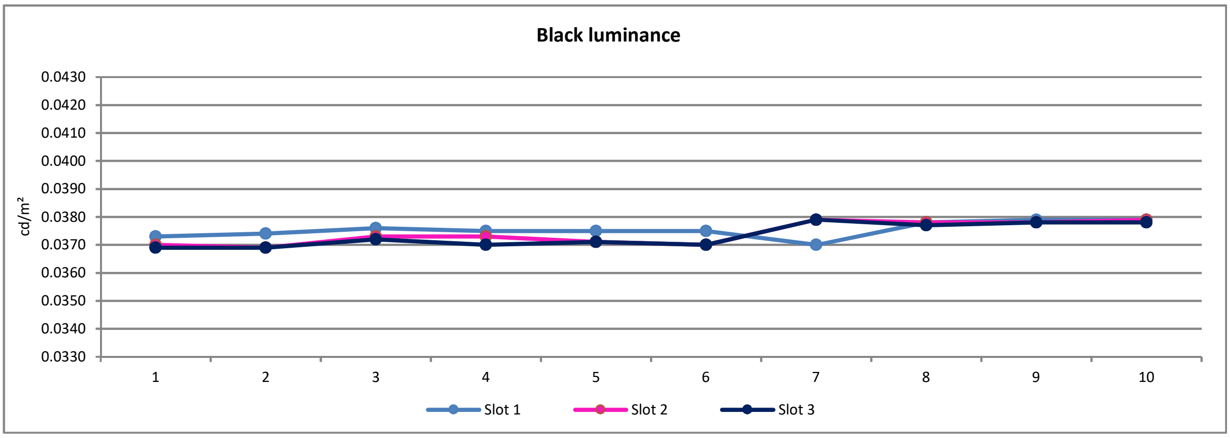


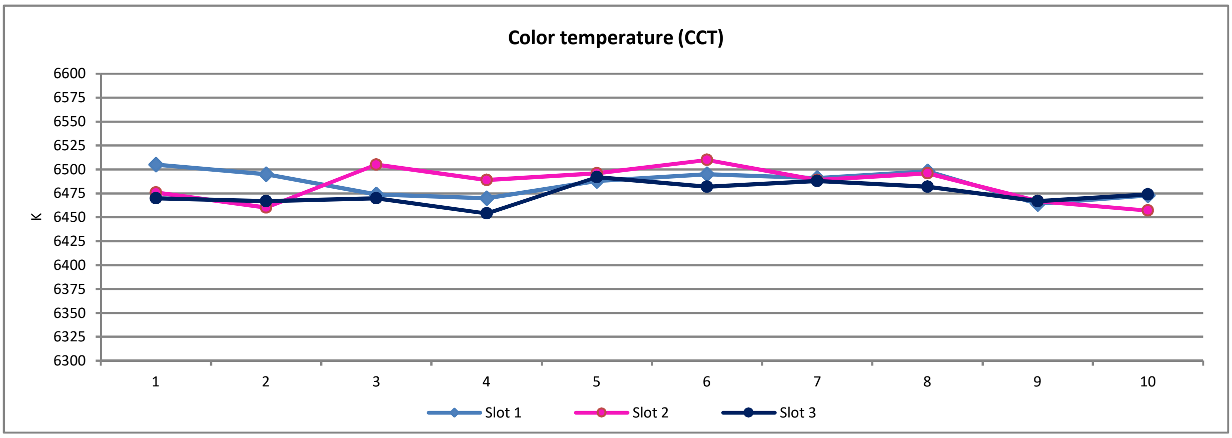


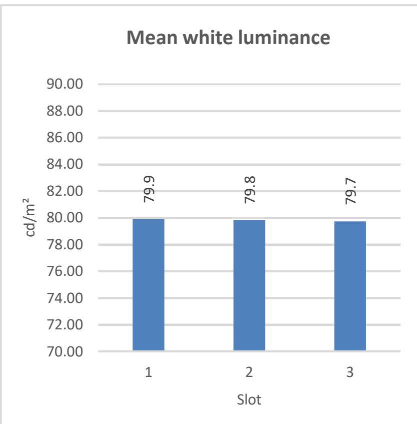
3| 3 Display performance data / Calibrated and profiled (Display3_MD1_sRGB_80_V1.icm)

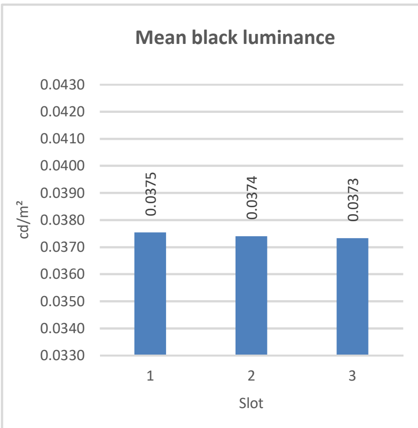
1.5 - Performance data - visualization of the measured values

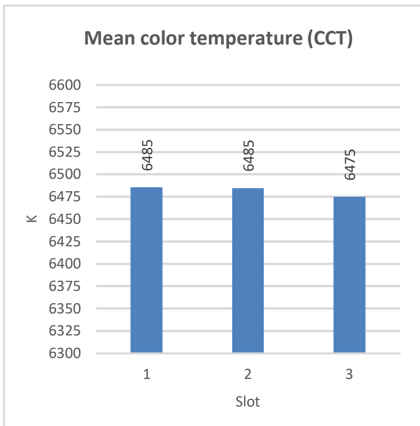












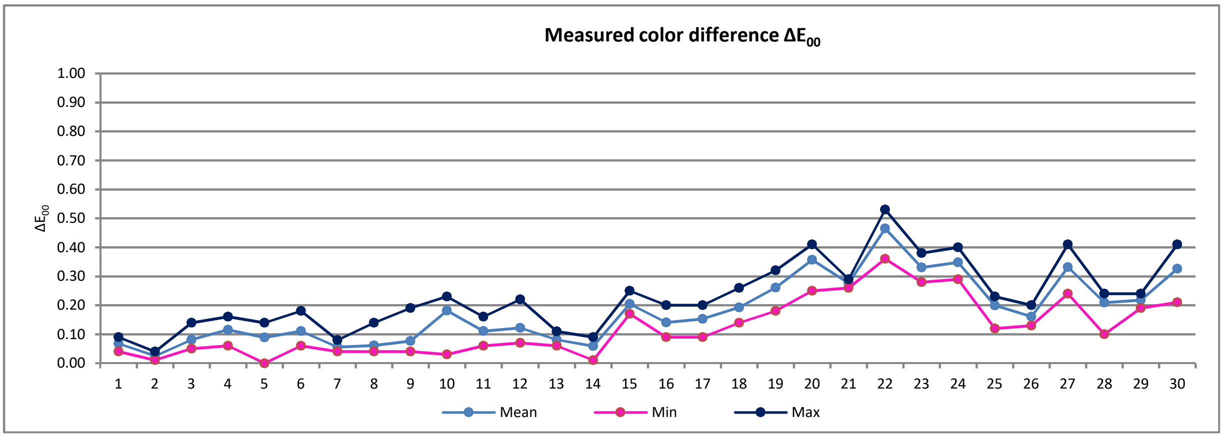
3| 3 Display performance data / Calibrated and profiled (Display3_MD1_sRGB_80_V1.icm)

1.6 - Color accuracy - measured color difference ΔE_{00}

	Device Values			Nominal Values			Day 1		Day 2		Day 3		Day 4		Day 5		ΔE_{00}			
Color	R	G	B	L*	a*	b*	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	Mean	Min	Max	SD
1	128	0	0	26.83	58.12	41.99	0.06	0.04	0.07	0.05	0.08	0.06	0.09	0.08	0.07	0.08	0.07	0.04	0.09	0.0147
2	255	0	0	55.30	98.02	86.98	0.04	0.02	0.04	0.01	0.01	0.02	0.03	0.02	0.03	0.03	0.03	0.01	0.04	0.0102
3	255	128	128	69.41	61.31	25.85	0.08	0.08	0.08	0.05	0.07	0.05	0.14	0.06	0.09	0.11	0.08	0.05	0.14	0.0262
4	0	128	0	45.33	-66.34	54.56	0.10	0.09	0.11	0.10	0.16	0.06	0.12	0.15	0.11	0.15	0.12	0.06	0.16	0.0294
5	0	255	0	87.37	-110.14	95.32	0.05	0.00	0.05	0.06	0.11	0.10	0.14	0.14	0.12	0.12	0.09	0.00	0.14	0.0441
6	128	255	128	90.45	-73.75	53.57	0.14	0.09	0.06	0.06	0.08	0.10	0.18	0.14	0.13	0.13	0.11	0.06	0.18	0.0373
7	0	0	128	9.15	51.42	-71.36	0.05	0.05	0.05	0.04	0.07	0.05	0.06	0.04	0.08	0.07	0.06	0.04	0.08	0.0128
8	0	0	255	26.70	84.32	-119.74	0.06	0.04	0.06	0.04	0.05	0.04	0.06	0.04	0.08	0.14	0.06	0.04	0.14	0.0291
9	128	128	255	57.78	30.95	-68.13	0.05	0.19	0.05	0.05	0.07	0.04	0.07	0.07	0.09	0.09	0.08	0.04	0.19	0.0410
10	0	128	128	47.14	-43.04	-9.74	0.23	0.19	0.20	0.03	0.17	0.18	0.17	0.21	0.21	0.22	0.18	0.03	0.23	0.0539
11	0	255	255	89.86	-70.61	-16.27	0.14	0.06	0.10	0.11	0.12	0.09	0.11	0.16	0.09	0.13	0.11	0.06	0.16	0.0270
12	170	255	255	94.26	-35.40	-9.37	0.09	0.12	0.11	0.07	0.09	0.22	0.14	0.12	0.12	0.14	0.12	0.07	0.22	0.0389
13	128	0	128	29.67	68.49	-37.08	0.08	0.07	0.09	0.07	0.09	0.06	0.08	0.09	0.07	0.11	0.08	0.06	0.11	0.0137
14	255	0	255	60.10	113.74	-63.26	0.06	0.01	0.07	0.05	0.07	0.03	0.09	0.07	0.07	0.07	0.06	0.01	0.09	0.0221
15	255	170	255	80.35	51.33	-30.81	0.21	0.17	0.21	0.17	0.21	0.19	0.25	0.21	0.23	0.20	0.21	0.17	0.25	0.0233
16	128	128	0	51.87	-11.15	63.77	0.13	0.09	0.13	0.11	0.16	0.12	0.16	0.16	0.15	0.20	0.14	0.09	0.20	0.0298
17	255	255	0	97.75	-18.94	111.41	0.16	0.09	0.17	0.16	0.18	0.11	0.13	0.18	0.20	0.15	0.15	0.09	0.20	0.0323
18	255	255	170	98.65	-10.78	44.37	0.17	0.18	0.21	0.17	0.24	0.14	0.16	0.19	0.26	0.21	0.19	0.14	0.26	0.0352
19	170	85	85	47.66	43.78	18.40	0.20	0.25	0.18	0.32	0.32	0.27	0.30	0.31	0.18	0.28	0.26	0.18	0.32	0.0532
20	85	170	85	62.46	-53.48	37.81	0.29	0.32	0.36	0.25	0.41	0.33	0.40	0.40	0.40	0.41	0.36	0.25	0.41	0.0540
21	85	85	170	39.21	22.02	-48.14	0.28	0.28	0.28	0.28	0.26	0.28	0.26	0.26	0.29	0.29	0.28	0.26	0.29	0.0111
22	85	170	170	63.77	-36.46	-8.82	0.51	0.46	0.46	0.36	0.46	0.49	0.44	0.44	0.53	0.50	0.47	0.36	0.53	0.0452
23	170	85	170	49.52	54.27	-30.84	0.38	0.29	0.34	0.32	0.34	0.28	0.35	0.34	0.33	0.33	0.33	0.28	0.38	0.0272
24	170	170	85	68.20	-10.75	46.82	0.37	0.31	0.35	0.29	0.37	0.33	0.38	0.40	0.32	0.36	0.35	0.29	0.40	0.0328
25	255	0	170	57.17	105.18	-17.24	0.22	0.12	0.22	0.20	0.22	0.19	0.21	0.22	0.16	0.23	0.20	0.12	0.23	0.0327
26	170	255	0	91.89	-63.23	101.91	0.14	0.17	0.14	0.15	0.13	0.20	0.18	0.19	0.15	0.15	0.16	0.13	0.20	0.0224
27	0	170	255	64.44	-22.10	-57.25	0.28	0.24	0.28	0.27	0.41	0.29	0.40	0.41	0.37	0.37	0.33	0.24	0.41	0.0626
28	0	255	170	88.34	-92.42	28.57	0.23	0.22	0.24	0.10	0.21	0.20	0.21	0.21	0.23	0.24	0.21	0.10	0.24	0.0386
29	170	0	255	44.79	96.92	-89.06	0.21	0.19	0.22	0.19	0.23	0.21	0.24	0.23	0.23	0.23	0.22	0.19	0.24	0.0166
30	255	170	0	77.05	32.49	94.69	0.34	0.21	0.25	0.30	0.37	0.32	0.34	0.37	0.35	0.41	0.33	0.21	0.41	0.0564

	Mean	Min	Max	SD
Mean	0.18	0.12	0.23	0.0325

1.6.1 - Color accuracy - visualization of the measured color difference ΔE_{00}

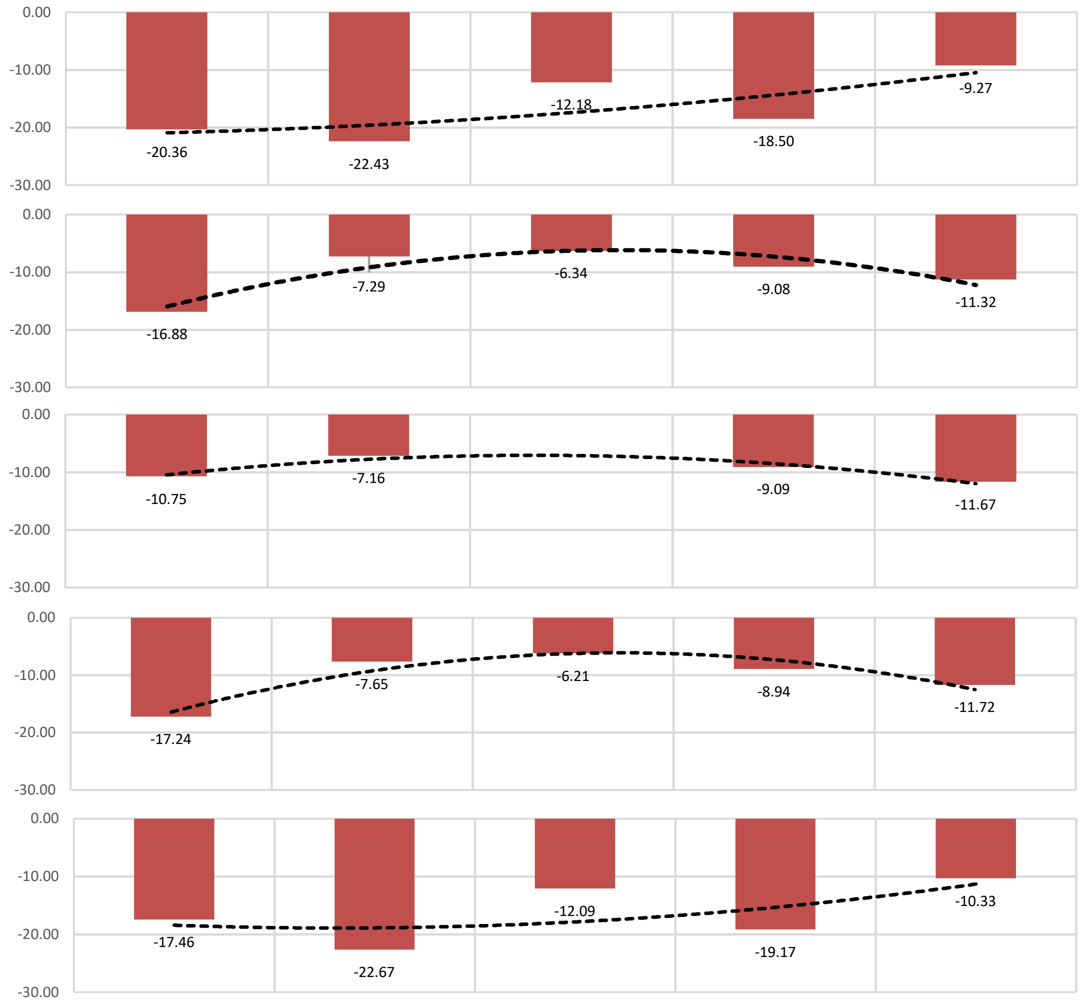


3| 3 Display performance data / Calibrated and profiled (Display3_MD1_sRGB_80_V1.icm)

1.7 - Display uniformity - measured values (5x5 matrix)

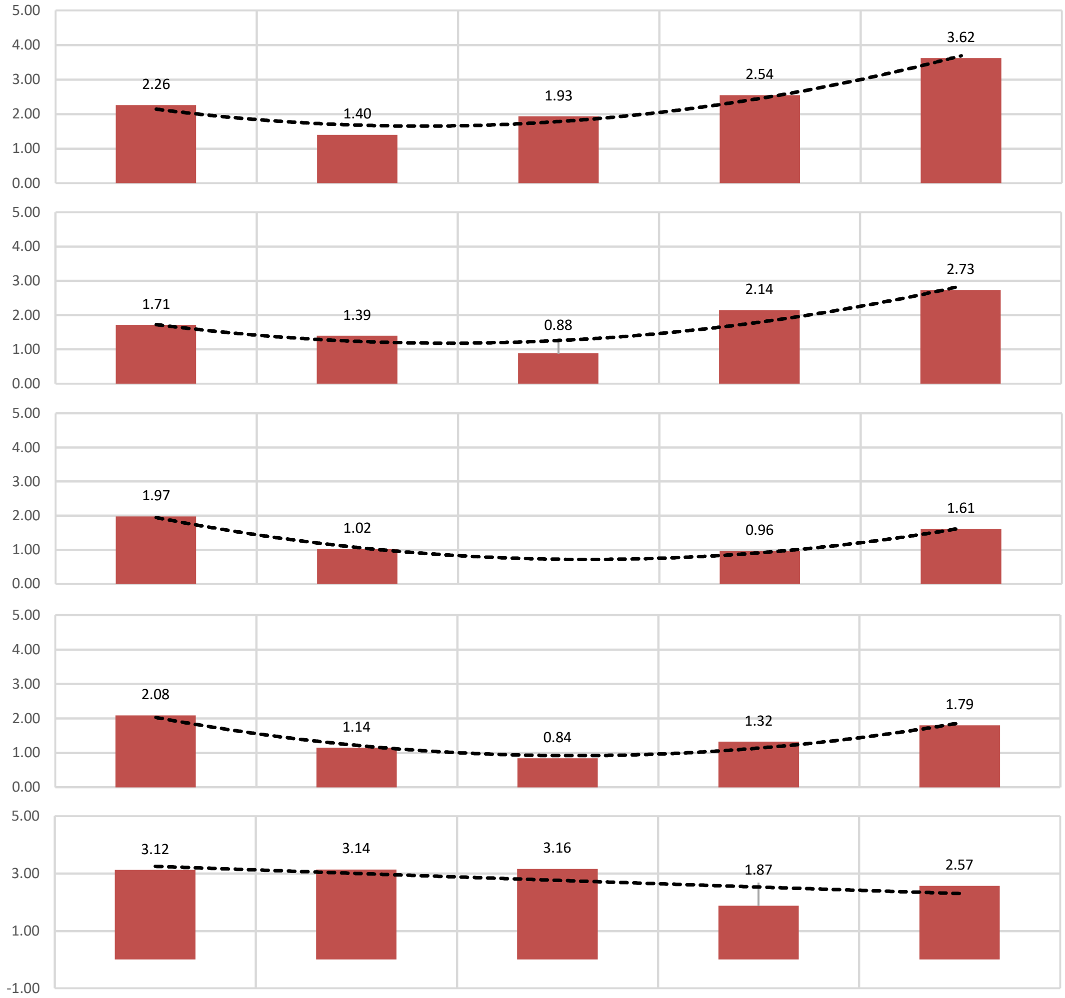
	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00
100%	63.56	-20.36	2.26	61.91	-22.43	1.40	70.10	-12.18	1.93	65.05	-18.50	2.54	72.42	-9.27	3.62
75%	33.41	-9.90	-0.57	32.00	-11.67	-0.44	36.51	-6.02	0.01	33.90	-9.29	1.07	37.41	-4.89	2.25
50%	14.27	-3.51	0.17	13.47	-4.51	0.02	15.32	-2.19	0.55	14.20	-3.59	1.05	15.67	-1.75	2.99
25%	3.47	-0.60	1.43	3.19	-0.94	1.01	3.55	-0.50	0.54	3.32	-0.79	2.13	3.73	-0.27	3.75
100%	66.34	-16.88	1.71	74.00	-7.29	1.39	74.75	-6.34	0.88	72.56	-9.08	2.14	70.78	-11.32	2.73
75%	34.86	-8.09	-1.02	37.80	-4.41	-0.68	38.67	-3.31	-0.42	37.75	-4.46	0.40	36.89	-5.54	1.26
50%	14.93	-2.68	-0.07	15.56	-1.88	0.50	16.00	-1.34	-0.36	15.71	-1.70	0.55	15.46	-2.02	1.87
25%	3.59	-0.45	1.37	3.56	-0.48	1.49	3.66	-0.36	0.62	3.62	-0.41	1.56	3.67	-0.35	3.14
100%	71.23	-10.75	1.97	74.10	-7.16	1.02	**79.82**			72.56	-9.09	0.96	70.50	-11.67	1.61
75%	37.48	-4.81	-0.71	38.05	-4.09	-1.14	**41.31**			37.75	-4.47	-0.46	36.80	-5.66	0.22
50%	15.89	-1.47	-0.06	15.67	-1.76	0.63	**17.07**			15.77	-1.63	0.57	15.47	-2.01	0.87
25%	3.80	-0.19	1.04	3.60	-0.44	1.45	**3.95**			3.65	-0.37	0.84	3.69	-0.33	1.83
100%	66.06	-17.24	2.08	73.71	-7.65	1.14	74.86	-6.21	0.84	72.68	-8.94	1.32	70.46	-11.72	1.79
75%	35.05	-7.85	0.06	37.87	-4.31	-0.88	38.96	-2.95	-0.68	38.08	-4.05	-0.26	37.06	-5.34	0.11
50%	14.92	-2.69	0.70	15.58	-1.87	-0.21	16.22	-1.06	-0.31	15.98	-1.36	0.19	15.72	-1.69	0.38
25%	3.58	-0.46	1.22	3.52	-0.54	1.44	3.71	-0.30	0.39	3.72	-0.29	0.82	3.74	-0.26	1.55
100%	65.88	-17.46	3.12	61.72	-22.67	3.14	70.16	-12.09	3.16	64.51	-19.17	1.87	71.57	-10.33	2.57
75%	35.14	-7.74	0.69	32.29	-11.30	0.77	37.24	-5.11	0.64	34.44	-8.61	0.00	37.94	-4.23	0.70
50%	15.10	-2.47	1.48	13.46	-4.52	1.33	15.79	-1.61	0.85	14.66	-3.01	0.17	16.18	-1.12	0.91
25%	3.69	-0.33	1.73	3.10	-1.06	2.25	3.71	-0.30	1.34	3.51	-0.54	0.34	3.92	-0.03	1.06

1.7.1 - Display uniformity - Visualization of the luminance difference (%)



3| 3 Display performance data / Calibrated and profiled (Display3_MD1_sRGB_80_V1.icm)

1.7.2 - Display uniformity - Visualization of the chromaticity difference ΔC^*_{00}

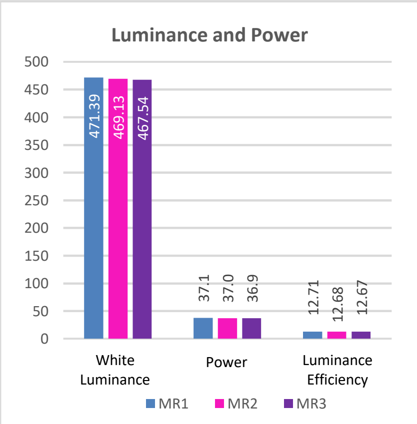


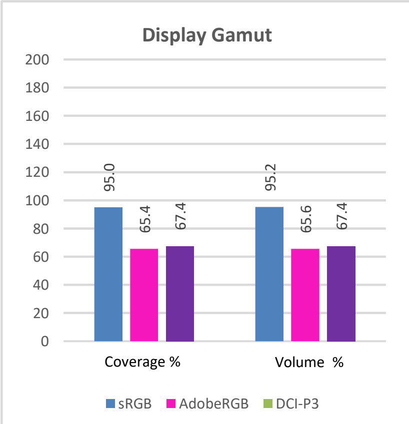
3| 4 Display performance data / Uncalibrated with maximum device settings

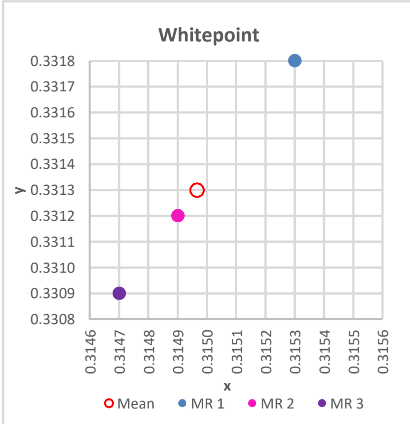
1.1 - Display performance data

	White Lum. (cd/m²)	Power (W)	Lum. Eff. (cd/W)	Black Lum. (cd/m²)	Whitepoint (CIE_xy)		Display Gamut					
							sRGB		AdobeRGB		DCI-P3	
					x	y	Cov. (%)	Vol. (%)	Cov. (%)	Vol. (%)	Cov. (%)	Vol. (%)
MR 1	471.39	37.1	12.71	0.4776	0.3153	0.3318	95.1	95.2	65.5	65.6	67.5	67.5
MR 2	469.13	37.0	12.68	0.4729	0.3149	0.3312	95.0	95.3	65.5	65.6	67.5	67.5
MR 3	467.54	36.9	12.67	0.4744	0.3147	0.3309	94.8	95.1	65.3	65.5	67.3	67.3

Mean	469.35	37.0	12.69	0.4750	0.3150	0.3313	95.0	95.2	65.4	65.6	67.4	67.4
Min	471.39	37.1	12.71	0.4776	0.3153	0.3318	95.1	95.3	65.5	65.6	67.5	67.5
Max	467.54	36.9	12.67	0.4729	0.3147	0.3309	94.8	95.1	65.3	65.5	67.3	67.3
SD	1.5797	0.0816	0.0151	0.3296	94.9300	0.0004	0.1247	0.0816	0.0943	0.0471	0.0943	0.0943

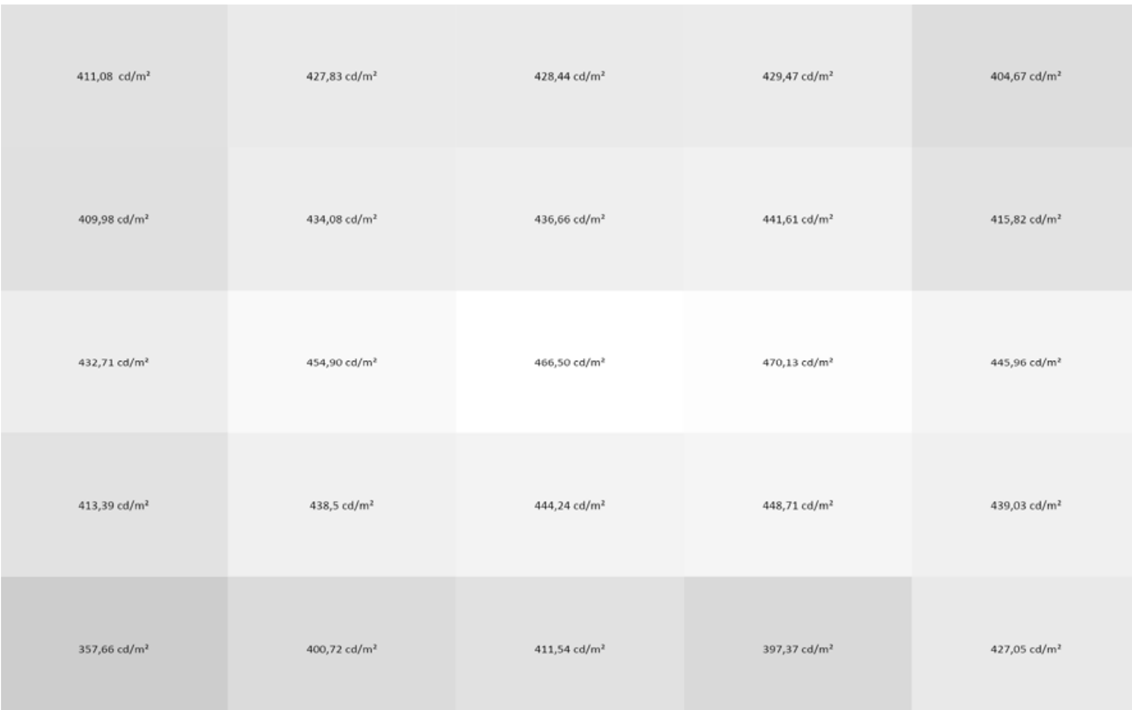






1.2 - Display uniformity - Visualization of the mean values in the 5x5 matrix

	Lum. cd/m²	Delta %	Lum. cd/m²	Delta %	Lum. cd/m²	Delta %	Lum. cd/m²	Delta %	Lum. cd/m²	Delta %
100%	411.08	-11.88	427.83	-8.29	428.44	-8.16	429.47	-7.94	404.67	-13.25
100%	409.98	-12.12	434.08	-6.95	436.66	-6.40	441.61	-5.34	415.82	-10.86
100%	432.71	-7.24	454.90	-2.49	466.50	0.00	470.13	0.78	445.96	-4.41
100%	413.39	-11.39	438.50	-6.00	444.24	-4.77	448.71	-3.81	439.03	-5.89
100%	375.66	-19.47	400.72	-14.10	411.54	-11.78	397.37	-14.82	427.05	-8.46



3| 4 Display performance data / Uncalibrated with maximum device settings

1.2.1 - Display uniformity - Measured values from three control measurements (5x5 matrix)

	Lum. cd/m²	Delta %	ΔC^*_{00}	Lum. cd/m²	Delta %	ΔC^*_{00}	Lum. cd/m²	Delta %	ΔC^*_{00}	Lum. cd/m²	Delta %	ΔC^*_{00}	Lum. cd/m²	Delta %	ΔC^*_{00}
100%	413.39	-11.73	2.00	430.22	-8.14	0.86	430.64	-8.05	1.10	429.94	-8.20	1.29	406.68	-13.16	1.21
75%	229.02	-6.01	1.37	231.84	-5.41	0.19	233.01	-5.16	0.57	234.11	-4.93	0.86	220.88	-7.75	0.61
50%	98.92	-1.71	1.18	96.66	-2.19	0.43	95.75	-2.39	0.67	96.15	-2.30	0.83	91.03	-3.40	0.56
25%	22.69	-0.25	0.62	21.74	-0.46	0.24	21.32	-0.55	0.41	21.32	-0.55	0.41	20.32	-0.76	0.29
100%	413.07	-11.80	2.55	436.01	-6.90	0.60	437.14	-6.66	0.86	442.79	-5.45	1.05	416.81	-11.00	1.26
75%	230.64	-5.67	1.68	236.30	-4.46	0.26	238.47	-3.99	0.33	244.03	-2.81	0.72	228.98	-6.02	0.58
50%	100.64	-1.34	1.34	99.32	-1.62	0.40	98.71	-1.75	0.33	101.27	-1.21	0.73	95.26	-2.49	0.50
25%	23.21	-0.14	0.76	22.41	-0.31	0.21	22.01	-0.40	0.23	22.53	-0.29	0.23	21.27	-0.56	0.28
100%	435.94	-6.92	2.45	457.79	-2.25	0.67	**468.33**			472.34	0.86	0.14	448.35	-4.27	1.00
75%	245.20	-2.56	1.96	248.90	-1.77	0.72	**257.18**			261.58	0.94	0.03	248.22	-1.91	0.47
50%	107.91	0.21	1.71	105.13	-0.38	0.73	**106.93**			108.98	0.44	0.30	103.46	-0.74	0.49
25%	25.04	0.25	0.96	23.83	-0.01	0.36	**23.88**			24.33	0.10	0.04	23.10	-0.16	0.12
100%	416.61	-11.04	2.74	442.74	-5.46	0.84	448.13	-4.31	0.75	451.80	-3.53	1.04	442.32	-5.55	1.23
75%	234.89	-4.76	2.30	243.27	-2.97	0.76	247.85	-1.99	0.37	253.01	-0.89	0.42	246.01	-2.38	0.64
50%	103.51	-0.73	1.88	103.22	-0.79	0.69	103.01	-0.84	0.14	105.78	-0.24	0.04	103.03	-0.83	0.42
25%	24.07	0.04	1.10	23.31	-0.12	0.34	22.95	-0.20	0.10	23.51	-0.08	-0.14	23.10	-0.16	0.11
100%	378.32	-19.22	1.67	404.57	-13.61	1.20	414.78	-11.43	2.38	399.61	-14.67	2.91	429.33	-8.33	2.41
75%	217.13	-8.55	1.53	226.49	-6.55	1.15	233.73	-5.01	1.79	226.90	-6.47	1.89	244.76	-2.65	1.72
50%	96.76	-2.17	1.21	97.00	-2.12	0.64	98.00	-1.91	0.82	95.14	-2.52	0.98	103.83	-0.66	1.05
25%	22.57	-0.28	0.67	21.85	-0.43	0.17	21.71	-0.46	0.12	21.05	-0.60	0.19	23.33	-0.12	0.11

100%	410.28	-12.15	2.24	426.85	-8.60	0.89	427.97	-8.36	1.21	428.96	-8.15	1.51	404.10	-13.47	1.31
75%	226.62	-6.35	1.37	229.41	-5.75	0.03	230.55	-5.50	0.42	232.78	-5.03	0.71	218.75	-8.03	0.39
50%	97.39	-1.90	1.34	95.01	-2.41	0.51	94.28	-2.57	0.69	95.13	-2.39	0.86	89.60	-3.57	0.42
25%	22.25	-0.32	0.80	21.27	-0.53	0.43	20.91	-0.61	0.41	21.06	-0.57	0.62	19.88	-0.83	0.33
100%	410.03	-12.21	2.57	432.94	-7.30	0.83	437.70	-6.28	1.10	441.60	-5.45	1.36	416.06	-10.91	1.58
75%	227.84	-6.08	1.52	233.61	-4.85	0.12	238.01	-3.91	0.31	242.57	-2.93	0.72	227.56	-6.14	0.69
50%	98.78	-1.61	1.36	97.57	-1.87	0.51	98.02	-1.77	0.46	100.20	-1.30	0.73	94.16	-2.60	0.63
25%	22.69	-0.22	0.97	21.92	-0.39	0.38	21.83	-0.41	0.99	22.27	-0.31	0.81	21.02	-0.58	0.42
100%	432.50	-7.39	2.63	454.45	-2.69	0.83	**467.03**			469.74	0.58	0.45	445.44	-4.62	1.25
75%	242.10	-3.03	1.91	246.28	-2.14	0.65	**256.25**			259.53	0.70	0.54	245.65	-2.27	0.47
50%	105.91	-0.08	1.77	103.53	-0.59	0.99	**106.28**			107.76	0.32	0.39	101.93	-0.93	0.62
25%	24.45	0.15	1.08	23.39	-0.07	0.56	**23.74**			24.00	0.05	0.19	22.77	-0.21	0.59
100%	412.50	-11.68	2.93	435.88	-6.67	0.96	442.84	-5.18	0.77	447.63	-4.15	0.96	437.69	-6.28	1.31
75%	231.65	-5.27	2.23	238.89	-3.72	0.64	244.53	-2.51	0.27	250.29	-1.28	0.60	242.95	-2.85	0.55
50%	101.50	-1.02	2.00	100.96	-1.14	0.81	101.29	-1.07	0.30	104.29	-0.43	0.52	101.41	-1.04	0.57
25%	23.52	-0.05	1.26	22.77	-0.21	0.67	22.59	-0.25	0.61	23.15	-0.13	0.29	22.70	-0.22	0.65
100%	374.70	-19.77	1.82	399.22	-14.52	1.03	410.03	-12.21	2.30	396.70	-15.06	2.74	426.39	-8.70	2.33
75%	214.36	-8.97	1.44	222.88	-7.15	0.97	230.87	-5.44	1.65	225.06	-6.68	1.72	242.50	-2.94	1.58
50%	95.04	-2.41	1.36	95.14	-2.39	0.60	96.51	-2.09	0.98	94.13	-2.60	1.00	102.62	-0.78	1.23
25%	22.17	-0.34	0.94	21.38	-0.51	0.12	21.35	-0.51	0.24	20.79	-0.63	0.43	23.03	-0.15	0.64

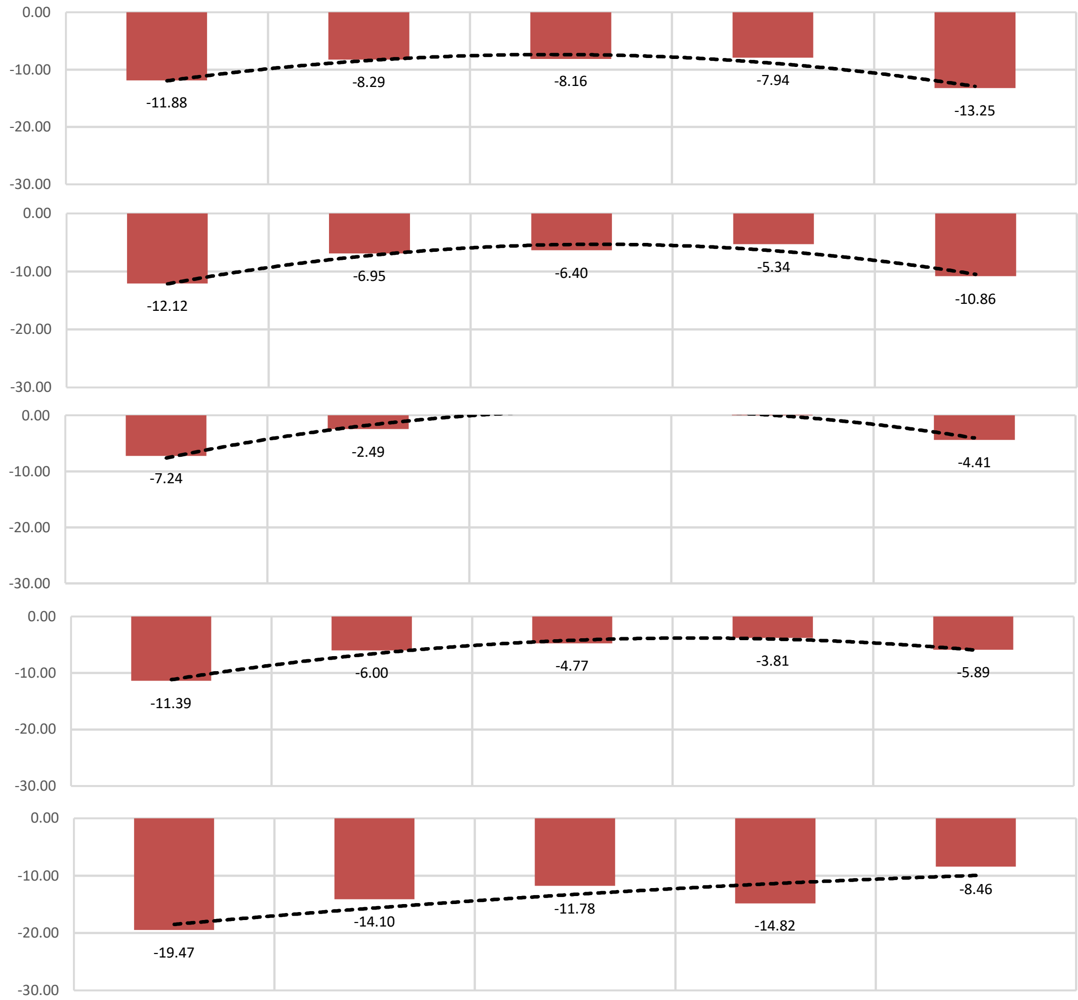
100%	409.56	-11.76	2.02	426.43	-8.13	0.68	426.72	-8.06	1.06	429.50	-7.47	1.31	403.23	-13.13	1.22
75%	226.61	-5.98	1.24	229.40	-5.38	0.03	230.21	-5.21	0.31	233.28	-4.54	0.65	218.18	-7.80	0.36
50%	97.53	-1.67	1.26	95.04	-2.21	0.35	94.03	-2.43	0.52	95.38	-2.13	0.77	89.41	-3.42	0.41
25%	22.29	-0.24	0.72	21.23	-0.47	0.30	20.08	-0.56	0.34	21.14	-0.49	0.60	19.88	-0.76	0.35
100%	406.83	-12.35	2.41	433.30	-6.65	0.63	435.14	-6.25	0.92	440.45	-5.11	1.14	414.58	-10.68	1.31
75%	225.94	-6.13	1.31	233.95	-4.40	0.07	236.67	-3.82	0.15	242.00	-2.67	0.52	226.86	-5.93	0.43
50%	97.98	-1.57	1.23	97.80	-1.61	0.36	97.40	-1.70	0.26	99.91	-1.16	0.64	93.91	-2.45	0.47
25%	22.51	-0.19	0.78	21.97	-0.31	0.23	21.61	-0.39	0.09	22.17	-0.27	0.39	19.88	-0.54	0.31
100%	429.69	-7.42	2.44	452.45	-2.52	0.57	**464.15**			468.31	0.90	0.15	444.08	-4.33	1.10
75%	240.58	-2.97	1.72	245.22	-1.97	0.60	**254.38**			258.77	0.95	-0.13	245.11	-2.00	0.35
50%	105.29	0.00	1.64	103.12	-0.47	0.75	**105.29**			107.45	0.47	0.18	101.74	-0.76	0.55
25%	24.30	0.19	1.02	23.29	-0.03	0.41	**23.41**			23.89	0.10	0.07	22.70	-0.15	0.31
100%	411.06	-11.44	2.64	436.88	-5.88	0.83	441.74	-4.83	0.79	446.71	-3.76	1.01	437.08	-5.83	1.35
75%	230.93	-5.05	1.98	239.44	-3.22	0.64	243.94	-2.25	0.33	249.92	-0.96	0.36	242.65	-2.53	0.57
50%	101.22	-0.88	1.85	101.21	-0.88	0.72	101.14	-0.89	0.34	104.21	-0.23	0.22	101.34	-0.85	0.57
25%	23.45	0.01	1.15	22.88	-0.11	0.49	22.52	-0.19	0.22	23.15	-0.06	-0.08	22.70	-0.15	0.31
100%	373.97	-19.43	1.65	398.38	-14.17	1.08	409.80	-11.71	2.35	395.79	-14.73	2.86	425.43	-8.34	2.53
75%	214.33	-8.63	1.31	222.62	-6.84	1.00	230.64	-5.11	1.68	224.57	-6.42	1.73	242.29	-2.60	1.65
50%	95.19	-2.18	1.24	95.03	-2.21	0.56	96.43	-1.91	1.07	94.01	-2.43	1.14	102.62	-0.57	1.34
25%	22.21	-0.26	0.85	21.38	-0.44	0.10	21.35	-0.44	0.22	20.79	-0.56	0.39	23.08	-0.07	0.34

3| 4 Display performance data / Uncalibrated with maximum device settings

1.2.2 - Display uniformity - Mean measured values (5x5 matrix)

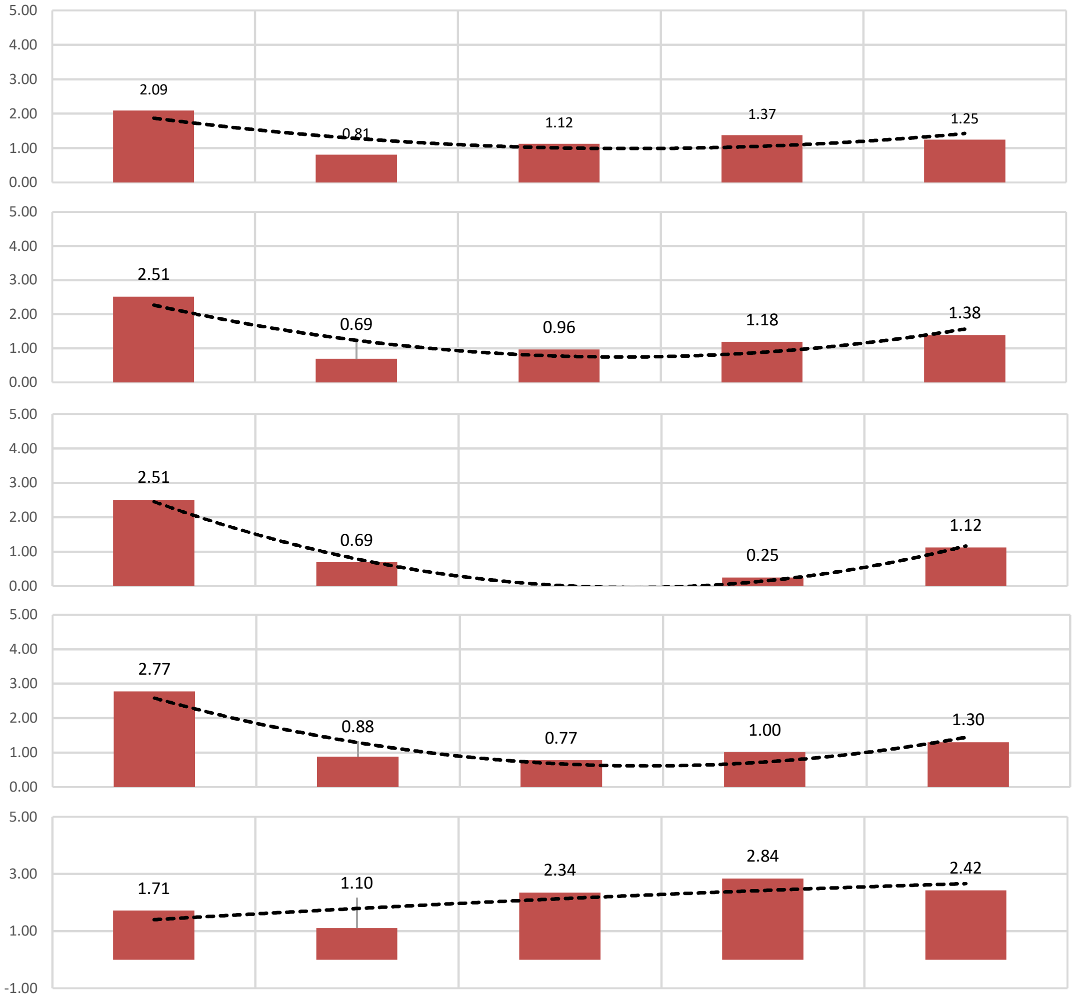
	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00
100%	411.08	-11.88	2.09	427.83	-8.29	0.81	428.44	-8.16	1.12	429.47	-7.94	1.37	404.67	-13.25	1.25
75%	227.42	-6.11	1.33	230.22	-5.51	0.08	231.26	-5.29	0.43	233.39	-4.83	0.74	219.27	-7.86	0.45
50%	97.95	-1.76	1.26	95.57	-2.27	0.43	94.69	-2.46	0.63	95.55	-2.27	0.82	90.01	-3.46	0.46
25%	22.41	-0.27	0.71	21.41	-0.49	0.32	20.77	-0.57	0.39	21.17	-0.54	0.54	20.03	-0.78	0.32
100%	409.98	-12.12	2.51	434.08	-6.95	0.69	436.66	-6.40	0.96	441.61	-5.34	1.18	415.82	-10.86	1.38
75%	228.14	-5.96	1.50	234.62	-4.57	0.15	237.72	-3.91	0.26	242.87	-2.80	0.65	227.80	-6.03	0.57
50%	99.13	-1.51	1.31	98.23	-1.70	0.42	98.04	-1.74	0.35	100.46	-1.22	0.70	94.44	-2.51	0.53
25%	22.80	-0.18	0.84	22.10	-0.34	0.27	21.82	-0.40	0.44	22.32	-0.29	0.48	20.72	-0.56	0.34
100%	432.71	-7.24	2.51	454.90	-2.49	0.69	**466.50**			470.13	0.78	0.25	445.96	-4.41	1.12
75%	242.63	-2.85	1.86	246.80	-1.96	0.66	**255.94**			259.96	0.86	0.15	246.33	-2.06	0.43
50%	106.37	0.04	1.71	103.93	-0.48	0.82	**106.17**			108.06	0.41	0.29	102.38	-0.81	0.55
25%	24.60	0.20	1.02	23.50	-0.04	0.44	**23.68**			24.07	0.08	0.10	22.86	-0.17	0.34
100%	413.39	-11.39	2.77	438.50	-6.00	0.88	444.24	-4.77	0.77	448.71	-3.81	1.00	439.03	-5.89	1.30
75%	232.49	-5.03	2.17	240.53	-3.30	0.68	245.44	-2.25	0.32	251.07	-1.04	0.46	243.87	-2.59	0.59
50%	102.08	-0.88	1.91	101.80	-0.94	0.74	101.81	-0.93	0.26	104.76	-0.30	0.26	101.93	-0.91	0.52
25%	23.68	0.00	1.17	22.99	-0.15	0.50	22.69	-0.21	0.31	23.27	-0.09	0.02	22.83	-0.18	0.36
100%	375.66	-19.47	1.71	400.72	-14.10	1.10	411.54	-11.78	2.34	397.37	-14.82	2.84	427.05	-8.46	2.42
75%	215.27	-8.72	1.43	224.00	-6.85	1.04	231.75	-5.19	1.71	225.51	-6.52	1.78	243.18	-2.73	1.65
50%	95.66	-2.25	1.27	95.72	-2.24	0.60	96.98	-1.97	0.96	94.43	-2.52	1.04	103.02	-0.67	1.21
25%	22.32	-0.29	0.82	21.54	-0.46	0.13	21.47	-0.47	0.19	20.88	-0.60	0.34	23.15	-0.11	0.36

1.2.3 - Display uniformity - Visualization of the mean luminance differences (%) in the 5 x 5 matrix



3| 4 Display performance data / Uncalibrated with maximum device settings

1.2.4 - Display uniformity - Visualization of the mean chromaticity difference ΔC^*_{00}



3| 4 Display performance data / Calibrated and profiled (Display4_MD1_sRGB_80_V1.icm)

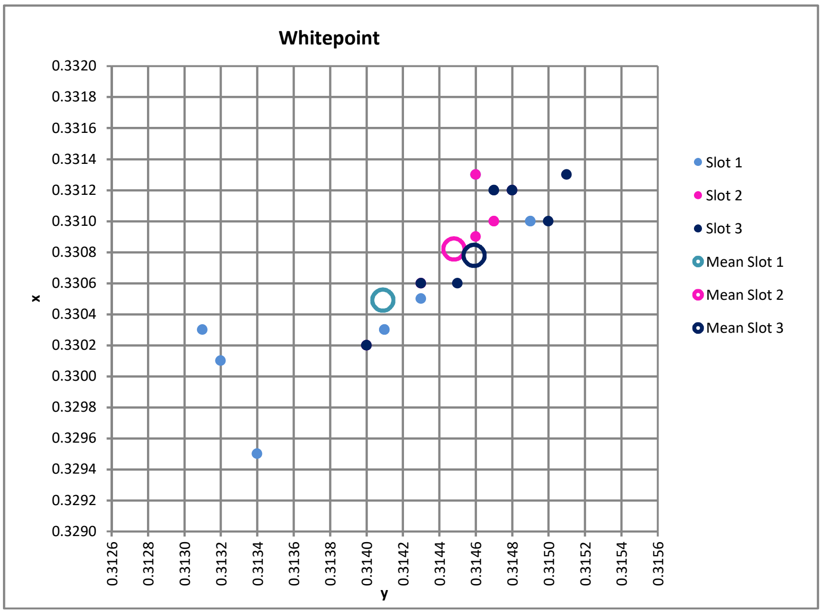
1.3 - Performance data (test period of 5 days)

		White Lum. (cd/m²)	Black Lum. (cd/m²)	CCT (K)	Whitepoint X	Y	Z	x	y
Day 1	Slot 1	81.10	0.1200	6408	95.10	100.00	107.50	0.3143	0.3305
		81.20	0.1200	6407	95.06	100.00	107.40	0.3143	0.3306
	Slot 2	81.20	0.1200	6407	95.06	100.00	107.40	0.3143	0.3306
		81.20	0.1200	6407	95.06	100.00	107.40	0.3143	0.3306
	Slot 3	81.20	0.1201	6407	95.06	100.00	107.40	0.3143	0.3306
		81.30	0.1201	6357	95.11	100.00	106.71	0.3151	0.3313
Day 2	Slot 1	81.50	0.1212	6374	95.12	100.00	106.99	0.3149	0.3310
		81.50	0.1211	6374	95.12	100.00	106.99	0.3149	0.3310
	Slot 2	81.40	0.1211	6384	95.06	100.00	107.03	0.3147	0.3310
		81.60	0.1216	6381	95.08	100.00	107.03	0.3147	0.3310
	Slot 3	81.50	0.1203	6383	95.01	100.00	106.93	0.3147	0.3312
		81.50	0.1204	6383	95.01	100.00	106.93	0.3147	0.3312
Day 3	Slot 1	80.80	0.1198	6471	94.79	100.00	107.94	0.3131	0.3303
		81.00	0.1203	6467	94.89	100.00	108.04	0.3132	0.3301
	Slot 2	81.20	0.1202	6378	95.03	100.00	106.88	0.3148	0.3312
		81.20	0.1202	6388	94.96	100.00	106.92	0.3146	0.3313
	Slot 3	81.20	0.1201	6378	95.03	100.00	106.88	0.3148	0.3312
		81.20	0.1202	6397	95.12	100.00	107.36	0.3145	0.3306
Day 4	Slot 1	81.20	0.1202	6417	95.11	100.00	107.64	0.3141	0.3303
		81.20	0.1202	6417	95.11	100.00	107.64	0.3141	0.3303
	Slot 2	81.20	0.1203	6425	95.11	100.00	107.78	0.3140	0.3302
		81.20	0.1203	6425	95.11	100.00	107.78	0.3140	0.3302
	Slot 3	81.20	0.1202	6425	95.11	100.00	107.78	0.3140	0.3302
		81.20	0.1201	6425	95.11	100.00	107.78	0.3140	0.3302
Day 5	Slot 1	80.80	0.1204	6461	95.13	100.00	108.40	0.3134	0.3295
		81.20	0.1210	6388	94.96	100.00	106.92	0.3146	0.3313
	Slot 2	81.20	0.1210	6378	95.03	100.00	106.88	0.3148	0.3312
		81.20	0.1211	6388	95.07	100.00	107.12	0.3146	0.3309
	Slot 3	81.40	0.1203	6375	95.05	100.00	106.89	0.3148	0.3312
		81.30	0.1202	6367	95.16	100.00	106.94	0.3150	0.3310

Mean	81.2	0.1204	6401	95.06	100.00	107.31	0.3144	0.3307
Min	80.8	0.1198	6357	94.79	100.00	106.71	0.3131	0.3295
Max	81.6	0.1216	6471	95.16	100.00	108.40	0.3151	0.3313
SD	0.1779	0.0004	29	0.0763	0.0000	0.4285	0.0005	0.0005

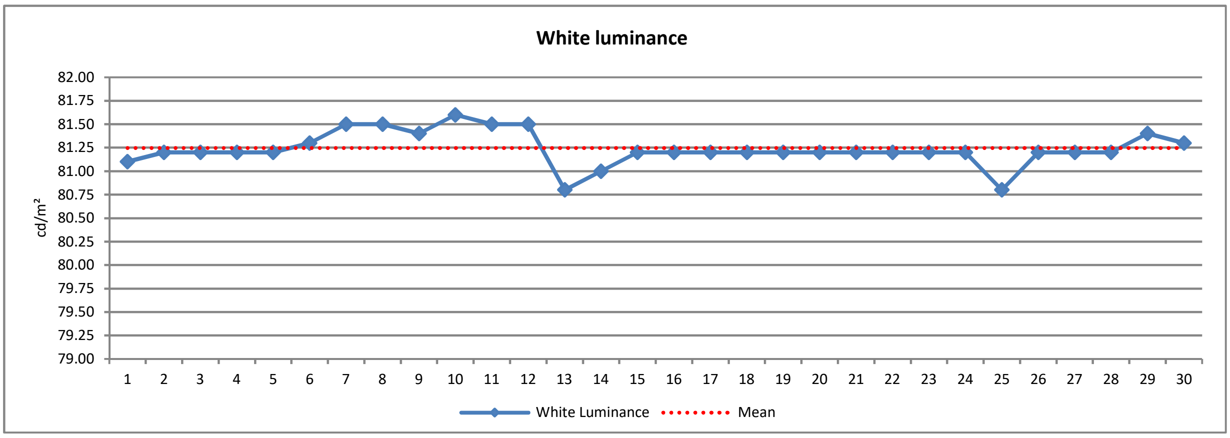
		White Lum. (cd/m²)	Black Lum. (cd/m²)	CCT (K)	Whitepoint X	Y	Z	x	y
Slot 1	Mean	81.15	0.1204	6418	95.04	100.00	107.55	0.3141	0.3305
	Min	80.80	0.1198	6374	94.79	100.00	106.92	0.3131	0.3295
	Max	81.50	0.1212	6471	95.13	100.00	108.40	0.3149	0.3313
	SD	0.2291	0.0005	35	0.1123	0.0000	0.4669	0.0006	0.0005
Slot 2	Mean	81.26	0.1206	6396	95.06	100.00	107.22	0.3145	0.3308
	Min	81.20	0.1200	6378	94.96	100.00	106.88	0.3140	0.3302
	Max	81.60	0.1216	6425	95.11	100.00	107.78	0.3148	0.3313
	SD	0.1281	0.0005	18	0.0415	0.0000	0.3310	0.0003	0.0004
Slot 3	Mean	81.30	0.1202	6390	95.08	100.00	107.16	0.3146	0.3308
	Min	81.20	0.1201	6357	95.01	100.00	106.71	0.3140	0.3295
	Max	81.50	0.1204	6425	95.16	100.00	107.78	0.3151	0.3313
	SD	0.1183	0.0001	22	0.0492	0.0000	0.3707	0.0004	0.0006
Day 1	Mean	81.20	0.1200	6399	95.08	100.00	107.30	0.3144	0.3307
	Min	81.10	0.1200	6357	95.06	100.00	106.71	0.3143	0.3305
	Max	81.30	0.1201	6408	95.11	100.00	107.50	0.3151	0.3313
	SD	0.0577	0.0000	19	0.0214	0.0000	0.2671	0.0003	0.0003
Day 2	Mean	81.50	0.1210	6380	95.07	100.00	106.98	0.3148	0.3311
	Min	81.40	0.1203	6374	95.01	100.00	106.93	0.3147	0.3310
	Max	81.60	0.1216	6384	95.12	100.00	107.03	0.3149	0.3312
	SD	0.0577	0.0005	4	0.0453	0.0000	0.0411	0.0001	0.0001
Day 3	Mean	81.10	0.1201	6413	94.97	100.00	107.34	0.3142	0.3308
	Min	80.80	0.1198	6378	94.79	100.00	106.88	0.3131	0.3301
	Max	81.20	0.1203	6471	95.12	100.00	108.04	0.3148	0.3313
	SD	0.1528	0.0002	40	0.1069	0.0000	0.4916	0.0007	0.0005
Day 4	Mean	81.20	0.1202	6422	95.11	100.00	107.73	0.3140	0.3302
	Min	81.20	0.1201	6417	95.11	100.00	107.64	0.3140	0.3302
	Max	81.20	0.1203	6425	95.11	100.00	107.78	0.3141	0.3303
	SD	0.0000	0.0001	4	0.0000	0.0000	0.0660	0.0000	0.0000
Day 5	Mean	81.18	0.1207	6393	95.07	100.00	107.19	0.3145	0.3309
	Min	80.80	0.1202	6367	94.96	100.00	106.88	0.3134	0.3295
	Max	81.40	0.1211	6461	95.16	100.00	108.40	0.3150	0.3313
	SD	0.1863	0.0004	31	0.0655	0.0000	0.5463	0.0005	0.0006

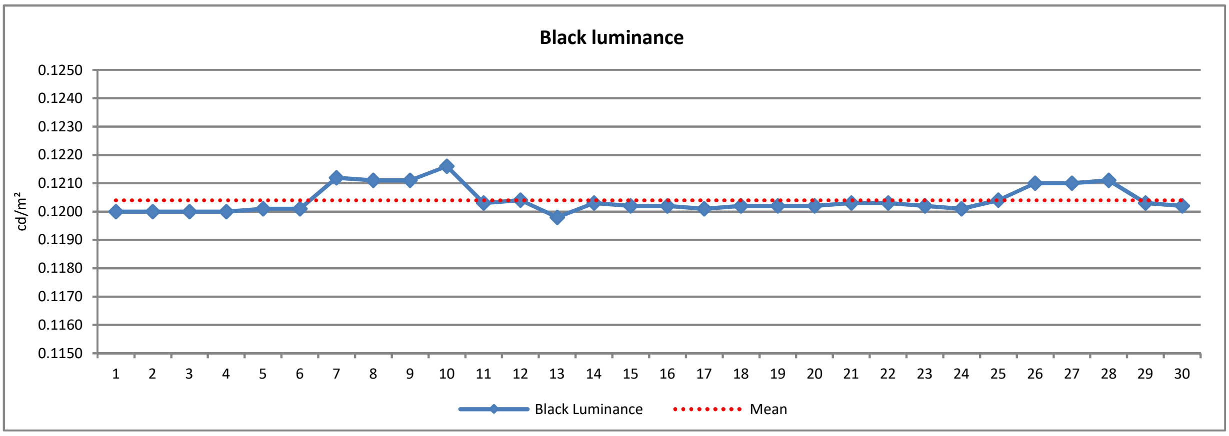
1.4 - Performance data - visualization of the measured whitepoints in the CIE xy chromaticity diagram

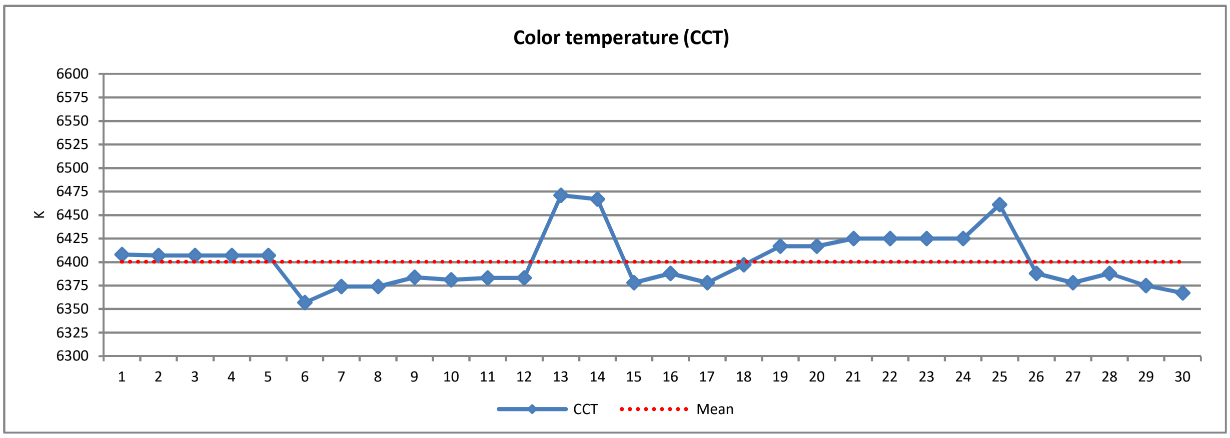


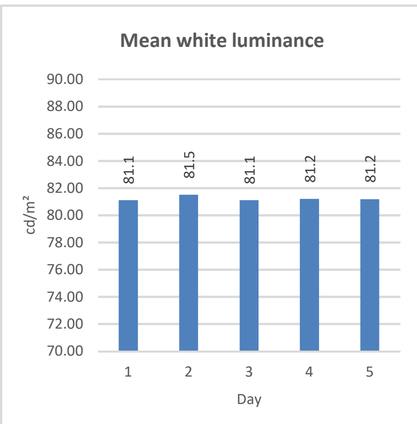
3| 4 Display performance data / Calibrated and profiled (Display4_MD1_sRGB_80_V1.icm)

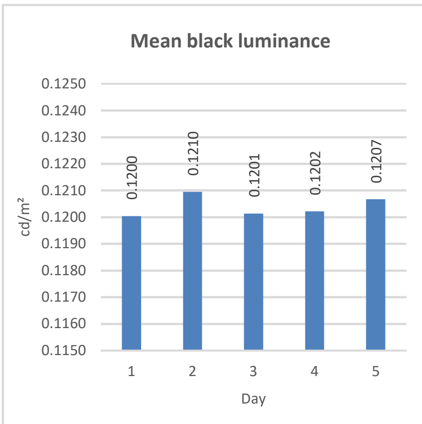
1.5 - Performance data - visualization of the measured values

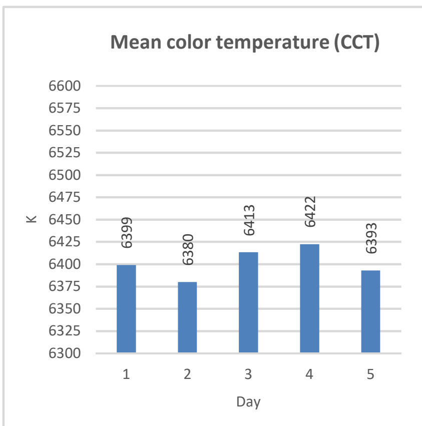






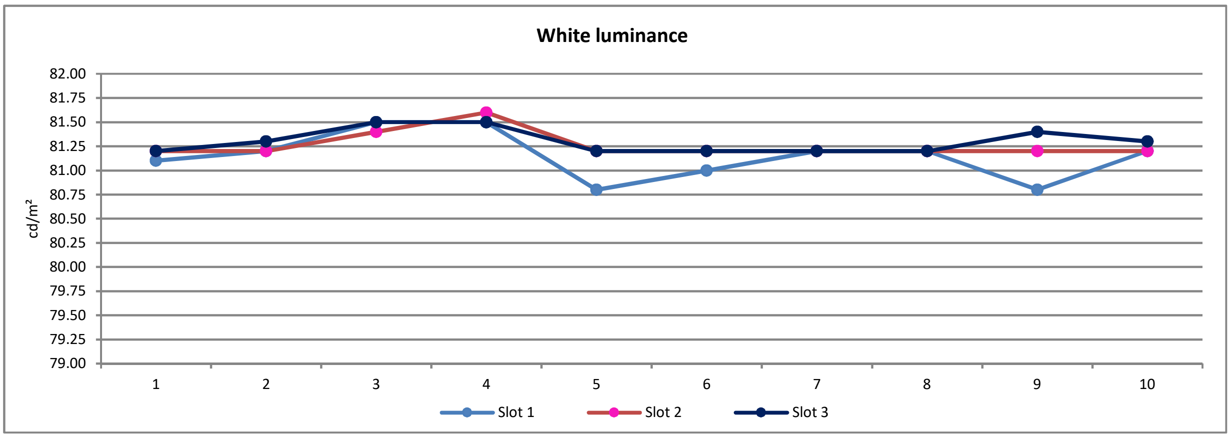


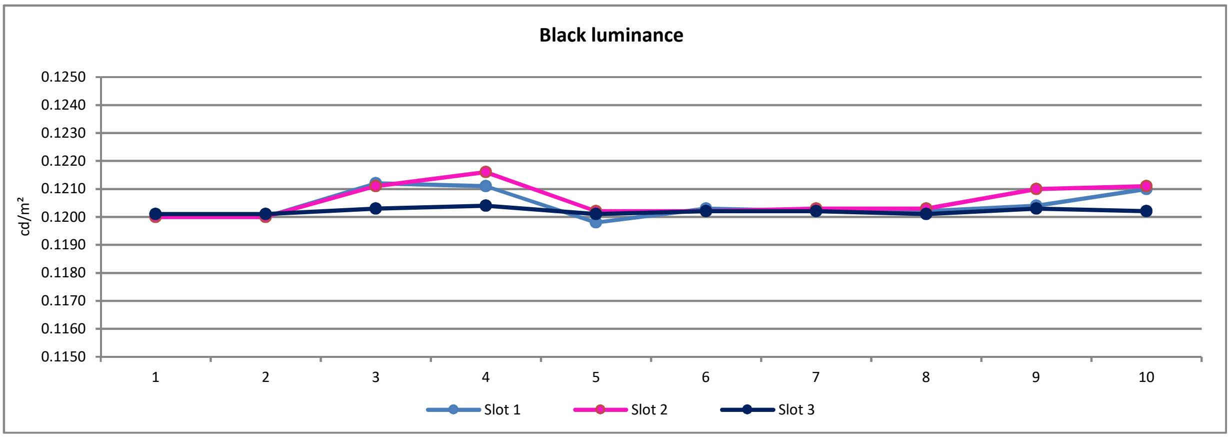


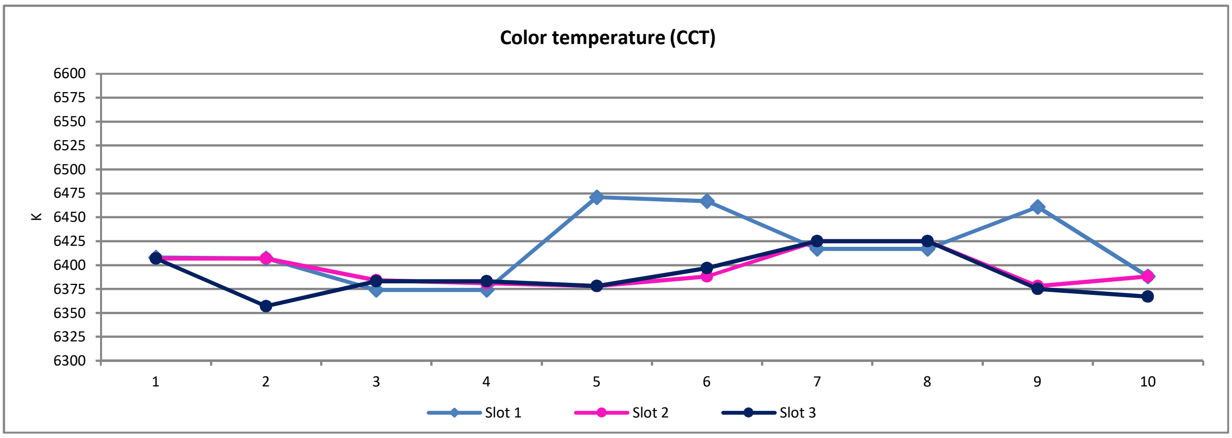


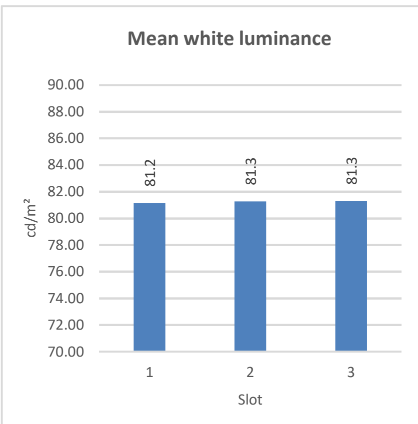
3| 4 Display performance data / Calibrated and profiled (Display4_MD1_sRGB_80_V1.icm)

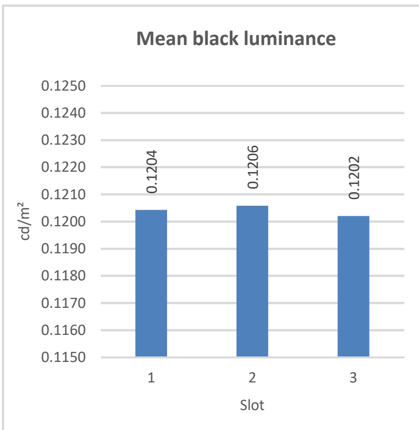
1.5 - Performance data - visualization of the measured values

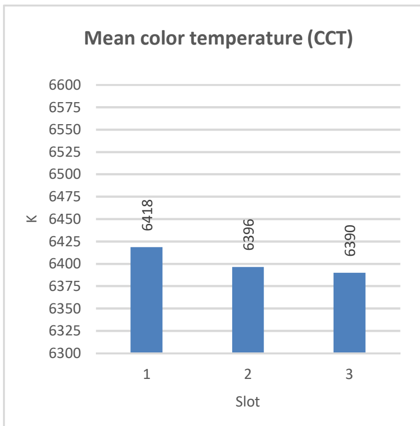












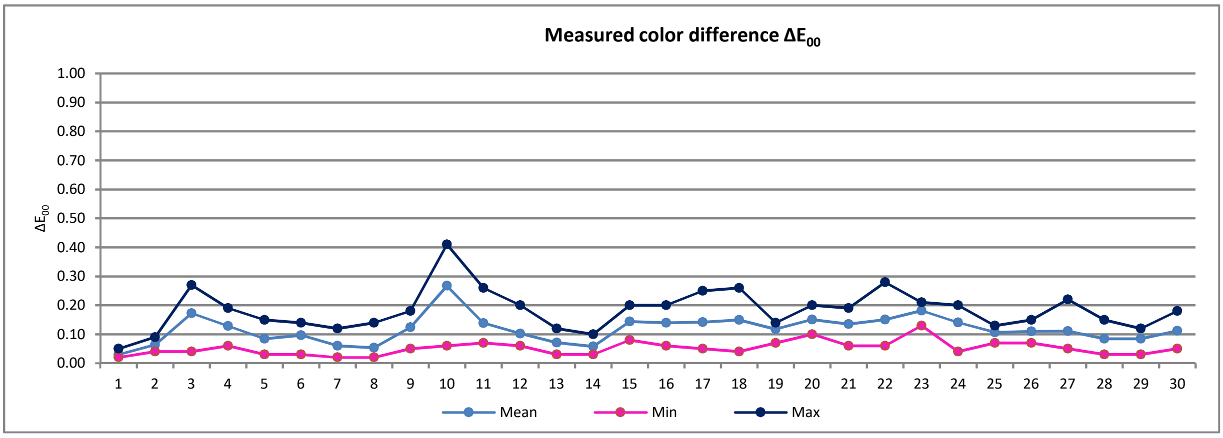
3| 4 Display performance data / Calibrated and profiled (Display4_MD1_sRGB_80_V1.icm)

1.6 - Color accuracy - measured color difference ΔE_{00}

	Device Values			Nominal Values			Day 1		Day 2		Day 3		Day 4		Day 5		ΔE_{00}			
Color	R	G	B	L*	a*	b*	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	Mean	Min	Max	SD
1	128	0	0	25.44	47.54	37.58	0.03	0.05	0.03	0.03	0.02	0.03	0.03	0.04	0.02	0.02	0.03	0.02	0.05	0.0089
2	255	0	0	53.60	80.61	68.74	0.05	0.07	0.06	0.05	0.08	0.04	0.08	0.09	0.05	0.06	0.06	0.04	0.09	0.0155
3	255	128	128	68.50	49.01	23.78	0.04	0.05	0.16	0.22	0.21	0.23	0.19	0.20	0.27	0.16	0.17	0.04	0.27	0.0710
4	0	128	0	46.63	-44.95	46.87	0.06	0.10	0.10	0.11	0.11	0.15	0.14	0.14	0.19	0.18	0.13	0.06	0.19	0.0376
5	0	255	0	88.51	-75.72	80.04	0.03	0.09	0.08	0.08	0.15	0.06	0.05	0.11	0.10	0.09	0.08	0.03	0.15	0.0317
6	128	255	128	91.24	-53.87	49.24	0.03	0.06	0.10	0.11	0.13	0.12	0.09	0.07	0.14	0.11	0.10	0.03	0.14	0.0323
7	0	0	128	12.28	38.99	-64.82	0.02	0.03	0.04	0.08	0.12	0.07	0.07	0.06	0.06	0.05	0.06	0.02	0.12	0.0268
8	0	0	255	29.76	69.15	-111.27	0.05	0.05	0.05	0.05	0.14	0.02	0.03	0.05	0.04	0.05	0.05	0.02	0.14	0.0307
9	128	128	255	58.06	26.20	-64.83	0.06	0.06	0.05	0.16	0.18	0.16	0.18	0.09	0.15	0.15	0.12	0.05	0.18	0.0500
10	0	128	128	48.19	-28.99	-8.43	0.06	0.09	0.12	0.32	0.27	0.41	0.35	0.34	0.39	0.32	0.27	0.06	0.41	0.1222
11	0	255	255	91.27	-48.46	-14.37	0.10	0.14	0.07	0.13	0.16	0.26	0.08	0.09	0.22	0.14	0.14	0.07	0.26	0.0582
12	170	255	255	94.84	-26.27	-8.51	0.10	0.07	0.06	0.13	0.20	0.10	0.09	0.07	0.14	0.06	0.10	0.06	0.20	0.0419
13	128	0	128	29.23	55.25	-36.27	0.03	0.04	0.07	0.08	0.12	0.11	0.08	0.07	0.07	0.04	0.07	0.03	0.12	0.0277
14	255	0	255	59.37	93.89	-61.31	0.05	0.10	0.09	0.07	0.05	0.04	0.03	0.04	0.06	0.05	0.06	0.03	0.10	0.0214
15	255	170	255	79.86	42.19	-29.89	0.11	0.08	0.10	0.16	0.09	0.18	0.17	0.17	0.20	0.18	0.14	0.08	0.20	0.0418
16	128	128	0	52.30	-9.55	54.68	0.06	0.07	0.13	0.11	0.13	0.18	0.16	0.18	0.20	0.18	0.14	0.06	0.20	0.0460
17	255	255	0	97.71	-16.87	92.28	0.05	0.09	0.10	0.16	0.25	0.15	0.14	0.12	0.19	0.17	0.14	0.05	0.25	0.0534
18	255	255	170	98.66	-9.86	40.66	0.05	0.04	0.09	0.17	0.21	0.17	0.26	0.14	0.19	0.18	0.15	0.04	0.26	0.0669
19	170	85	85	46.43	34.46	15.82	0.13	0.12	0.07	0.14	0.09	0.14	0.13	0.13	0.12	0.10	0.12	0.07	0.14	0.0219
20	85	170	85	62.88	-38.05	34.46	0.11	0.17	0.10	0.15	0.11	0.18	0.20	0.12	0.19	0.18	0.15	0.10	0.20	0.0359
21	85	85	170	39.35	17.99	-46.38	0.07	0.06	0.09	0.12	0.13	0.18	0.19	0.19	0.18	0.14	0.14	0.06	0.19	0.0472
22	85	170	170	64.25	-25.25	-8.35	0.06	0.07	0.16	0.08	0.17	0.19	0.14	0.24	0.28	0.12	0.15	0.06	0.28	0.0689
23	170	85	170	48.74	43.47	-30.72	0.21	0.20	0.19	0.20	0.13	0.17	0.19	0.18	0.17	0.18	0.18	0.13	0.21	0.0214
24	170	170	85	67.97	-8.72	42.08	0.09	0.08	0.19	0.12	0.04	0.20	0.16	0.16	0.19	0.18	0.14	0.04	0.20	0.0524
25	255	0	170	56.10	86.27	-17.60	0.07	0.12	0.12	0.07	0.13	0.13	0.11	0.12	0.09	0.10	0.11	0.07	0.13	0.0215
26	170	255	0	92.37	-47.72	85.14	0.07	0.08	0.11	0.10	0.15	0.12	0.14	0.09	0.12	0.12	0.11	0.07	0.15	0.0241
27	0	170	255	65.32	-11.92	-53.84	0.07	0.16	0.07	0.05	0.22	0.08	0.07	0.11	0.14	0.14	0.11	0.05	0.22	0.0507
28	0	255	170	89.63	-63.78	26.66	0.06	0.15	0.10	0.11	0.06	0.11	0.05	0.03	0.08	0.09	0.08	0.03	0.15	0.0335
29	170	0	255	44.71	79.75	-85.84	0.10	0.12	0.10	0.10	0.12	0.06	0.03	0.04	0.08	0.09	0.08	0.03	0.12	0.0297
30	255	170	0	76.38	25.19	78.91	0.08	0.11	0.05	0.12	0.17	0.18	0.08	0.15	0.09	0.09	0.11	0.05	0.18	0.0404

Mean	0.12	0.05	0.18	0.0411

1.6.1 - Color accuracy - visualization of the measured color difference ΔE_{00}

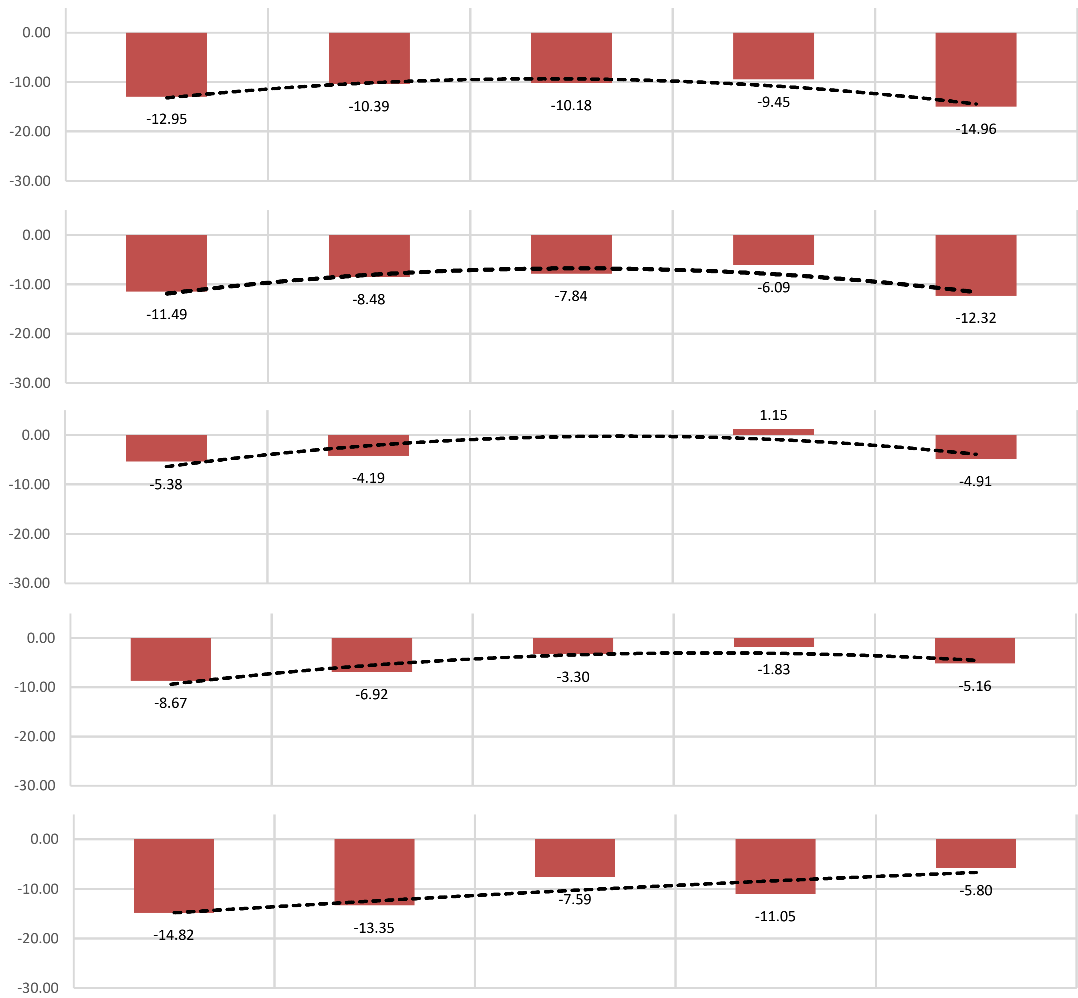


3| 4 Display performance data / Calibrated and profiled (Display4_MD1_sRGB_80_V1.icm)

1.7 - Display uniformity - measured values (5x5 matrix)

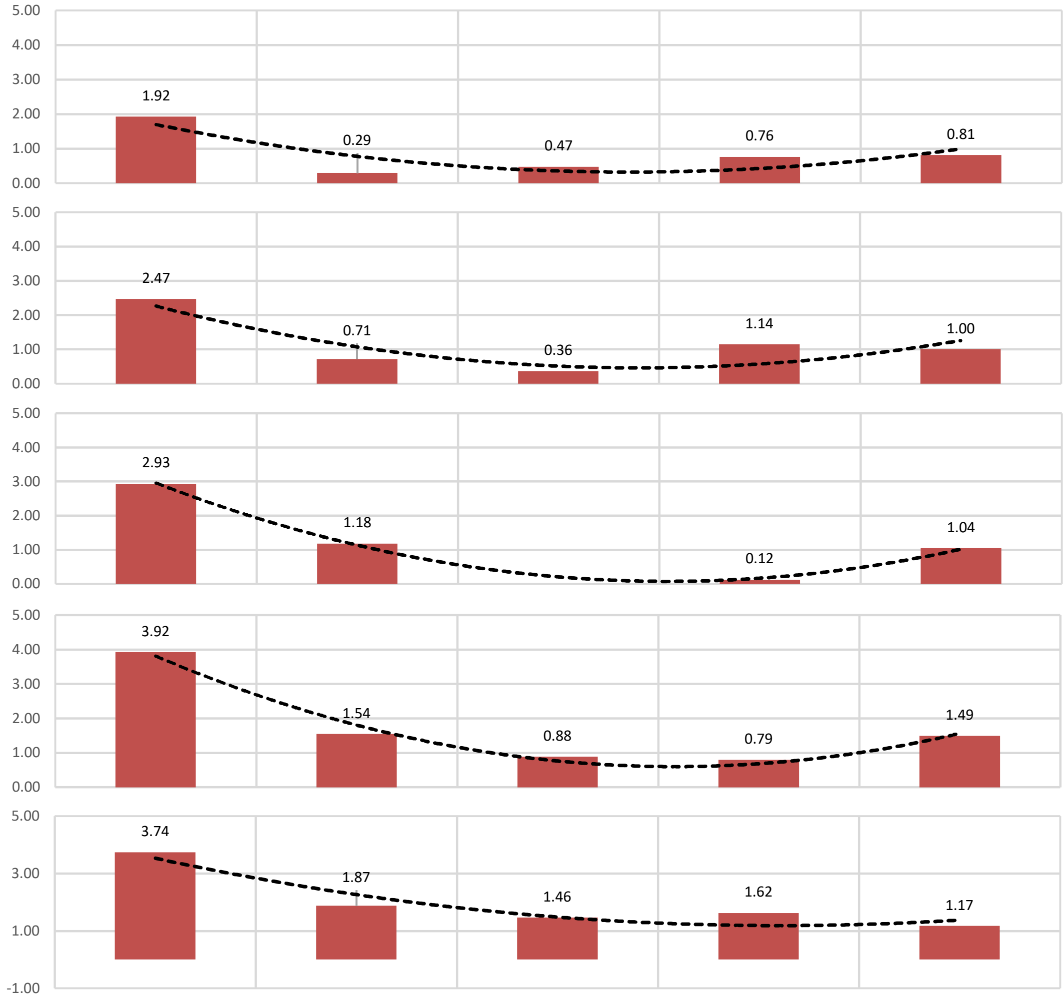
	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00	Lum. cd/m²	Delta %	ΔC*00
100%	69.73	-12.95	1.92	71.78	-10.39	0.29	71.95	-10.18	0.47	72.54	-9.45	0.76	68.12	-14.96	0.81
75%	38.46	-5.71	0.03	38.51	-5.65	0.04	38.23	-5.99	-0.93	38.64	-5.48	-1.16	36.24	-8.48	-0.33
50%	17.12	-1.81	0.31	16.59	-2.47	-0.18	16.36	-2.76	-0.59	16.51	-2.57	-0.95	15.53	-3.80	-0.56
25%	3.85	-0.34	0.20	3.71	-0.51	0.02	3.63	-0.62	-0.34	3.66	-0.58	-0.38	3.44	-0.85	-0.08
100%	70.90	-11.49	2.47	73.31	-8.48	0.71	73.82	-7.84	0.36	75.23	-6.09	1.14	70.24	-12.32	1.00
75%	39.41	-4.52	0.17	39.57	-4.32	0.37	39.45	-4.48	-0.76	40.37	-3.33	-1.10	37.70	-6.65	-0.47
50%	17.67	-1.12	0.58	17.23	-1.68	-0.17	16.95	-2.02	-0.71	17.37	-1.49	-1.20	16.27	-2.87	-0.31
25%	3.99	-0.17	0.19	3.85	-0.34	0.14	3.76	-0.46	-0.24	3.84	-0.35	-0.50	3.61	-0.63	0.01
100%	75.80	-5.38	2.93	76.74	-4.19	1.18	**80.10**			81.02	1.15	0.12	76.17	-4.91	1.04
75%	42.44	-0.75	0.95	41.53	-1.87	0.86	**43.03**			43.64	0.75	-0.66	41.03	-2.50	0.16
50%	19.17	0.75	1.05	18.19	-0.47	0.58	**18.57**			18.87	0.38	-0.61	17.72	-1.06	0.06
25%	4.33	0.26	0.51	4.08	-0.06	0.36	**4.12**			4.18	0.07	-0.26	3.94	-0.23	0.20
100%	73.16	-8.67	3.92	74.56	-6.92	1.54	77.46	-3.30	0.88	78.64	-1.83	0.79	75.97	-5.16	1.49
75%	40.95	-2.60	1.59	40.53	-3.12	0.90	41.55	-1.85	0.46	42.47	-0.70	0.24	40.99	-2.55	0.38
50%	18.51	-0.08	1.48	17.75	-1.02	0.41	17.90	-0.83	0.24	18.39	-0.23	-0.20	17.75	-1.02	0.45
25%	4.20	0.09	0.88	3.98	-0.18	0.42	3.96	-0.18	0.35	4.07	-0.06	0.02	3.95	-0.21	0.25
100%	68.23	-14.82	3.74	69.41	-13.35	1.87	74.02	-7.59	1.46	71.25	-11.05	1.62	75.46	-5.80	1.17
75%	38.35	-5.85	1.46	37.96	-6.33	0.91	39.93	-3.87	0.57	38.52	-5.63	0.91	41.07	-2.46	0.56
50%	17.37	-1.50	1.32	16.66	-2.38	0.45	17.21	-1.69	0.12	16.62	-2.44	0.34	17.90	-0.83	0.28
25%	3.97	-0.20	0.94	3.73	-0.49	0.40	3.81	-0.39	0.29	3.68	-0.56	0.33	4.00	-0.16	0.15

1.7.1 - Display uniformity - Visualization of the luminance difference (%)



3| 4 Display performance data / Calibrated and profiled (Display4_MD1_sRGB_80_V1.icm)

1.7.2 - Display uniformity - Visualization of the chromaticity difference ΔC*$_{00}$



Annex 4 Colormatching experiments

* Annotation:

Due to the high volume, only the data obtained for User ID 01 are presented here in the annex of the elaboration. All other data are available on request.

4| 1 Hygiene and safety concept

1.1 - Regulations and policies

Hygiene and safety concept

Hochschule Offenburg
offenburg.university

Experiments in the Laboratory Digital Color + Color Management (D113)

Colormatching Experiments with wide color gamut QD-enhanced LCDs

VAUDERWANGE Oliver - PhD candidate, Hochschule Offenburg
JAVAHIRALY Nicolas - Teacher Researcher, University of Strasbourg
CURTICAPEAN Dan - Teacher Researcher, Hochschule Offenburg

Laboratory

- Room size 7 x 3 m (25 qm²)
- Ventilation through open windows possible.
- Number of computer workstations: 2
- Experiments are carried out on the PC, control with mouse and keyboard.
- Position of the participants defined by chin rest.
- Separation by privacy wall (additional partition wall made of plexiglass available).
- Distance of 1,5m can be realized.

Organization:

- Number of persons: max. 2 test persons and 1 supervisor
- Total duration of experiments: 60 min. with 2 runs and 10 min. break.
- Planned time frame: 90 min / 60 min experiments + 30 min ventilation and disinfection.
- Questionnaire on personal health is to be filled in.
- Surface and hand disinfectants will be provided.
- After completion of the experiments, all surfaces, chin rest, keyboard and mouse disinfected.

Realization:

- Questionnaire on personal health must be filled in before entering the laboratory.
- Test persons enter room with mouth and nose protection.
- Test persons can remove the mouth and nose protection for the test.
- The supervisor always wears mouth and nose protection if a safety distance of 2 m is undercut.
- When leaving the room all persons must wear the mouth and nose protection.
- The test participants leave the laboratory immediately.
- Ventilate the room and disinfect the workplaces.

4| 1 Hygiene and safety concept

1.2 - Questionaire on personal health

Hochschule Offenburg
offenburg.university

Fragebogen SARS-CoV-2-Risiko für Teilnehmer der Versuchsreihen im Rahmen der PhD-Thesis „Characterization of Color Vision by Spectrometry and Nanotechnology: Application to Media Photonics“.

Erhebung personenbezogener Daten

Datum und Uhrzeit	
Name	
Geburtsdatum *	
Adresse *	
Telefon	
E-Mail	

* optional / freiwillige Angaben

Kontaktrisiko Evaluation

Bitte beantworten Sie die Fragen zur Einschätzung des Kontaktrisikos mit SARS-CoV-2	**Ja**	**Nein**
Hatten Sie Kontakt zu einem bestätigten SARS-CoV-2 Fall innerhalb der letzten 14 Tage?	[ ]	[ ]
Bestand in der Vergangenheit die Anordnung einer behördlichen Quarantäne im Zusammenhang mit SARS-CoV-2? Wenn ja, bitte Datum des Ablaufs der Anordnung angeben:	[ ] ____________	[ ]

Symptome-Evaluation

Bitte beantworten Sie die Fragen zur aktuellen klinischen Symptomatik! (ausgenommen chronische Krankheiten, wie z.B. Heuschnupfen)	**Ja**	**Nein**
Fieber	[ ]	[ ]
Allgemeines Krankheitsgefühl, Kopf- und Gliederschmerzen	[ ]	[ ]
(Trockener) Husten	[ ]	[ ]
Atemnot (Dyspnoe)	[ ]	[ ]
Geschmacks- und/oder Riechstörungen	[ ]	[ ]
Halsschmerzen	[ ]	[ ]
Kopfschmerzen	[ ]	[ ]
Schnupfen (Rhinitis)	[ ]	[ ]
Übermäßiges Kältegefühl	[ ]	[ ]
Durchfall (Diarrhoe)	[ ]	[ ]

Die vorgenannten Daten erhebt der Versuchsleiter auf der Rechtsgrundlage des Art. 6 Abs. 1 S. 1 lit. d, f DSGVO zum Zwecke des Schutzes der Mitarbeiter_innen und Versuchsteilnehmer_innen.
Eine Verarbeitung zu anderen, als den vorgenannten Zwecken findet ausdrücklich nicht statt.
Der Zugang zu den Daten innerhalb der Hochschule Offenburg ist streng limitiert.
Die Daten werden spätestens zwei Monate nach Erhebung gelöscht / vernichtet.
Eine Weitergabe der Daten an Dritte findet nicht statt.
Rückfragen zum Datenschutz können Sie an oliver.vauderwange@hs-offenburg.de richten.

4| 2 Accompanying documents (to be edited by the participants)

1.1 - Information form and consent

INFORMATION FORM AND CONSENT

Colormatching experiments with wide color gamut QD-enhanced LCDs

VAUDERWANGE Oliver - PhD Candidate, Hochschule Offenburg
JAVAHIRALY Nicolas – MCF-HDR, University of Strasbourg
CURTICAPEAN Dan - Professor, Hochschule Offenburg

Using "you "herein refers to the research participant. "You" includes the person authorized to give consent for the subject's participation in this research study.

The IT department of the **University of Strasbourg, Offenburg University** and the **iCube Laboratory** involved in research projects in the field of computer science in order to understand the disadvantages of new technologies and find solutions to their side effects.

The Project:

During the experiments, the test persons are given the task of performing visual color matching experiments in a defined environment. Color fields with defined target colors are shown on the displays. Within these color fields there is a defined mask in which these target colors are to be mixed by the test person with the help of the three primary colors red, green and blue until the visual congruence is as exact as possible. To simplify and shorten the time frame of the fitting process, a similar color tone is already displayed in the mask.

The objective is to obtain as many data sets as possible that allow an assessment of the color reproduction quality of the displays used and also allow an analysis of the visual color perception of the test persons as a group. The acquired data are digitally stored and evaluated. The contents of the questionnaires are also stored digitally and used for evaluation.

Today we are asking for your participation in this project, the steps will be detailed in the next section.

We invite you to read this Information form to decide whether to participate in this research project. It is important to understand this form. Do not hesitate to ask questions. Take any time necessary to make your decision.

initials participant

______

4| 2 Accompanying documents (to be edited by the participants)

Before agreeing to participate, the investigator must tell you:

1. **Experimental procedure presentation**

   1) Introduction
      Presentation of the test environment and introduction to the tasks to be performed.

   2) Setting up the test environment
      You take a seat at the selected test device. Then the settings of the used chin rest are checked to ensure the required measuring distance from the display. Then a most comfortable seating position is adjusted.

   3) Collection of data:
      The experiments to be performed are divided into two sub-experiments, which they process one after the other. After a break of 10 minutes, the experiments are repeated once.

   4) Concluding questionnaire:
      Finally, you may fill out a questionnaire that allows us to characterize you more precisely as a test person. For this purpose, questions will be asked about the person and the experience in the field of digital media and media production.
      The total time of this experience will be about 60 minutes.

2. **What are the advantages and benefits?**

   You will not gain any direct benefit by participating in this research.

3. **What are the disadvantages and risks?**

   Due to the current pandemic situation, experiments with test persons at Offenburg University are only possible with the permission of the university administration. This is available. A safety and hygiene concept has been worked out, which must be strictly fulfilled and every invited participant is informed in advance.

   No inconvenience is to be expected during the experiments. Should you still feel uncomfortable, do not hesitate to withdraw from the experiment

4. **In what cases can we withdraw from the experience?**

   You can ask to terminate the experiment at any time.

5. **How is confidentiality ensured?**

All information obtained for this research project will remain confidential, unless authorized by you or an exception to the law. To do this, this information will be anonymised.

The files will still remain after the end of the research, the responsibility of the research team that conducted the project at Offenburg University.

Moreover, the results of this research may be published or disclosed in a scientific congress but no identifiable information will be unveiled.

initials participant ______

4| 2 Accompanying documents (to be edited by the participants)

6. **Participation of freedom**

Your participation in this research project is voluntary. You may withdraw from this research at any time.

7. **In case of questions or problems, with whom can we communicate?**

For more information about this research, please contact the researcher in charge of this research
Oliver VAUDERWANGE: oliver.vauderwange@hs-offenburg.de
Dan CURTICAPEAN: dan.curticapean@hs-offenburg.de
Nicolas JAVAHIRALY: n.javahiraly@unistra.fr

Responsibility

By signing this declaration of consent, you do not waive your statutory rights.
Furthermore, you do not release investigators from their legal and professional responsibility.

8. **Consent and assent**

The experiment executors explained the nature and conduct of the research project. I have read the declaration of consent and received a copy. I had the opportunity to ask questions which were answered satisfactorily. Upon reflection, I agree to participate in this research project.
I allow the research team to use the data obtained from my participation in this project.

__________________________ ____________________

Name of participant giving consent Signature Date

initials participant ______

4| 2 Accompanying documents (to be edited by the participants)

1.2 - Questionaire for participants sociological profile

Colormatching Experiments with wide color gamut QD-enhanced LCDs

VAUDERWANGE Oliver - PhD candidate, Hochschule Offenburg
JAVAHIRALY Nicolas - Teacher Researcher, University of Strasbourg
CURTICAPEAN Dan - Teacher Researcher, Hochschule Offenburg

Participants' sociological profile / Soziologisches Profil der Teilnehmer

Questionnaire to establish a user profile of the participant. This information will be treated anonymously. / Fragebogen zur Erstellung eines Benutzerprofils des Teilnehmers. Diese Informationen werden anonym behandelt.

* Erforderlich

1. ID *

____

Personal informations / Persönliche Informationen

2. Gender / Geschlecht *

Markieren Sie nur ein Oval.

- ◯ Female
- ◯ Male
- ◯ Diverse

3. Age / Alter *

Wählen Sie alle zutreffenden Antworten aus.

	< 20	20 - 29	30 - 39	40 - 49	50 - 59	60 - 69
Age	☐	☐	☐	☐	☐	☐

4. Profession / Beruf *

____

initials participant

____

4| 2 Accompanying documents (to be edited by the participants)

Visual perception / Visuelle Wahrnehmung

Do you have limitations in your visual perception? / Leiden sie unter Einschränkungen der visuellen Wahrnehmung?

5. Do you wear eyeglasses? / Tragen Sie eine Brille? *

Wählen Sie alle zutreffenden Antworten aus.

	Farsightedness/ Weitsichitgkeit	Nearsightedness/ Kurzsichtigkeit
Ametropia / Fehlsichtigkeit	☐	☐

6. Do you have color vision disorders? / Leiden Sie unter Störungen der Farbwahrnehmung? *

Wählen Sie alle zutreffenden Antworten aus.

	Achromosia/ Farbenblindheit	Monochromasia/ Monochromasie	Dichromasia/ Dichromasie	Protanopia/ Rotblindheit	Deuteranopia/ Grünblindheit	Tritanopia/ Blaublindheit
Color vision disorders	☐	☐	☐	☐	☐	☐

7. Other visual disorders / Weitere Sehstörungen *

____

Experience in digital media and media production / Erfahrung im Bereich digitale Medien und Medienproduktion

The following questions allow us to assess their experience in working with digital color. / Die folgenden Fragen erlauben uns, ihre Erfahrung im Umgang mit digitaler Farbe einzuschätzen.

8. Which digital display devices do you use? / Welche digitalen Wiedergabegeräte nutzen Sie? *

Wählen Sie alle zutreffenden Antworten aus.

	Computer	Laptop	Tablet	Smartphone	TV
Devices /Geräte	☐	☐	☐	☐	☐

9. Do you use software from the following areas to create and edit digital information? / Nutzen Sie Software aus folgenden Bereichen zur Erstellung und Bearbeitung digitaler Information? *

Wählen Sie alle zutreffenden Antworten aus.

	Text editing/ Textbearbeitung	Layout design/ Layoutgestaltung	Drawing/ Zeichnen	Image editing/ Bildbearbeitung	Animation/ Grafikanimation	Video editing/ Videobearbeitun
Area / Bereich	☐	☐	☐	☐	☐	☐

initials participant

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4| 2 Accompanying documents (to be edited by the participants)

10. Do you have experience in the following areas of digital media production? Please differentiate between profession and hobby. / Haben Sie Erfahrung in folgenden Bereichen der digitalen Medienproduktion? Unterscheiden Sie bitte zwischen Beruf und Hobby. *

Wählen Sie alle zutreffenden Antworten aus.

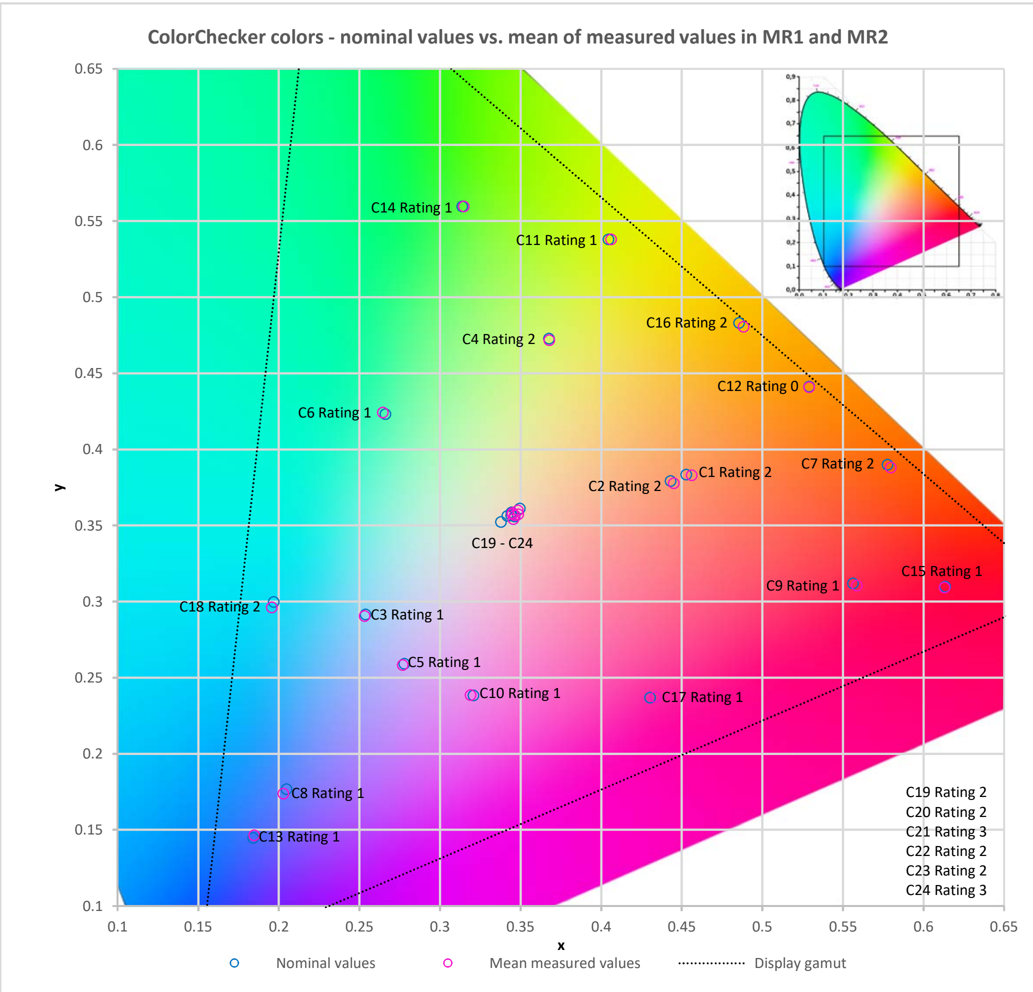
	None / Keine	Photography / Fotografie	Design / Gestaltung	Animation / Animation	Movie / Film
Profession / Beruf	☐	☐	☐	☐	☐
Studies / Studium	☐	☐	☐	☐	☐
Hobby / Hobby	☐	☐	☐	☐	☐

initials participant ______

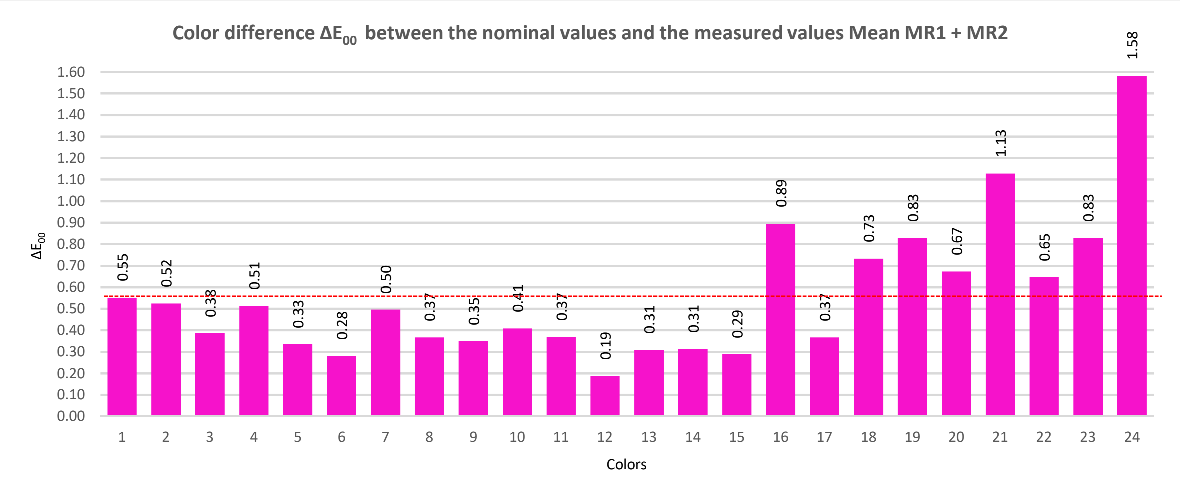
4| 3 ColorChecker values based on the used display profile

1.1 - Defined target values - ColorChecker Basis (CC) - Display 1 (AdobeRGB)

Color	Device values			Nominal values					Mean measured values						
Color	R	G	B	L*	a*	b*	x	y	L*	a*	b*	x	y	ΔE_{00}	Rating
1	107	82	70	38.60	15.61	16.13	0.4431	0.3790	38.43	16.30	16.08	0.4452	0.3776	0.55	2
2	184	146	129	65.98	24.83	27.80	0.4530	0.3832	65.59	25.69	28.28	0.4562	0.3828	0.52	2
3	101	122	153	50.00	-9.41	-26.94	0.2540	0.2914	49.67	-9.15	-27.11	0.2534	0.2904	0.38	1
4	95	107	69	45.66	-18.34	27.35	0.3677	0.4726	45.22	-17.80	27.00	0.3680	0.4717	0.51	2
5	128	127	173	53.52	10.91	-35.25	0.2780	0.2590	53.28	10.77	-35.50	0.2769	0.2581	0.33	1
6	129	188	171	73.91	-51.41	5.89	0.2662	0.4231	73.76	-52.14	5.70	0.2647	0.4241	0.28	1
7	201	123	56	65.00	53.87	74.70	0.5779	0.3897	64.72	54.74	74.52	0.5799	0.3880	0.50	2
8	77	92	166	39.00	15.09	-58.77	0.2048	0.1765	38.62	15.46	-59.59	0.2030	0.1737	0.37	1
9	174	83	97	50.92	65.66	23.03	0.5563	0.3118	50.67	66.52	23.04	0.5588	0.3103	0.35	1
10	86	61	104	29.05	22.89	-24.02	0.3208	0.2382	28.75	22.26	-23.93	0.3191	0.2385	0.41	1
11	167	188	75	79.15	-32.55	80.97	0.4046	0.5378	79.09	-32.02	81.74	0.4062	0.5378	0.37	1
12	213	160	55	75.61	29.82	89.29	0.5291	0.4411	75.60	30.09	89.02	0.5292	0.4406	0.19	0
13	49	65	143	28.32	18.51	-59.45	0.1842	0.1447	28.02	17.93	-58.45	0.1849	0.1462	0.31	1
14	99	148	80	61.66	-55.26	46.94	0.3140	0.5596	61.35	-54.75	46.89	0.3149	0.5594	0.31	1
15	155	52	59	42.65	68.58	33.40	0.6136	0.3097	42.90	69.01	33.24	0.6132	0.3091	0.29	1
16	227	197	52	87.45	6.29	102.03	0.4857	0.4830	87.75	7.99	102.38	0.4885	0.4805	0.89	2
17	169	85	147	49.28	66.21	-21.89	0.4304	0.2368	49.32	67.05	-21.28	0.4339	0.2371	0.37	1
18	61	135	167	53.96	-36.06	-32.32	0.1970	0.2995	53.49	-35.33	-33.26	0.1957	0.2960	0.73	2
19	245	245	242	97.24	0.69	1.92	0.3497	0.3611	97.14	0.83	1.09	0.3485	0.3597	0.83	2
20	200	201	201	81.12	-0.49	-0.30	0.3444	0.3584	81.05	-0.04	-0.30	0.3451	0.3581	0.67	2
21	160	161	162	66.41	0.21	-0.89	0.3442	0.3563	66.35	0.92	-0.45	0.3465	0.3566	1.13	3
22	120	120	121	50.50	0.96	-0.57	0.3464	0.3557	50.46	1.10	0.07	0.3487	0.3572	0.65	2
23	84	85	86	35.92	-0.32	-0.82	0.3419	0.3562	36.01	0.10	-0.27	0.3450	0.3574	0.83	2
24	52	53	54	20.95	-0.26	-1.39	0.3379	0.3522	21.09	0.67	-0.63	0.3456	0.3541	1.58	3
													Mean	0.56	1.54

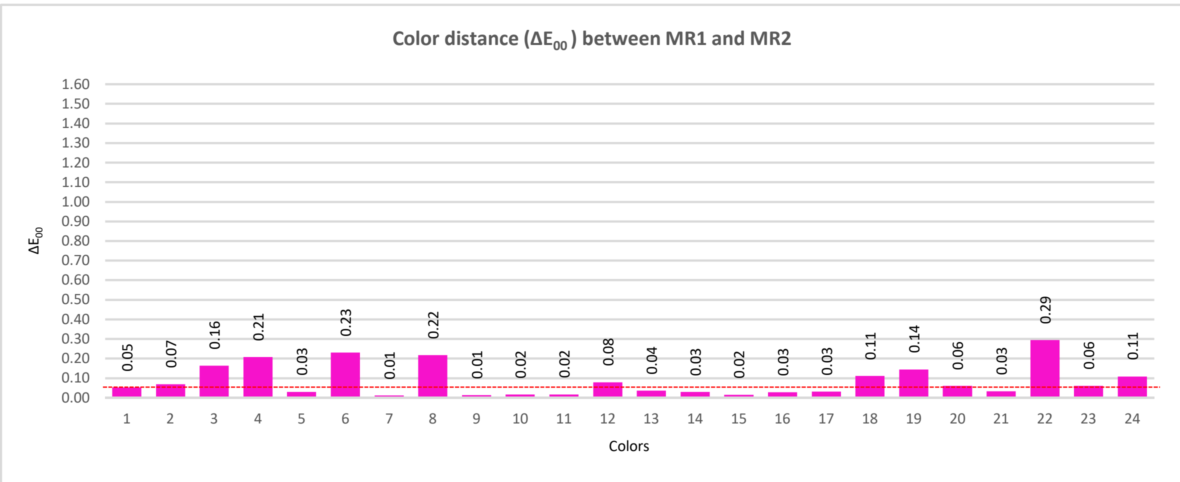


4| 3 ColorChecker values based on the used display profile



1.1.1 - Data basis - results of reference measurements

Color		Measured values MR 1						Measured values MR 2						MR1 vs MR2	
		L*	a*	b*	x	y	ΔE_{00}	L*	a*	b*	x	y	ΔE_{00}	ΔE_{00}	Rating
	1	38.43	16.26	16.08	0.4452	0.3776	0.53	38.43	16.33	16.08	0.4452	0.3776	0.58	0.05	0
	2	65.59	25.74	28.27	0.4562	0.3828	0.55	65.59	25.63	28.28	0.4562	0.3828	0.50	0.07	0
	3	49.68	-9.26	-27.12	0.2534	0.2904	0.34	49.66	-9.03	-27.10	0.2534	0.2904	0.44	0.16	0
	4	45.23	-17.98	27.02	0.3680	0.4717	0.46	45.21	-17.62	26.98	0.3680	0.4717	0.58	0.21	1
	5	53.27	10.79	-35.51	0.2769	0.2581	0.33	53.28	10.74	-35.49	0.2769	0.2581	0.34	0.03	0
	6	73.78	-52.23	5.91	0.2647	0.4241	0.27	73.74	-52.05	5.49	0.2647	0.4241	0.34	0.23	1
	7	64.71	54.74	74.51	0.5799	0.3880	0.50	64.72	54.74	74.53	0.5799	0.3880	0.49	0.01	0
	8	38.63	15.61	-59.57	0.2030	0.1737	0.35	38.61	15.30	-59.60	0.2030	0.1737	0.41	0.22	1
	9	50.66	66.50	23.03	0.5588	0.3103	0.35	50.67	66.53	23.05	0.5588	0.3103	0.35	0.01	0
	10	28.75	22.25	-23.93	0.3191	0.2385	0.41	28.75	22.27	-23.92	0.3191	0.2385	0.40	0.02	0
	11	79.09	-32.04	81.75	0.4062	0.5378	0.36	79.08	-32.00	81.72	0.4062	0.5378	0.37	0.02	0
	12	75.60	30.01	89.02	0.5292	0.4406	0.15	75.60	30.16	89.02	0.5292	0.4406	0.23	0.08	0
	13	28.02	17.97	-58.47	0.1849	0.1462	0.30	28.01	17.89	-58.42	0.1849	0.1462	0.31	0.04	0
	14	61.36	-54.76	46.91	0.3149	0.5594	0.30	61.33	-54.73	46.87	0.3149	0.5594	0.32	0.03	0
	15	42.89	69.00	33.22	0.6132	0.3091	0.29	42.90	69.01	33.25	0.6132	0.3091	0.29	0.02	0
	16	87.75	7.96	102.39	0.4885	0.4805	0.88	87.74	8.01	102.37	0.4885	0.4805	0.91	0.03	0
	17	49.31	67.07	-21.32	0.4339	0.2371	0.36	49.32	67.02	-21.24	0.4339	0.2371	0.37	0.03	0
	18	53.51	-35.39	-33.17	0.1957	0.2960	0.68	53.47	-35.27	-33.35	0.1957	0.2960	0.79	0.11	0
	19	97.14	0.78	1.09	0.3485	0.3597	0.80	97.13	0.88	1.08	0.3485	0.3597	0.86	0.14	0
	20	81.05	-0.05	-0.28	0.3451	0.3581	0.65	81.04	-0.02	-0.32	0.3451	0.3581	0.69	0.06	0
	21	66.36	0.91	-0.45	0.3465	0.3566	1.11	66.34	0.93	-0.45	0.3465	0.3566	1.14	0.03	0
	22	50.46	1.20	0.07	0.3487	0.3572	0.71	50.45	0.99	0.06	0.3487	0.3572	0.61	0.29	1
	23	36.01	0.08	-0.27	0.3450	0.3574	0.80	36.01	0.12	-0.26	0.3450	0.3574	0.85	0.06	0
	24	21.09	0.64	-0.59	0.3456	0.3541	1.56	21.09	0.70	-0.66	0.3456	0.3541	1.60	0.11	0
						Mean	0.54					Mean	0.57	Mean 0.09	0.17

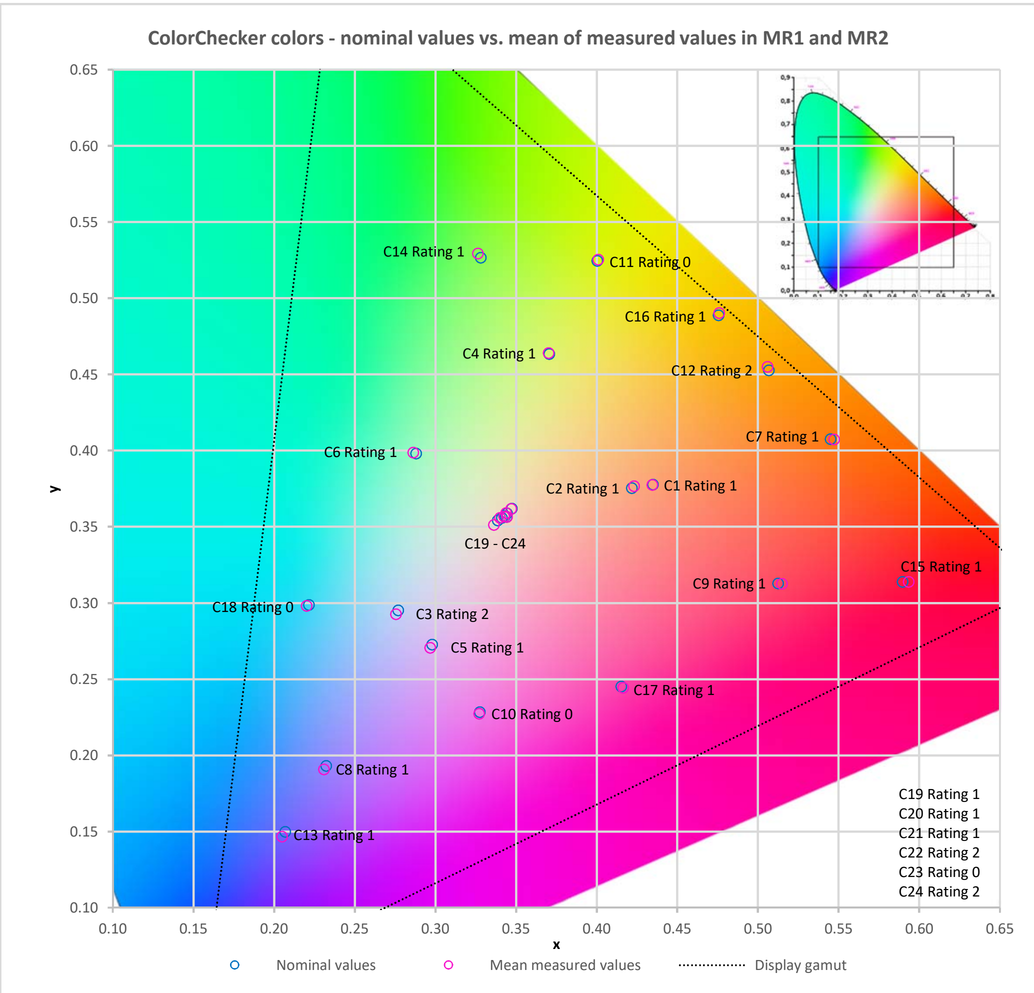


4| 3 ColorChecker values based on the used display profile

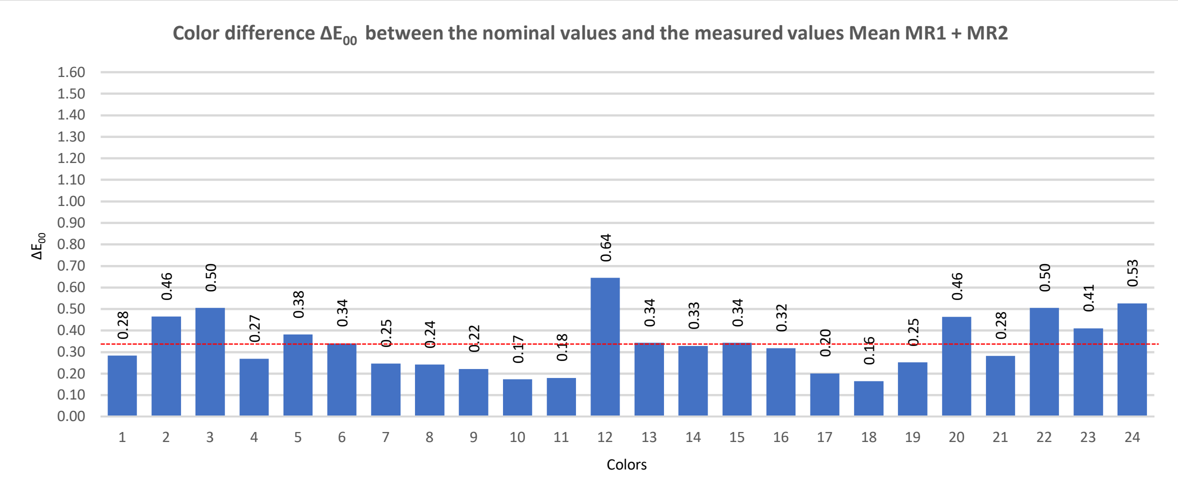
1.2 - Defined target values - ColorChecker Basis (CC) - Display 2 (AdobeRGB)

	Device values			Nominal values					Mean measured values						
Color	R	G	B	L*	a*	b*	x	y	L*	a*	b*	x	y	ΔE_{00}	Rating
1	107	82	70	37.51	14.09	14.38	0.4350	0.3776	37.21	13.99	14.20	0.4347	0.3774	0.28	1
2	184	146	129	64.56	18.29	18.24	0.4220	0.3752	64.61	18.29	18.95	0.4234	0.3765	0.46	1
3	101	122	153	50.23	-2.51	-23.61	0.2771	0.2951	49.88	-2.13	-24.33	0.2758	0.2925	0.50	2
4	95	107	69	43.66	-15.49	24.94	0.3707	0.4632	43.39	-15.63	24.94	0.3704	0.4640	0.27	1
5	128	127	173	54.42	13.01	-29.25	0.2980	0.2725	54.15	13.30	-29.87	0.2968	0.2706	0.38	1
6	129	188	171	71.96	-34.53	2.26	0.2882	0.3980	71.95	-35.37	2.16	0.2865	0.3986	0.34	1
7	201	123	56	60.81	38.23	63.49	0.5452	0.4074	60.65	38.69	64.25	0.5473	0.4072	0.25	1
8	77	92	166	39.58	18.46	-51.20	0.2324	0.1929	39.41	18.92	-51.95	0.2310	0.1906	0.24	1
9	174	83	97	48.64	53.92	13.57	0.5126	0.3127	48.58	54.50	13.93	0.5150	0.3124	0.22	1
10	86	61	104	29.35	27.70	-25.89	0.3276	0.2283	29.15	27.84	-26.03	0.3273	0.2273	0.17	0
11	167	188	75	73.72	-28.96	68.42	0.4004	0.5245	73.76	-28.95	69.04	0.4011	0.5253	0.18	0
12	213	160	55	70.88	19.15	78.26	0.5068	0.4526	70.95	18.33	79.34	0.5061	0.4548	0.64	2
13	49	65	143	28.20	24.31	-55.88	0.2070	0.1498	27.86	24.92	-56.72	0.2050	0.1467	0.34	1
14	99	148	80	57.11	-42.63	38.50	0.3282	0.5264	57.13	-43.63	38.92	0.3264	0.5293	0.33	1
15	155	52	59	39.51	59.62	26.87	0.5898	0.3138	39.47	60.24	27.68	0.5935	0.3137	0.34	1
16	227	197	52	81.50	1.32	93.41	0.4758	0.4888	81.57	0.97	94.70	0.4760	0.4903	0.32	1
17	169	85	147	49.02	57.96	-21.16	0.4153	0.2451	49.02	58.68	-21.24	0.4166	0.2443	0.20	1
18	61	135	167	52.47	-24.69	-29.35	0.2216	0.2987	52.45	-25.00	-29.67	0.2203	0.2980	0.16	0
19	245	245	242	96.60	-0.58	1.70	0.3476	0.3618	96.58	-0.74	1.59	0.3472	0.3617	0.25	1
20	200	201	201	81.32	-0.53	-0.16	0.3446	0.3587	81.03	-0.82	-0.20	0.3440	0.3589	0.46	1
21	160	161	162	66.69	-0.32	-0.80	0.3434	0.3571	66.61	-0.43	-1.04	0.3427	0.3567	0.28	1
22	120	120	121	50.77	0.24	-0.69	0.3444	0.3563	50.27	0.25	-0.62	0.3446	0.3565	0.50	2
23	84	85	86	35.84	-0.36	-0.94	0.3414	0.3558	35.65	-0.61	-1.06	0.3402	0.3558	0.41	0
24	52	53	54	20.91	-0.41	-1.09	0.3387	0.3540	20.70	-0.34	-1.61	0.3365	0.3512	0.53	2

Mean	0.34	1.00

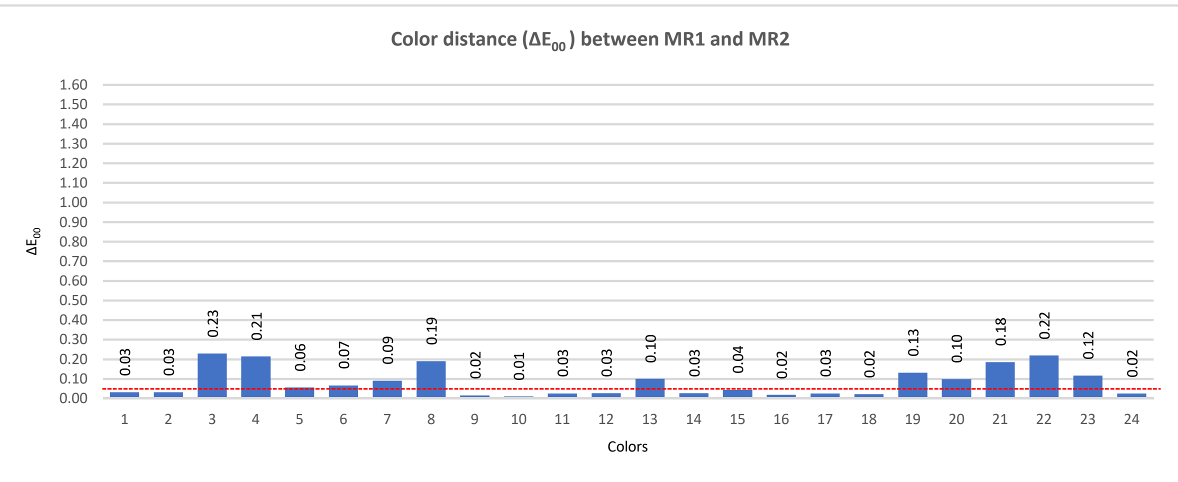


4| 3 ColorChecker values based on the used display profile



1.2.1 - Data basis - results of reference measurements

		Measured values MR 1						Measured values MR 2						MR1 vs MR2	
Color		L*	a*	b*	x	y	ΔE_{00}	L*	a*	b*	x	y	ΔE_{00}	ΔE_{00}	Rating
	1	37.21	13.97	14.19	0.4346	0.3774	0.28	37.20	14.01	14.21	0.4347	0.3774	0.28	0.03	0
	2	64.61	18.26	18.93	0.4233	0.3765	0.46	64.61	18.31	18.97	0.4235	0.3765	0.47	0.03	0
	3	49.87	-1.99	-24.37	0.2759	0.2922	0.58	49.89	-2.26	-24.28	0.2756	0.2927	0.45	0.23	1
	4	43.37	-15.45	24.91	0.3708	0.4636	0.27	43.40	-15.80	24.97	0.3699	0.4644	0.31	0.21	1
	5	54.15	13.24	-29.83	0.2968	0.2707	0.37	54.14	13.35	-29.91	0.2968	0.2704	0.39	0.06	0
	6	71.94	-35.30	2.12	0.2865	0.3984	0.32	71.95	-35.43	2.19	0.2864	0.3987	0.36	0.07	0
	7	60.64	38.76	64.23	0.5474	0.4070	0.26	60.66	38.61	64.27	0.5471	0.4073	0.24	0.09	0
	8	39.39	18.81	-52.00	0.2306	0.1905	0.28	39.42	19.02	-51.89	0.2314	0.1907	0.24	0.19	0
	9	48.58	54.48	13.91	0.5149	0.3124	0.21	48.58	54.51	13.94	0.5151	0.3124	0.23	0.02	0
	10	29.15	27.84	-26.03	0.3273	0.2273	0.17	29.14	27.83	-26.02	0.3273	0.2273	0.17	0.01	0
	11	73.75	-28.96	69.01	0.4010	0.5253	0.17	73.77	-28.94	69.06	0.4011	0.5253	0.19	0.03	0
	12	70.96	18.35	79.34	0.5061	0.4548	0.63	70.94	18.31	79.33	0.5060	0.4548	0.65	0.03	0
	13	27.85	24.86	-56.75	0.2047	0.1466	0.35	27.86	24.97	-56.68	0.2053	0.1467	0.34	0.10	0
	14	57.13	-43.66	38.91	0.3263	0.5293	0.34	57.12	-43.60	38.92	0.3265	0.5293	0.32	0.03	0
	15	39.49	60.28	27.70	0.5936	0.3137	0.35	39.45	60.20	27.65	0.5934	0.3137	0.33	0.04	0
	16	81.58	0.98	94.70	0.4760	0.4902	0.32	81.56	0.96	94.70	0.4760	0.4903	0.32	0.02	0
	17	49.02	58.67	-21.26	0.4165	0.2442	0.20	49.01	58.69	-21.21	0.4167	0.2443	0.20	0.03	0
	18	52.45	-25.01	-29.69	0.2202	0.2979	0.17	52.44	-24.98	-29.65	0.2203	0.2980	0.16	0.02	0
	19	96.58	-0.78	1.60	0.3471	0.3618	0.31	96.57	-0.69	1.57	0.3472	0.3616	0.20	0.13	0
	20	81.03	-0.85	-0.22	0.3439	0.3589	0.50	81.02	-0.79	-0.17	0.3441	0.3589	0.43	0.10	0
	21	66.61	-0.42	-1.13	0.3425	0.3564	0.35	66.60	-0.44	-0.94	0.3428	0.3569	0.23	0.18	0
	22	50.30	0.18	-0.60	0.3445	0.3566	0.49	50.24	0.32	-0.64	0.3447	0.3563	0.55	0.22	1
	23	35.65	-0.65	-1.07	0.3400	0.3558	0.46	35.64	-0.57	-1.05	0.3404	0.3557	0.36	0.12	0
	24	20.70	-0.33	-1.62	0.3364	0.3511	0.54	20.70	-0.34	-1.60	0.3365	0.3512	0.52	0.02	0
						Mean	0.35					Mean	0.33	Mean 0.08	0.13

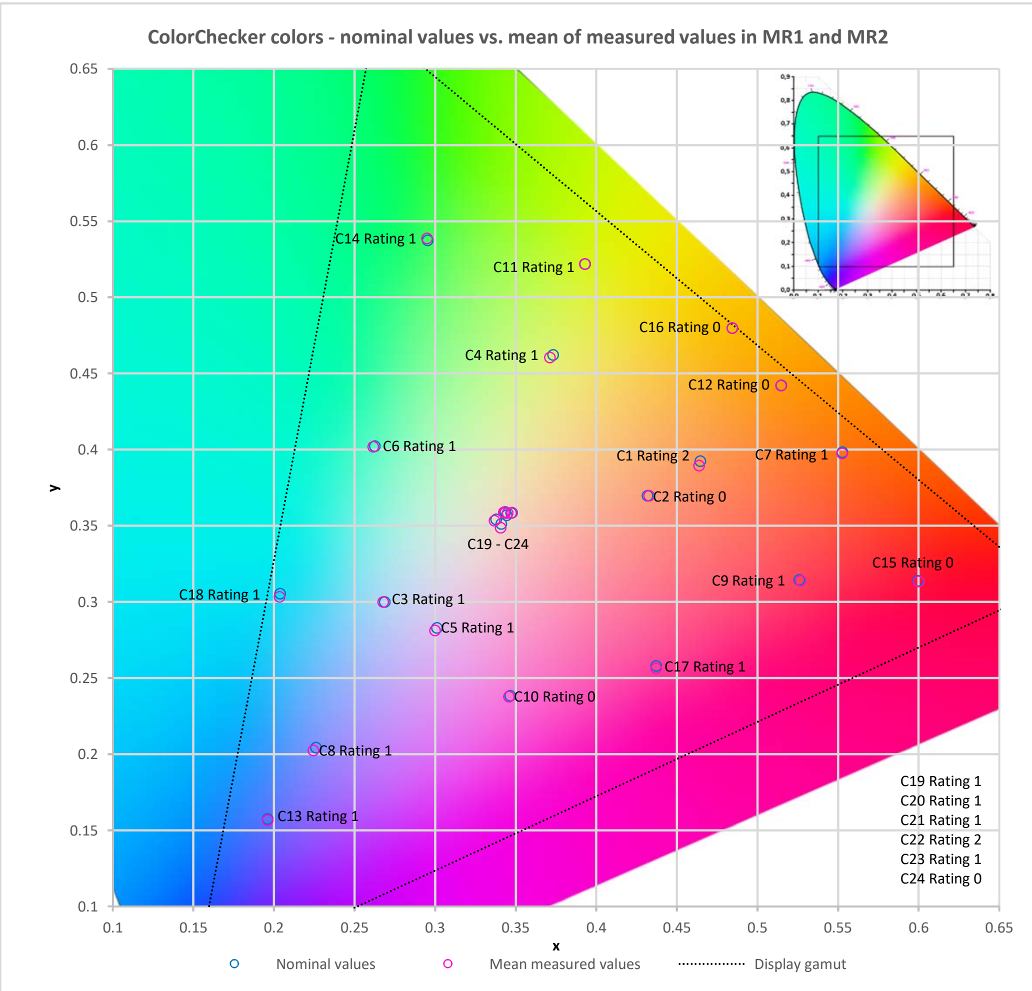


4| 3 ColorChecker values based on the used display profile

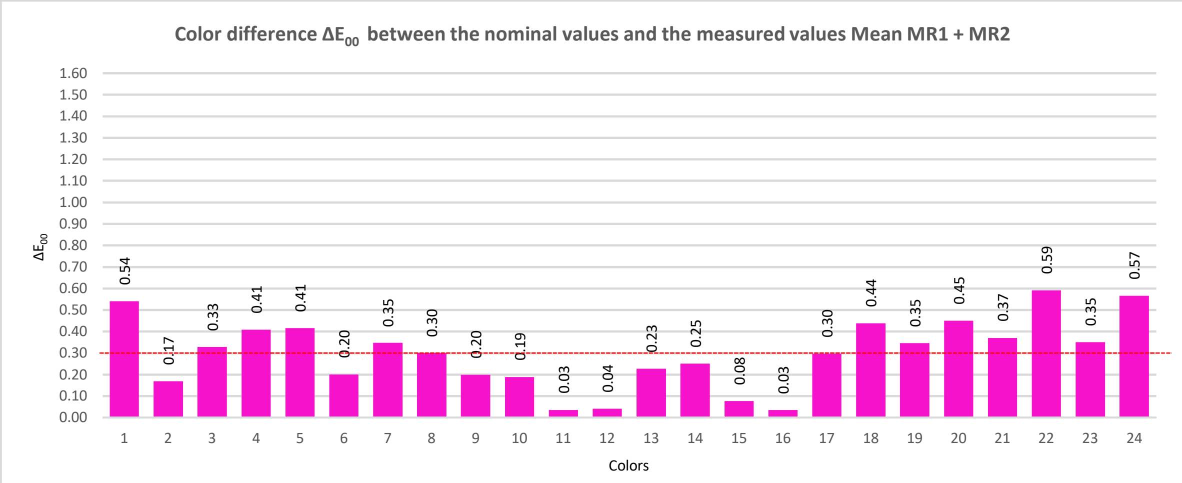
1.3 - Defined target values - ColorChecker Basis (CC) - Display 3 (sRGB)

Color		Device values			Nominal values					Mean measured values						
		R	G	B	L*	a*	b*	x	y	L*	a*	b*	x	y	ΔE_{00}	Rating
	1	116	81	57	38.46	16.67	22.38	0.4647	0.3923	38.26	17.10	21.92	0.4640	0.3894	0.54	2
	2	199	147	129	65.92	23.40	18.83	0.4320	0.3696	65.77	23.60	19.00	0.4329	0.3697	0.17	0
	3	91	122	156	49.73	-6.72	-23.09	0.2689	0.2998	49.61	-7.10	-23.16	0.2679	0.2998	0.33	1
	4	94	108	64	43.97	-14.80	25.24	0.3733	0.4621	43.83	-14.87	24.52	0.3714	0.4603	0.41	1
	5	130	128	176	55.15	10.34	-26.06	0.3013	0.2829	54.83	10.51	-26.62	0.3000	0.2811	0.41	1
	6	92	190	172	70.05	-45.12	-0.49	0.2628	0.4022	69.98	-45.41	-0.77	0.2617	0.4017	0.20	1
	7	224	124	47	63.45	44.26	64.39	0.5529	0.3982	63.30	44.41	63.69	0.5527	0.3974	0.35	1
	8	68	91	170	39.46	11.28	-47.88	0.2262	0.2043	39.17	11.39	-48.37	0.2246	0.2024	0.30	1
	9	198	82	97	51.75	58.97	17.44	0.5261	0.3143	51.57	59.20	17.40	0.5270	0.3137	0.20	1
	10	94	58	106	30.55	29.55	-22.71	0.3468	0.2382	30.35	29.41	-22.80	0.3460	0.2377	0.19	0
	11	159	189	63	72.35	-30.04	63.52	0.3931	0.5217	72.34	-30.12	63.54	0.3930	0.5218	0.03	0
	12	230	162	39	72.30	24.74	77.57	0.5149	0.4421	72.33	24.73	77.42	0.5147	0.4420	0.04	0
	13	35	63	147	27.69	16.87	-53.34	0.1961	0.1573	27.55	17.24	-53.46	0.1963	0.1564	0.23	1
	14	67	149	74	55.01	-52.23	33.95	0.2955	0.5372	54.75	-52.37	34.03	0.2950	0.5385	0.25	1
	15	180	49	57	42.90	65.08	31.01	0.5997	0.3137	42.87	65.24	30.95	0.6001	0.3133	0.08	0
	16	238	198	20	81.70	6.51	92.91	0.4845	0.4798	81.68	6.55	92.81	0.4845	0.4797	0.03	0
	17	193	84	151	52.35	61.02	-15.04	0.4373	0.2578	52.14	61.57	-15.50	0.4373	0.2563	0.30	1
	18	0	136	170	51.11	-33.31	-28.83	0.2039	0.3053	50.84	-32.81	-29.28	0.2035	0.3033	0.44	1
	19	245	243	243	95.99	0.90	0.28	0.3474	0.3583	95.70	1.05	0.50	0.3480	0.3585	0.35	1
	20	200	202	202	81.15	-0.93	-0.27	0.3437	0.3588	80.66	-0.88	-0.56	0.3433	0.3583	0.45	1
	21	161	163	163	66.83	-0.96	-0.29	0.3433	0.3589	66.47	-1.08	-0.46	0.3427	0.3586	0.37	1
	22	121	121	122	50.92	0.18	-0.57	0.3446	0.3567	50.95	-0.10	-0.15	0.3451	0.3583	0.59	2
	23	82	84	86	35.70	-0.74	-1.58	0.3380	0.3541	35.38	-0.77	-1.83	0.3371	0.3532	0.35	1
	24	49	49	51	20.64	0.41	-1.30	0.3411	0.3511	20.37	0.71	-1.65	0.3407	0.3486	0.57	0

Mean	0.30	0.79



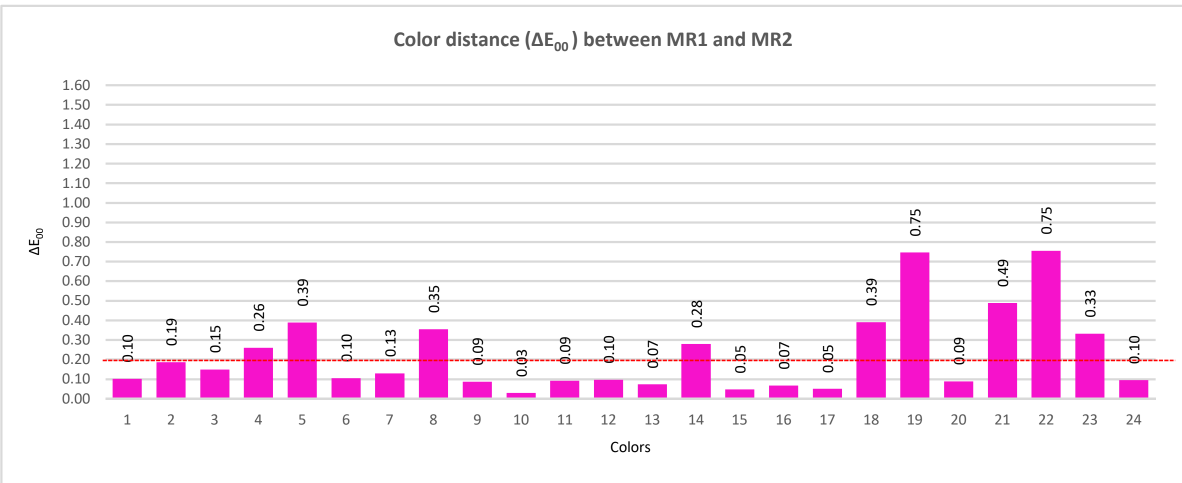
4| 3 ColorChecker values based on the used display profile



1.3.1 - Data basis - results of reference measurements

Color		Measured values MR 1						Measured values MR 2					
		L*	a*	b*	x	y	ΔE_{00}	L*	a*	b*	x	y	ΔE_{00}
	1	38.28	17.17	21.96	0.4654	0.3903	0.56	38.23	17.02	21.87	0.4625	0.3885	0.53
	2	65.78	23.43	18.97	0.4325	0.3698	0.14	65.75	23.77	19.03	0.4333	0.3695	0.23
	3	49.64	-7.18	-23.16	0.2677	0.2999	0.38	49.58	-7.01	-23.16	0.2680	0.2997	0.28
	4	43.87	-14.92	24.78	0.3719	0.4611	0.29	43.79	-14.82	24.26	0.3709	0.4595	0.53
	5	54.90	10.18	-26.31	0.3002	0.2822	0.36	54.75	10.84	-26.92	0.2998	0.2800	0.54
	6	70.01	-45.54	-0.77	0.2615	0.4018	0.22	69.94	-45.27	-0.77	0.2619	0.4016	0.19
	7	63.30	44.27	63.67	0.5524	0.3976	0.30	63.29	44.55	63.70	0.5530	0.3971	0.40
	8	39.17	11.12	-48.35	0.2240	0.2026	0.41	39.17	11.65	-48.38	0.2251	0.2022	0.28
	9	51.56	59.07	17.42	0.5268	0.3139	0.19	51.57	59.33	17.38	0.5272	0.3135	0.21
	10	30.36	29.43	-22.81	0.3460	0.2376	0.18	30.33	29.39	-22.79	0.3460	0.2377	0.20
	11	72.39	-30.13	63.63	0.3930	0.5219	0.05	72.29	-30.11	63.44	0.3929	0.5217	0.07
	12	72.34	24.80	77.39	0.5148	0.4418	0.08	72.31	24.65	77.45	0.5146	0.4421	0.04
	13	27.57	17.19	-53.46	0.1962	0.1565	0.19	27.53	17.29	-53.46	0.1963	0.1563	0.26
	14	54.76	-52.76	33.96	0.2939	0.5390	0.29	54.74	-51.98	34.09	0.2961	0.5380	0.28
	15	42.88	65.24	30.91	0.5999	0.3132	0.09	42.85	65.24	30.99	0.6002	0.3133	0.07
	16	81.69	6.49	92.80	0.4844	0.4798	0.02	81.67	6.61	92.82	0.4846	0.4796	0.06
	17	52.16	61.53	-15.52	0.4371	0.2563	0.28	52.12	61.60	-15.47	0.4374	0.2562	0.31
	18	50.83	-33.29	-29.34	0.2024	0.3034	0.36	50.84	-32.33	-29.21	0.2045	0.3031	0.57
	19	95.08	1.08	0.44	0.3479	0.3584	0.62	96.31	1.02	0.56	0.3480	0.3586	0.37
	20	80.68	-0.85	-0.58	0.3433	0.3582	0.46	80.63	-0.90	-0.54	0.3432	0.3583	0.45
	21	66.54	-1.24	-0.41	0.3425	0.3589	0.47	66.40	-0.91	-0.51	0.3429	0.3583	0.41
	22	50.94	0.15	-0.21	0.3455	0.3578	0.36	50.96	-0.35	-0.08	0.3447	0.3588	0.92
	23	35.40	-0.88	-1.80	0.3368	0.3535	0.37	35.36	-0.65	-1.85	0.3373	0.3529	0.40
	24	20.38	0.68	-1.66	0.3405	0.3486	0.54	20.35	0.74	-1.63	0.3409	0.3485	0.59
						Mean	0.30					Mean	0.34

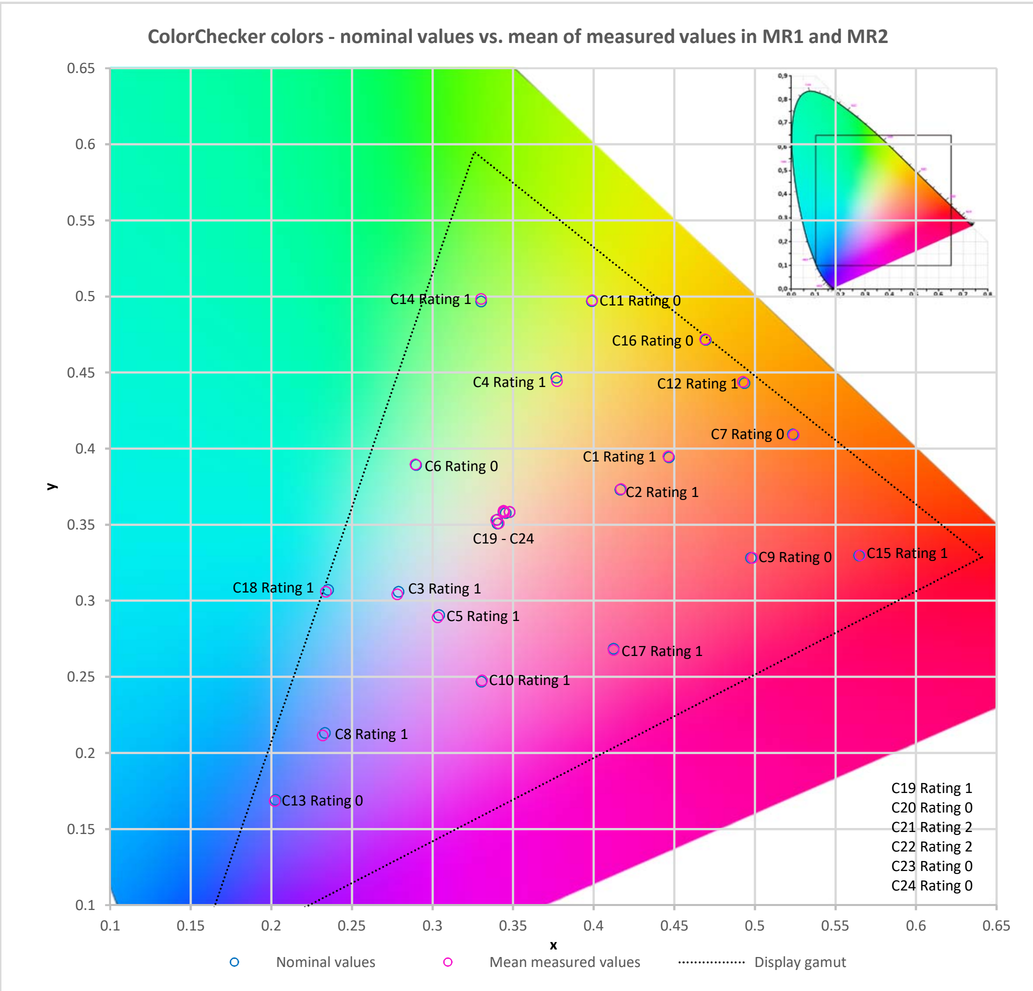
Color	MR1 vs MR2	
	ΔE_{00}	Rating
1	0.10	0
2	0.19	0
3	0.15	0
4	0.26	1
5	0.39	1
6	0.10	0
7	0.13	0
8	0.35	1
9	0.09	0
10	0.03	0
11	0.09	0
12	0.10	0
13	0.07	0
14	0.28	1
15	0.05	0
16	0.07	0
17	0.05	0
18	0.39	1
19	0.75	2
20	0.09	0
21	0.49	1
22	0.75	2
23	0.33	1
24	0.10	0
Mean	0.22	0.46



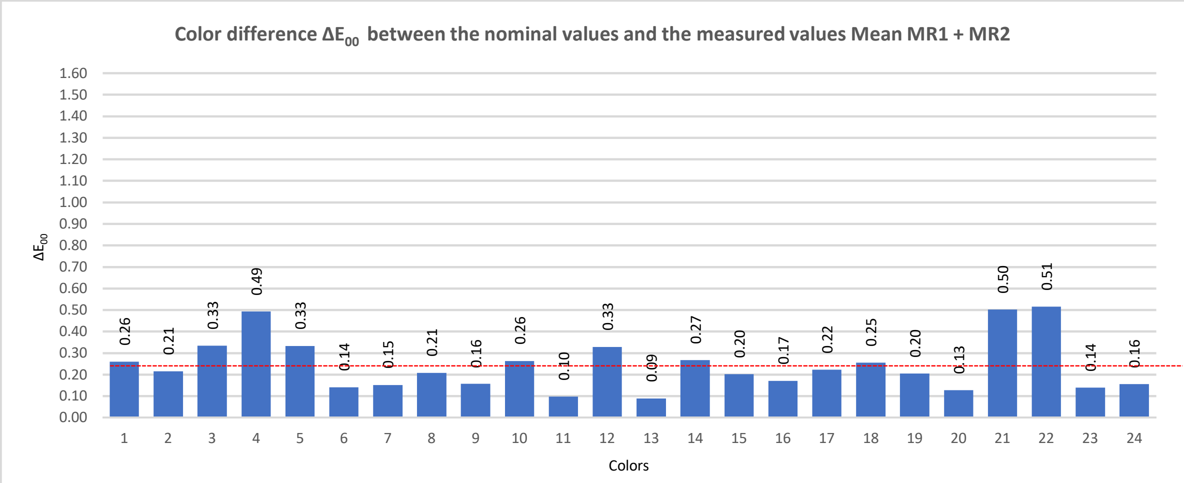
4| 3 ColorChecker values based on the used display profile

1.4 - Defined target values - ColorChecker Basis (CC) - Display 4 (sRGB)

	Device values			Nominal values					Mean measured values						
Color	R	G	B	L*	a*	b*	x	y	L*	a*	b*	x	y	ΔE_{00}	Rating
1	116	81	57	38.22	12.97	19.84	0.4469	0.3941	38.02	12.74	19.83	0.4465	0.3947	0.26	1
2	199	147	129	65.61	17.72	16.75	0.4167	0.3729	65.43	17.62	16.92	0.4171	0.3734	0.21	1
3	91	122	156	50.50	-5.19	-20.76	0.2790	0.3057	50.30	-4.97	-21.14	0.2783	0.3042	0.33	1
4	94	108	64	44.09	-11.21	22.49	0.3769	0.4464	43.79	-10.67	22.00	0.3774	0.4443	0.49	1
5	130	128	176	55.71	8.65	-23.69	0.3042	0.2904	55.44	8.81	-24.11	0.3033	0.2891	0.33	1
6	92	190	172	70.59	-30.73	0.00	0.2899	0.3891	70.66	-31.02	0.08	0.2896	0.3896	0.14	0
7	224	124	47	62.61	33.53	56.40	0.5236	0.4092	62.50	33.75	56.42	0.5243	0.4088	0.15	0
8	68	91	170	39.95	10.42	-44.93	0.2333	0.2131	39.77	10.63	-45.44	0.2320	0.2114	0.21	1
9	198	82	97	50.52	46.74	15.63	0.4976	0.3280	50.40	46.91	15.82	0.4987	0.3281	0.16	0
10	94	58	106	30.37	23.16	-22.09	0.3304	0.2466	30.14	22.87	-21.74	0.3309	0.2476	0.26	1
11	159	189	63	72.31	-22.47	55.74	0.3990	0.4967	72.36	-22.60	56.05	0.3991	0.4973	0.10	0
12	230	162	39	71.52	18.67	66.67	0.4936	0.4429	71.57	18.17	66.81	0.4928	0.4438	0.33	1
13	35	63	147	28.66	14.48	-50.16	0.2027	0.1691	28.57	14.64	-50.37	0.2022	0.1683	0.09	0
14	67	149	74	55.79	-35.99	30.87	0.3303	0.4965	55.54	-36.18	31.17	0.3304	0.4982	0.27	1
15	180	49	57	41.49	52.33	26.79	0.5647	0.3296	41.31	52.27	26.99	0.5657	0.3299	0.20	1
16	238	198	20	81.16	4.63	78.09	0.4696	0.4713	81.24	4.37	78.28	0.4693	0.4718	0.17	0
17	193	84	151	51.43	48.85	-15.08	0.4124	0.2684	51.25	49.13	-15.32	0.4125	0.2675	0.22	1
18	0	136	170	52.52	-21.71	-25.74	0.2354	0.3070	52.34	-21.83	-26.16	0.2340	0.3058	0.25	1
19	245	243	243	95.93	1.21	0.28	0.3479	0.3581	95.91	1.10	0.42	0.3479	0.3584	0.20	1
20	200	202	202	80.76	-0.32	-0.34	0.3446	0.3582	80.66	-0.30	-0.24	0.3448	0.3584	0.13	0
21	161	163	163	66.60	-0.39	-0.36	0.3442	0.3581	66.58	-0.69	-0.10	0.3442	0.3590	0.50	2
22	121	121	122	51.46	0.20	-0.25	0.3455	0.3576	51.39	-0.14	-0.29	0.3447	0.3579	0.51	2
23	82	84	86	35.66	-0.09	-1.54	0.3401	0.3532	35.63	-0.16	-1.65	0.3396	0.3529	0.14	0
24	49	49	51	20.71	0.39	-1.43	0.3404	0.3505	20.64	0.46	-1.33	0.3412	0.3508	0.16	0
													Mean	0.24	0.71

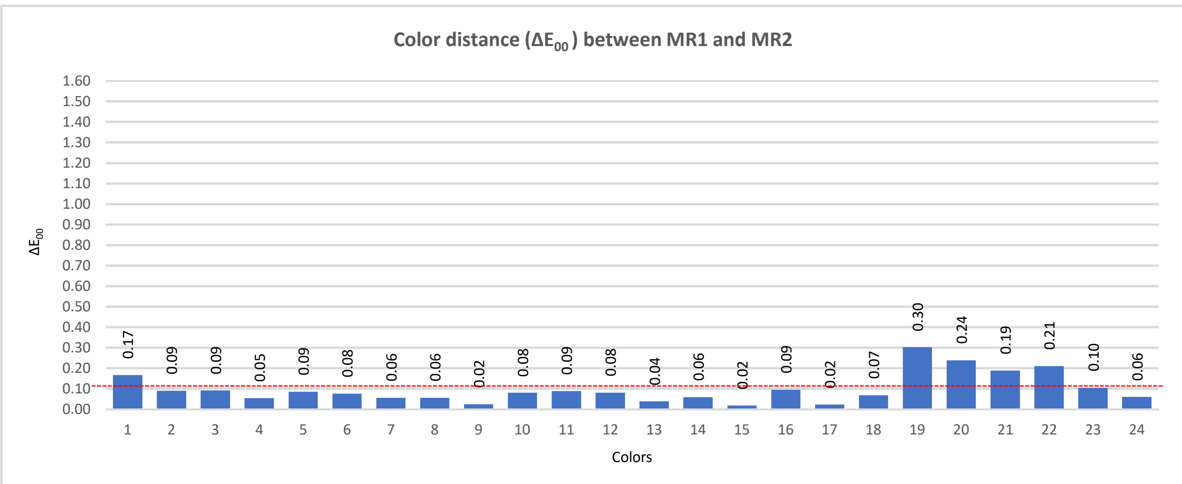


4| 3 ColorChecker values based on the used display profile



1.4.1 - Data basis - results of reference measurements

Color		Measured values MR 1						Measured values MR 2							MR1 vs MR2	
Color		L*	a*	b*	x	y	ΔE_{00}	L*	a*	b*	x	y	ΔE_{00}		ΔE_{00}	Rating
	1	37.94	12.71	19.89	0.4467	0.3950	0.33	38.09	12.76	19.76	0.4462	0.3944	0.19		0.17	0
	2	65.44	17.56	16.92	0.4169	0.3735	0.24	65.42	17.68	16.91	0.4172	0.3733	0.20		0.09	0
	3	50.30	-5.02	-21.13	0.2782	0.3043	0.31	50.29	-4.92	-21.14	0.2784	0.3041	0.37		0.09	0
	4	43.78	-10.70	22.01	0.3773	0.4444	0.48	43.80	-10.63	21.98	0.3774	0.4441	0.51		0.05	1
	5	55.44	8.75	-24.10	0.3032	0.2891	0.34	55.43	8.86	-24.12	0.3034	0.2890	0.34		0.09	0
	6	70.66	-31.10	0.09	0.2895	0.3897	0.18	70.65	-30.93	0.06	0.2897	0.3894	0.11		0.08	0
	7	62.50	33.70	56.42	0.5242	0.4089	0.13	62.49	33.80	56.42	0.5244	0.4087	0.18		0.06	0
	8	39.77	10.58	-45.43	0.2319	0.2114	0.21	39.76	10.67	-45.45	0.2320	0.2113	0.20		0.06	0
	9	50.40	46.87	15.82	0.4986	0.3281	0.16	50.40	46.94	15.82	0.4988	0.3280	0.16		0.02	0
	10	30.14	22.79	-21.73	0.3307	0.2477	0.28	30.14	22.94	-21.75	0.3310	0.2474	0.25		0.08	0
	11	72.37	-22.68	56.05	0.3989	0.4974	0.12	72.35	-22.51	56.05	0.3993	0.4972	0.10		0.09	0
	12	71.57	18.10	66.81	0.4926	0.4439	0.37	71.56	18.23	66.80	0.4929	0.4437	0.29		0.08	0
	13	28.57	14.61	-50.36	0.2022	0.1683	0.08	28.56	14.67	-50.37	0.2022	0.1682	0.10		0.04	0
	14	55.54	-36.25	31.18	0.3302	0.4983	0.27	55.53	-36.10	31.16	0.3305	0.4980	0.27		0.06	0
	15	41.31	52.24	26.99	0.5656	0.3299	0.20	41.31	52.29	26.99	0.5657	0.3298	0.20		0.02	0
	16	81.24	4.29	78.28	0.4691	0.4719	0.22	81.23	4.45	78.27	0.4694	0.4717	0.13		0.09	0
	17	51.25	49.10	-15.32	0.4124	0.2675	0.22	51.24	49.16	-15.32	0.4125	0.2674	0.23		0.02	0
	18	52.35	-21.89	-26.15	0.2339	0.3058	0.25	52.33	-21.77	-26.17	0.2341	0.3057	0.27		0.07	0
	19	95.88	1.17	0.30	0.3478	0.3581	0.07	95.93	1.03	0.53	0.3480	0.3586	0.35		0.30	1
	20	80.67	-0.38	-0.22	0.3447	0.3585	0.16	80.65	-0.22	-0.25	0.3449	0.3583	0.19		0.24	1
	21	66.59	-0.75	-0.09	0.3441	0.3591	0.59	66.57	-0.62	-0.11	0.3443	0.3589	0.42		0.19	0
	22	51.40	-0.21	-0.28	0.3445	0.3580	0.62	51.38	-0.07	-0.30	0.3448	0.3578	0.41		0.21	1
	23	35.64	-0.19	-1.64	0.3395	0.3530	0.17	35.62	-0.12	-1.65	0.3397	0.3528	0.12		0.10	0
	24	20.64	0.44	-1.32	0.3411	0.3509	0.14	20.63	0.48	-1.33	0.3413	0.3507	0.18		0.06	0
						Mean	0.25					Mean	0.24	Mean	0.10	0.17



4| 4 Colormatching data

1.1 - Task 1 - Digital device values and duration

C 1	Target values CC						time (s)
	R	107	G	82	B	70	time (s)
MR1	107	0	82	0	71	1	68
MR2	107	0	82	0	70	0	65

C 2	Target values CC						time (s)
	R	184	G	146	B	129	time (s)
MR1	183	-1	146	0	130	1	27
MR2	184	0	146	0	129	0	42

C 3	Target values CC						time (s)
	R	101	G	122	B	153	time (s)
MR1	100	-1	122	0	155	2	26
MR2	100	-1	122	0	154	1	52

C 4	Target values CC						time (s)
	R	95	G	107	B	69	time (s)
MR1	97	2	107	0	72	3	43
MR2	95	0	107	0	69	0	55

C 5	Target values CC						time (s)
	R	128	G	127	B	173	time (s)
MR1	129	1	127	0	175	2	37
MR2	128	0	127	0	172	-1	46

C 6	Target values CC						time (s)
	R	129	G	188	B	171	time (s)
MR1	132	3	188	0	174	3	34
MR2	129	0	188	0	171	0	54

C 8	Target values CC						time (s)
	R	77	G	92	B	166	time (s)
MR1	79	2	91	-1	169	3	243
MR2	79	2	91	-1	168	2	62

C 11	Target values CC						time (s)
	R	167	G	188	B	75	time (s)
MR1	167	0	188	0	71	-4	36
MR2	167	0	188	0	74	-1	157

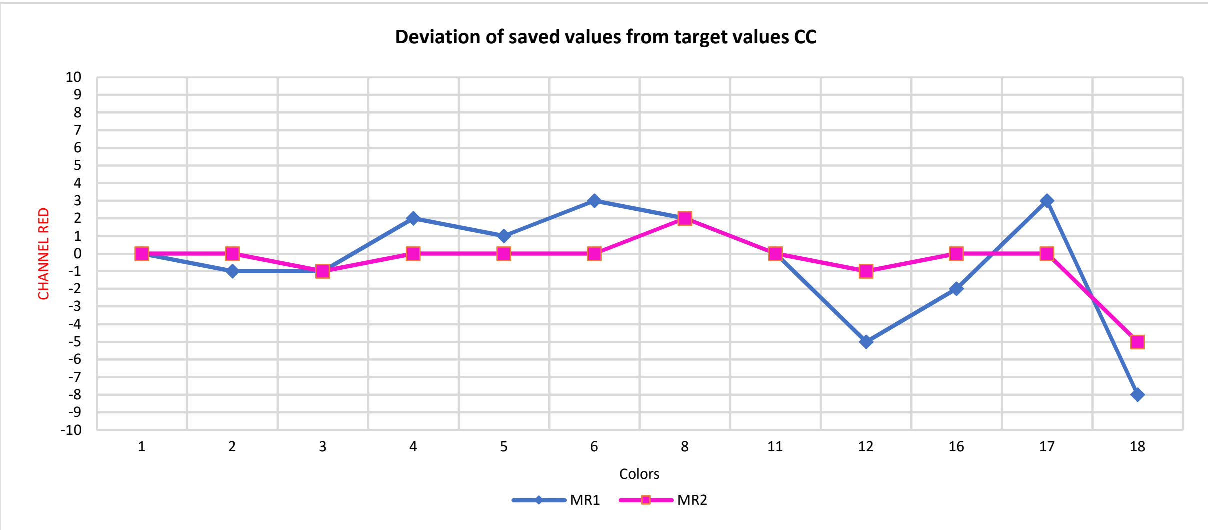
C 12	Target values CC						time (s)
	R	213	G	160	B	55	time (s)
MR1	208	-5	154	-6	18	-37	39
MR2	212	-1	160	0	52	-3	36

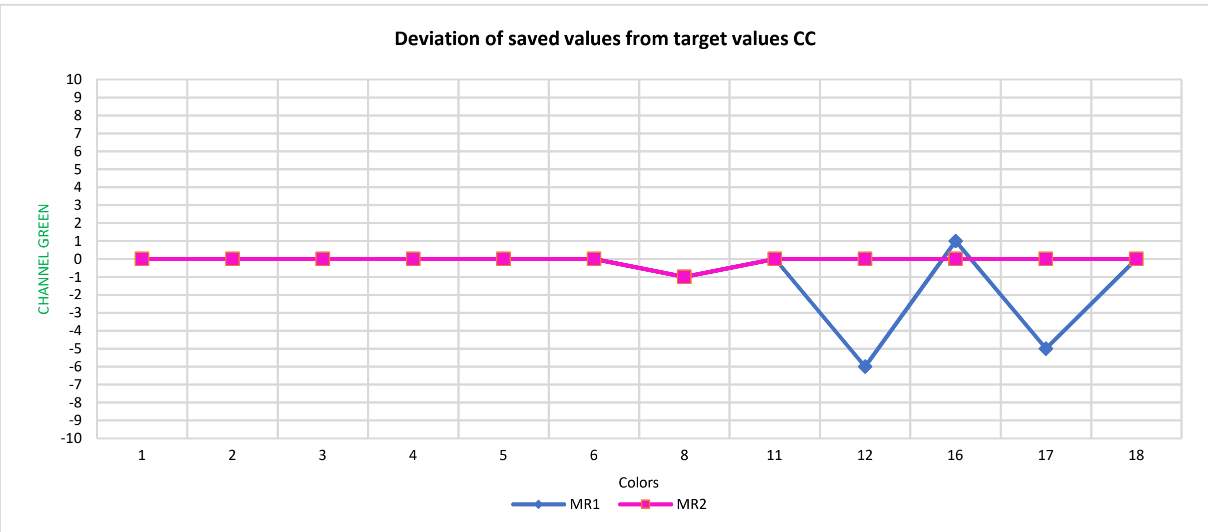
C 16	Target values CC						time (s)
	R	227	G	197	B	52	time (s)
MR1	225	-2	198	1	57	5	29
MR2	227	0	197	0	53	1	42

C 17	Target values CC						time (s)
	R	169	G	85	B	147	time (s)
MR1	172	3	80	-5	154	7	42
MR2	169	0	85	0	148	1	167

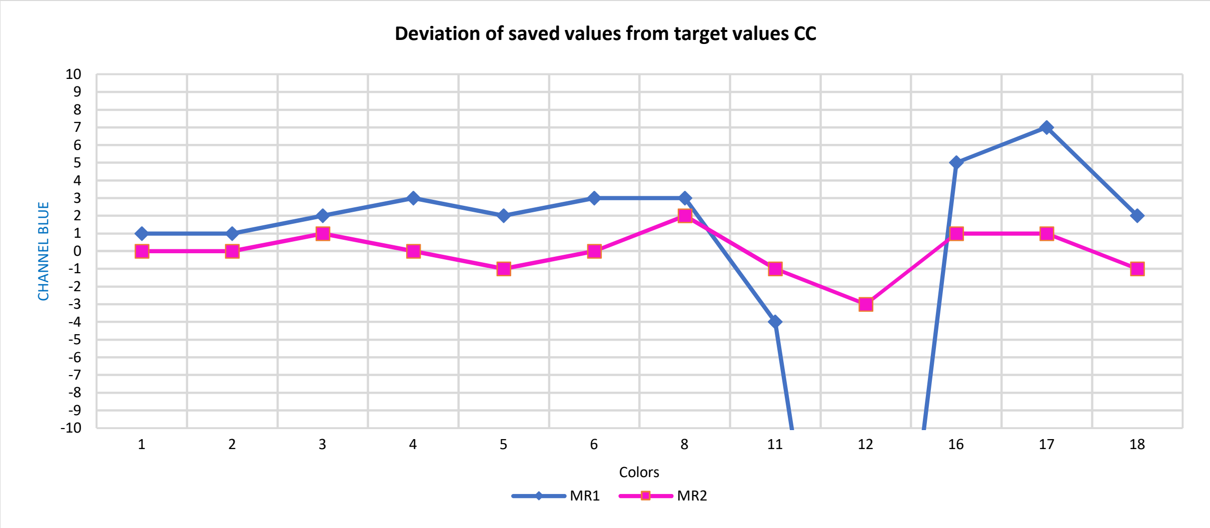
C 18	Target values CC						time (s)
	R	61	G	135	B	167	time (s)
MR1	53	-8	135	0	169	2	48
MR2	56	-5	135	0	166	-1	27

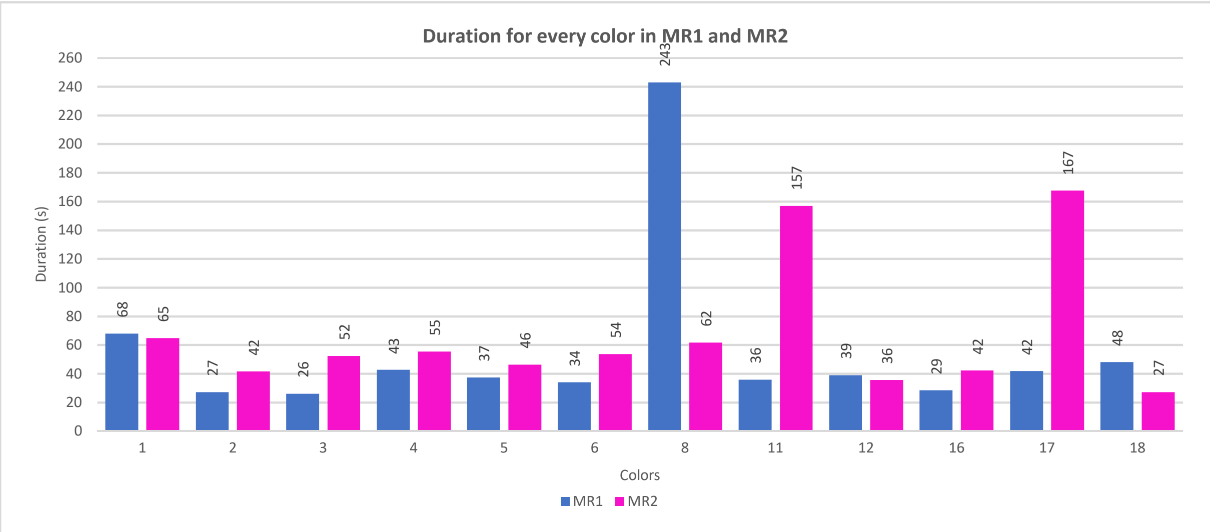
1.1.1 - Joint visualization of the saved values





4| 4 Colormatching data





4| 4 Colormatching data

1.2 - Task 2 - Digital device values and duration

C 1	Target values CC						
	R	107	G	82	B	70	time (s)
MR1	108	1	82	0	71	1	60
MR2	107	0	82	0	71	1	72

C 2	Target values CC						
	R	184	G	146	B	129	time (s)
MR1	184	0	146	0	131	2	33
MR2	185	1	147	1	130	1	49

C 3	Target values CC						
	R	101	G	122	B	153	time (s)
MR1	103	2	122	0	152	-1	38
MR2	101	0	123	1	154	1	44

C 4	Target values CC						
	R	95	G	107	B	69	time (s)
MR1	93	-2	107	0	69	0	48
MR2	94	-1	107	0	67	-2	33

C 5	Target values CC						
	R	128	G	127	B	173	time (s)
MR1	127	-1	127	0	171	-2	74
MR2	129	1	127	0	175	2	49

C 6	Target values CC						
	R	129	G	188	B	171	time (s)
MR1	129	0	188	0	172	1	18
MR2	129	0	188	0	172	1	67

C 7	Target values CC						
	R	201	G	123	B	56	time (s)
MR1	203	2	124	1	65	9	109
MR2	201	0	122	-1	58	2	51

C 8	Target values CC						
	R	77	G	92	B	166	time (s)
MR1	78	1	92	0	169	3	45
MR2	79	2	90	-2	169	3	56

C 9	Target values CC						
	R	174	G	83	B	97	time (s)
MR1	176	2	83	0	100	3	47
MR2	174	0	83	0	98	1	38

C 10	Target values CC						
	R	86	G	61	B	104	time (s)
MR1	86	0	61	0	104	0	46
MR2	85	-1	61	0	104	0	23

C 11	Target values CC						
	R	167	G	188	B	75	time (s)
MR1	171	4	188	0	83	8	39
MR2	166	-1	188	0	66	-9	26

C 12	Target values CC						
	R	213	G	160	B	55	time (s)
MR1	209	-4	160	0	42	-13	30
MR2	212	-1	159	-1	43	-12	31

C 13	Target values CC						
	R	49	G	65	B	143	time (s)
MR1	55	6	58	-7	152	9	85
MR2	52	3	64	-1	146	3	67

C 14	Target values CC						
	R	99	G	148	B	80	time (s)
MR1	96	-3	148	0	79	-1	39
MR2	100	1	148	0	82	2	87

C 15	Target values CC						
	R	155	G	52	B	59	time (s)
MR1	158	3	46	-6	63	4	48
MR2	153	-2	55	3	56	-3	31

C 16	Target values CC						
	R	227	G	197	B	52	time (s)
MR1	219	-8	192	-5	15	-37	13
MR2	228	1	198	1	53	1	33

C 17	Target values CC						
	R	169	G	85	B	147	time (s)
MR1	169	0	86	1	145	-2	67
MR2	168	-1	87	2	143	-4	66

C 18	Target values CC						
	R	61	G	135	B	167	time (s)
MR1	63	2	135	0	173	6	32
MR2	67	6	134	-1	170	3	53

C 19	Target values CC						
	R	245	G	245	B	242	time (s)
MR1	244	-1	246	1	238	-4	27
MR2	244	-1	245	0	246	4	47

C 20	Target values CC						
	R	200	G	201	B	201	time (s)
MR1	200	0	202	1	200	-1	43
MR2	200	0	202	1	204	3	49

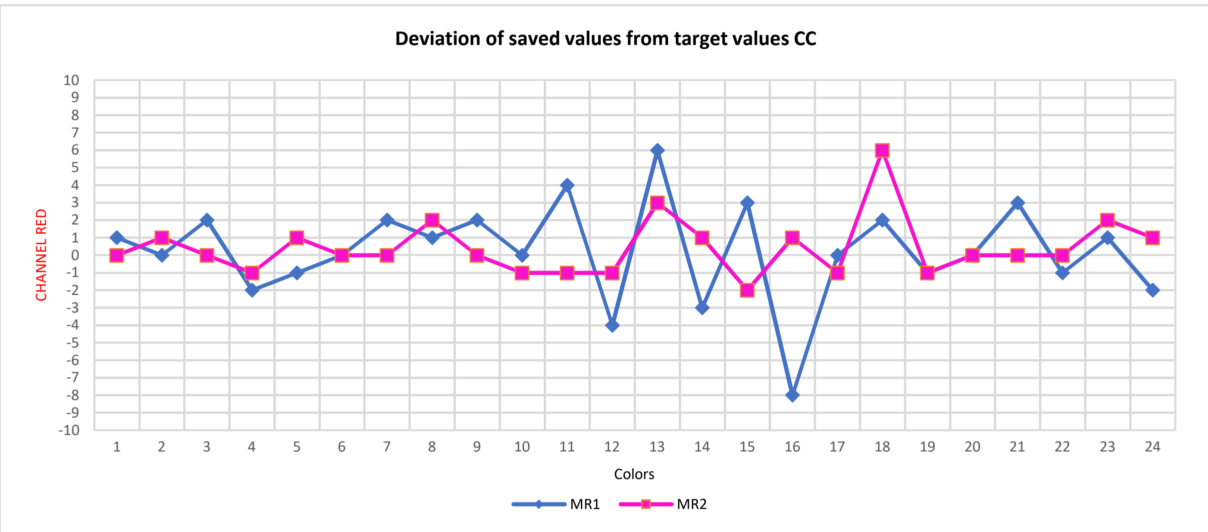
C 21	Target values CC						
	R	160	G	161	B	162	time (s)
MR1	163	3	160	-1	158	-4	30
MR2	160	0	161	0	161	-1	38

C 22	Target values CC						
	R	120	G	120	B	121	time (s)
MR1	119	-1	121	1	120	-1	21
MR2	120	0	120	0	122	1	44

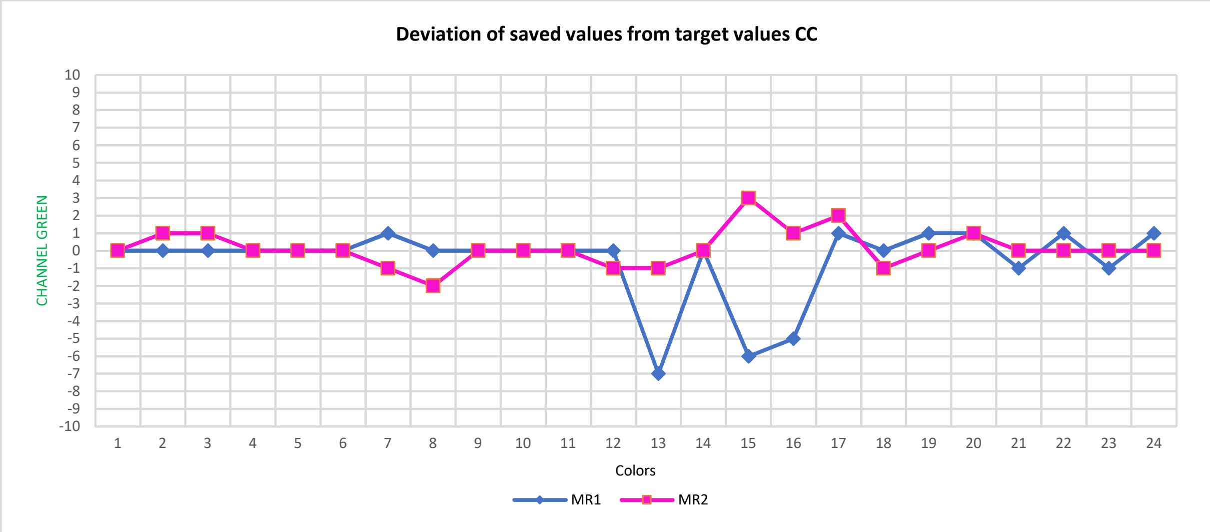
C 23	Target values CC						
	R	84	G	85	B	86	time (s)
MR1	85	1	84	-1	87	1	35
MR2	86	2	85	0	85	-1	52

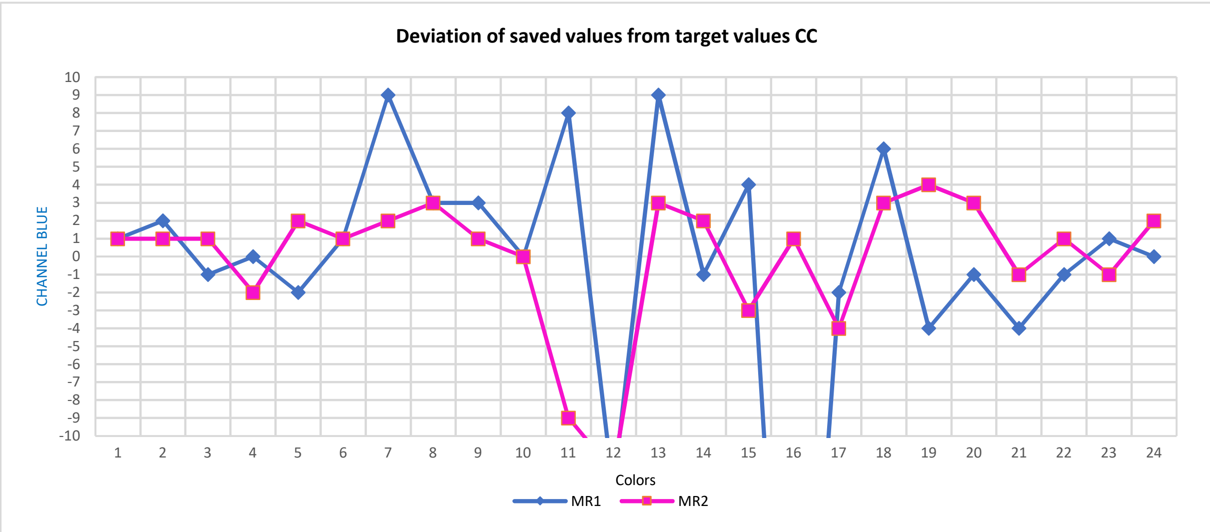
C 24	Target values CC						
	R	52	G	53	B	54	time (s)
MR1	50	-2	54	1	54	0	24
MR2	53	1	53	0	56	2	61

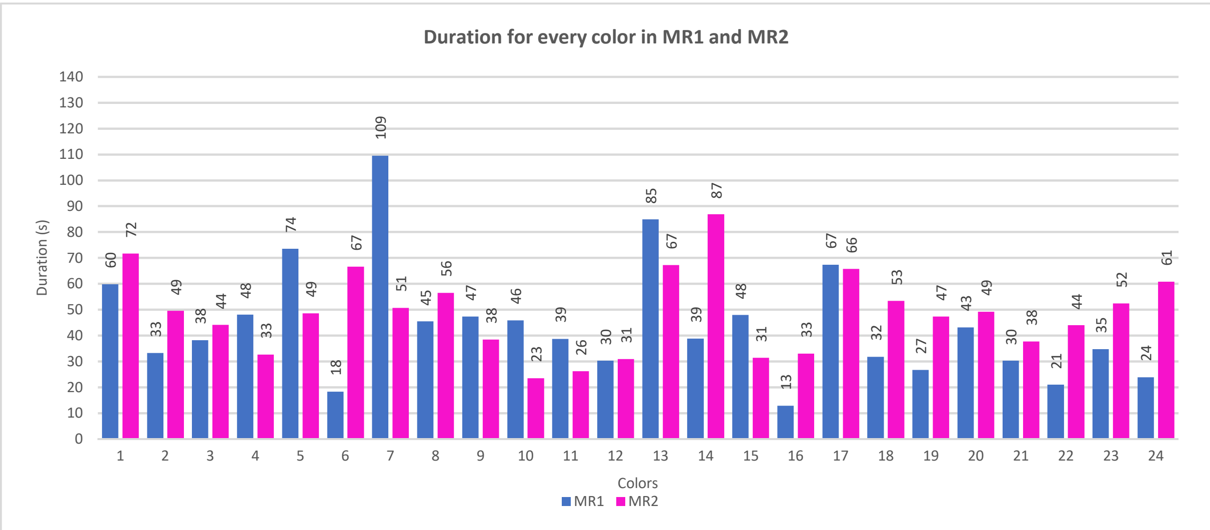
1.2.1 - Task 2 - Joint visualization of the saved values



4| 4 Colormatching data







4| 4 Colormatching data

2.1 - Task 1 - Digital device values, the resulting nominal values and the measured values

	Device Values MR 1			Nominal Values MR 1					Measured Values MR 1					
#	R	G	B	L*	a*	b*	x	y	L*	a*	b*	x	y	ΔE_{00}
1	107	82	71	38.57	15.69	15.46	0.4413	0.3771	38.43	16.49	15.36	0.4436	0.3753	0.64
2	183	146	130	65.83	24.20	26.66	0.4496	0.3822	65.42	25.25	26.83	0.4526	0.3811	0.67
3	100	122	155	49.94	-9.36	-28.69	0.2497	0.2863	49.56	-8.82	-29.21	0.2490	0.2841	0.56
4	97	107	72	45.73	-16.32	25.80	0.3698	0.4638	45.37	-15.55	25.67	0.3718	0.4624	0.57
5	129	127	175	53.60	12.22	-36.63	0.2772	0.2550	53.29	11.93	-36.68	0.2760	0.2548	0.38
6	132	188	174	73.97	-48.33	3.65	0.2682	0.4146	73.83	-49.14	4.33	0.2675	0.4168	0.45
8	79	91	170	38.99	18.68	-62.05	0.2036	0.1682	38.50	18.89	-62.73	0.2013	0.1655	0.46
11	167	188	71	79.26	-32.60	82.68	0.4059	0.5396	79.16	-32.06	83.29	0.4075	0.5394	0.34
12	208	154	18	76.15	31.41	95.85	0.5354	0.4419	75.50	32.65	95.50	0.5381	0.4396	0.83
16	225	198	57	87.51	4.72	100.98	0.4825	0.4848	87.66	5.85	101.30	0.4844	0.4832	0.59
17	172	80	154	49.23	71.20	-27.49	0.4229	0.2228	49.09	71.69	-27.15	0.4252	0.2228	0.25
18	53	135	169	54.08	-37.53	-34.00	0.1914	0.2956	53.57	-36.76	-34.80	0.1903	0.2922	0.72

	Device Values MR 2			Nominal Values MR 2					Measured Values MR 2					
#	R	G	B	L*	a*	b*	x	y	L*	a*	b*	x	y	ΔE_{00}
1	107	82	70	38.59	15.62	15.98	0.4427	0.3786	38.41	16.41	16.13	0.4458	0.3774	0.57
2	184	146	129	65.98	24.83	27.80	0.4530	0.3832	65.57	25.78	28.35	0.4564	0.3828	0.57
3	100	122	154	49.93	-9.71	-27.89	0.2509	0.2888	49.53	-9.47	-28.07	0.2504	0.2877	0.44
4	95	107	69	45.66	-18.34	27.35	0.3677	0.4726	45.21	-17.64	27.04	0.3691	0.4711	0.57
5	128	127	172	53.52	10.58	-34.44	0.2794	0.2611	53.23	10.10	-34.57	0.2778	0.2608	0.50
6	129	188	171	73.91	-51.41	5.89	0.2662	0.4231	73.71	-52.10	5.96	0.2649	0.4241	0.25
8	79	91	168	38.90	17.65	-60.46	0.2053	0.1716	38.53	18.45	-61.58	0.2033	0.1681	0.40
11	167	188	74	79.18	-32.56	81.40	0.4049	0.5382	79.11	-32.09	82.13	0.4065	0.5383	0.34
12	212	160	52	75.66	29.09	90.13	0.5283	0.4427	75.58	29.51	89.76	0.5289	0.4418	0.29
16	227	197	53	87.40	6.26	101.80	0.4856	0.4830	87.70	7.93	102.20	0.4884	0.4805	0.88
17	169	85	148	49.27	66.35	-22.67	0.4282	0.2353	49.30	67.16	-21.78	0.4327	0.2362	0.45
18	56	135	166	54.03	-38.22	-31.68	0.1945	0.3029	53.52	-37.47	-32.52	0.1933	0.2993	0.74

2.1.1 - Task 1 - Mean value of the reference measurements MR1 and MR2

	Nominal Values Mean MR1 + MR2					Measured Values Mean MR1 + MR2					
#	L*	a*	b*	x	y	L*	a*	b*	x	y	ΔE_{00}
1	38.58	15.66	15.72	0.4420	0.3779	38.42	16.45	15.75	0.4447	0.3764	0.60
2	65.91	24.52	27.23	0.4513	0.3827	65.50	25.52	27.59	0.4545	0.3820	0.61
3	49.94	-9.54	-28.29	0.2503	0.2876	49.55	-9.15	-28.64	0.2497	0.2859	0.49
4	45.70	-17.33	26.58	0.3688	0.4682	45.29	-16.60	26.36	0.3705	0.4668	0.57
5	53.56	11.40	-35.54	0.2783	0.2581	53.26	11.02	-35.63	0.2769	0.2578	0.43
6	73.94	-49.87	4.77	0.2672	0.4189	73.77	-50.62	5.15	0.2662	0.4205	0.32
8	38.95	18.17	-61.26	0.2045	0.1699	38.52	18.67	-62.16	0.2023	0.1668	0.41
11	79.22	-32.58	82.04	0.4054	0.5389	79.14	-32.08	82.71	0.4070	0.5389	0.34
12	75.91	30.25	92.99	0.5319	0.4423	75.54	31.08	92.63	0.5335	0.4407	0.55
16	87.46	5.49	101.39	0.4841	0.4839	87.68	6.89	101.75	0.4864	0.4819	0.74
17	49.25	68.78	-25.08	0.4256	0.2291	49.20	69.43	-24.47	0.4290	0.2295	0.33
18	54.06	-37.88	-32.84	0.1930	0.2993	53.55	-37.12	-33.66	0.1918	0.2958	0.73

2.1.2 - Task 1 - Color distances ΔE_{00} of the reference measurements MR1 and MR2 for evaluating repeatability

	Nominal Values				Measured Values			
	Color Distance ΔE_{00}				Color Distance ΔE_{00}			
#	MR1 vs MR2	MR1 + MR2 vs Mean $_{MR1+MR2}$			MR1 vs MR2	MR1 + MR2 vs Mean $_{MR1+MR2}$		
1	0.38	0.19	0.19	0.19	0.55	0.28	0.28	0.28
2	0.54	0.27	0.27	0.27	0.73	0.37	0.36	0.37
3	0.39	0.19	0.19	0.19	0.60	0.30	0.31	0.30
4	1.15	0.59	0.57	0.58	1.20	0.61	0.59	0.60
5	0.70	0.35	0.35	0.35	0.73	0.36	0.37	0.36
6	1.48	0.75	0.73	0.74	1.20	0.61	0.59	0.60
8	0.32	0.16	0.16	0.16	0.27	0.13	0.13	0.13
11	0.32	0.16	0.16	0.16	0.30	0.15	0.15	0.15
12	1.22	0.60	0.62	0.61	1.35	0.66	0.68	0.67
16	0.80	0.40	0.40	0.40	1.07	0.54	0.53	0.54
17	1.83	0.90	0.93	0.92	1.98	0.97	1.01	0.99
18	1.10	0.55	0.56	0.55	1.08	0.53	0.54	0.54

4| 4 Colormatching data

2.1.3 - Task 1 - Color distances ΔE_{00} of the reference measurements MR1 and MR2 to the target values (CC)

	Nominal Values											
	ColorChecker CC			MR1				MR2				Mean
#	L*	a*	b*	L*	a*	b*	ΔE_{00}	L*	a*	b*	ΔE_{00}	ΔE_{00}
1	38.60	15.61	16.13	38.57	15.69	15.46	0.49	38.59	15.62	15.98	0.11	0.30
2	65.98	24.83	27.80	65.83	24.20	26.66	0.54	65.98	24.83	27.80	0.00	0.27
3	50.00	-9.41	-26.94	49.94	-9.36	-28.69	0.68	49.93	-9.71	-27.89	0.43	0.56
4	45.66	-18.34	27.35	45.73	-16.32	25.80	1.15	45.66	-18.34	27.35	0.00	0.58
5	53.52	10.91	-35.25	53.60	12.22	-36.63	0.53	53.52	10.58	-34.44	0.29	0.41
6	73.91	-51.41	5.89	73.97	-48.33	3.65	1.48	73.91	-51.41	5.89	0.00	0.74
8	39.00	15.09	-58.77	38.99	18.68	-62.05	1.27	38.90	17.65	-60.46	1.09	1.18
11	79.15	-32.55	80.97	79.26	-32.60	82.68	0.43	79.18	-32.56	81.40	0.11	0.27
12	75.61	29.82	89.29	76.15	31.41	95.85	1.34	75.66	29.09	90.13	0.54	0.94
16	87.45	6.29	102.03	87.51	4.72	100.98	0.82	87.40	6.26	101.80	0.05	0.43
17	49.28	66.21	-21.89	49.23	71.20	-27.49	2.08	49.27	66.35	-22.67	0.29	1.19
18	53.96	-36.06	-32.32	54.08	-37.53	-34.00	0.71	54.03	-38.22	-31.68	1.00	0.85

	Measured Values											
	ColorChecker CC			MR1				MR2				Mean
#	L*	a*	b*	L*	a*	b*	ΔE_{00}	L*	a*	b*	ΔE_{00}	ΔE_{00}
1	38.43	16.30	16.08	38.43	16.49	15.36	0.57	38.41	16.41	16.13	0.08	0.32
2	65.59	25.69	28.28	65.42	25.25	26.83	0.71	65.57	25.78	28.35	0.05	0.38
3	49.67	-9.15	-27.11	49.56	-8.82	-29.21	0.83	49.53	-9.47	-28.07	0.46	0.65
4	45.22	-17.80	27.00	45.37	-15.55	25.67	1.28	45.21	-17.64	27.04	0.10	0.69
5	53.28	10.77	-35.50	53.29	11.93	-36.68	0.46	53.23	10.10	-34.57	0.29	0.38
6	73.76	-52.14	5.70	73.83	-49.14	4.33	1.12	73.71	-52.10	5.96	0.15	0.63
8	38.62	15.46	-59.59	38.50	18.89	-62.73	1.22	38.53	18.45	-61.58	1.27	1.24
11	79.09	-32.02	81.74	79.16	-32.06	83.29	0.38	79.11	-32.09	82.13	0.09	0.24
12	75.60	30.09	89.02	75.50	32.65	95.50	1.31	75.58	29.51	89.76	0.44	0.87
16	87.75	7.99	102.38	87.66	5.85	101.30	1.10	87.70	7.93	102.20	0.05	0.57
17	49.32	67.05	-21.28	49.09	71.69	-27.15	2.15	49.30	67.16	-21.78	0.19	1.17
18	53.49	-35.33	-33.26	53.57	-36.76	-34.80	0.66	53.52	-37.47	-32.52	1.02	0.84

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2.2 · Task 2 - Digital device values, the resulting nominal values and the measured values

	Device Values MR 1			Nominal Values MR 1					Measured Values MR 1					
#	R	G	B	L*	a*	b*	x	y	L*	a*	b*	x	y	ΔE_{00}
1	108	82	71	38.71	16.57	15.75	0.4446	0.3761	38.59	17.29	15.38	0.4458	0.3737	0.68
2	184	146	131	65.91	16.57	25.98	0.4499	0.3798	65.50	25.89	26.43	0.4529	0.3795	5.91
3	103	122	152	50.13	-8.39	-25.86	0.2589	0.2937	49.67	-8.34	-25.72	0.2588	0.2936	0.47
4	93	107	69	45.50	-19.88	27.01	0.3626	0.4751	45.07	-19.59	26.64	0.3626	0.4743	0.45
5	127	127	171	53.44	9.60	-33.84	0.2789	0.2631	53.14	9.43	-34.11	0.2776	0.2622	0.39
6	129	188	172	73.89	-51.10	5.05	0.2653	0.4206	73.73	-51.81	5.18	0.2641	0.4218	0.25
7	203	124	65	65.01	54.67	69.80	0.5748	0.3854	64.89	55.40	70.11	0.5767	0.3843	0.27
8	78	92	169	39.17	16.89	-60.82	0.2036	0.1718	38.84	16.82	-61.54	0.2010	0.1696	0.45
9	176	83	100	51.27	67.04	21.47	0.5544	0.3081	51.05	67.98	21.63	0.5574	0.3067	0.32
10	86	61	104	29.05	22.89	-24.02	0.3208	0.2382	28.73	22.24	-23.85	0.3194	0.2387	0.41
11	171	188	83	79.20	-28.76	78.07	0.4093	0.5279	79.15	-28.41	79.01	0.4108	0.5284	0.35
12	209	160	42	75.81	27.08	92.59	0.5262	0.4474	75.60	27.70	92.19	0.5273	0.4462	0.42
13	55	58	152	27.29	30.64	-68.11	0.1835	0.1206	27.12	30.48	-68.10	0.1827	0.1201	0.16
14	96	148	79	61.60	-57.71	47.09	0.3085	0.5647	61.15	-57.10	46.77	0.3091	0.5641	0.42
15	158	46	63	42.59	72.41	30.07	0.6150	0.2994	42.84	72.92	30.76	0.6167	0.2997	0.35
16	219	192	15	88.19	4.82	105.23	0.4847	0.4868	87.87	8.43	105.07	0.4874	0.4844	1.87
17	169	86	145	49.46	65.36	-19.95	0.4345	0.2412	49.34	65.97	-18.88	0.4394	0.2424	0.50
18	63	135	173	54.00	-32.25	-36.91	0.1949	0.2838	53.55	-31.56	-37.49	0.1942	0.2812	0.61
19	244	246	238	97.37	-2.41	5.72	0.3513	0.3697	97.34	-2.33	5.18	0.3505	0.3688	0.44
20	200	202	200	81.43	-1.60	0.89	0.3447	0.3617	81.25	-1.24	0.78	0.3451	0.3611	0.52
21	163	160	158	66.48	2.34	2.63	0.3559	0.3619	66.32	1.41	1.75	0.3522	0.3610	1.43
22	119	121	120	50.82	-1.26	0.74	0.3447	0.3622	50.76	-0.62	1.20	0.3474	0.3627	1.02
23	85	84	87	35.68	1.43	-1.82	0.3437	0.3497	35.70	1.07	-0.90	0.3458	0.3536	0.98
24	50	54	54	21.16	-3.24	-1.01	0.3272	0.3608	21.05	-0.61	-0.75	0.3395	0.3562	3.50

	Device Values MR 2			Nominal Values MR 2					Measured Values MR 2					
#	R	G	B	L*	a*	b*	x	y	L*	a*	b*	x	y	ΔE_{00}
1	107	82	70	38.60	15.61	16.13	0.4431	0.3790	38.42	16.39	16.14	0.4457	0.3775	0.60
2	185	147	130	66.32	24.81	27.72	0.4524	0.3830	65.94	25.77	28.31	0.4559	0.3827	0.56
3	101	123	154	50.35	-10.11	-27.09	0.2526	0.2919	49.89	-9.36	-27.46	0.2526	0.2897	0.71
4	94	107	67	45.64	-19.35	28.50	0.3674	0.4781	45.22	-18.67	28.33	0.3690	0.4770	0.54
5	129	127	175	53.60	12.22	-36.63	0.2772	0.2550	53.29	11.83	-36.68	0.2760	0.2548	0.43
6	129	188	172	73.89	-51.10	5.05	0.2653	0.4206	73.73	-51.81	5.18	0.2641	0.4218	0.25
7	201	122	58	64.57	54.96	73.17	0.5794	0.3868	64.40	55.53	72.96	0.5806	0.3856	0.34
8	79	90	169	38.66	18.99	-61.70	0.2043	0.1680	38.28	19.45	-62.37	0.2028	0.1655	0.36
9	174	83	98	50.90	65.71	22.23	0.5545	0.3107	50.77	66.66	22.49	0.5575	0.3095	0.27
10	85	61	104	28.90	22.29	-24.28	0.3178	0.2377	28.78	21.79	-23.78	0.3183	0.2395	0.30
11	166	188	66	79.36	-33.53	84.66	0.4057	0.5432	79.25	-32.96	85.11	0.4072	0.5428	0.32
12	212	159	43	75.80	30.08	92.71	0.5316	0.4425	75.60	30.65	92.26	0.5325	0.4413	0.40
13	52	64	146	28.40	21.84	-61.85	0.1850	0.1387	28.24	21.15	-60.91	0.1857	0.1404	0.25
14	100	148	82	61.63	-54.30	45.88	0.3148	0.5552	61.20	-53.92	45.97	0.3154	0.5559	0.40
15	153	55	56	42.62	66.34	35.86	0.6137	0.3163	42.97	66.31	35.16	0.6109	0.3161	0.45
16	228	198	53	87.69	5.67	102.11	0.4846	0.4839	88.13	7.87	102.73	0.4883	0.4807	1.17
17	168	87	143	49.44	63.91	-18.32	0.4367	0.2454	49.35	64.87	-17.13	0.4426	0.2465	0.60
18	67	134	170	53.55	-31.26	-35.14	0.1993	0.2877	53.21	-31.03	-35.78	0.1979	0.2853	0.45
19	244	245	246	97.14	0.93	-2.13	0.3436	0.3544	96.97	1.55	-1.44	0.3456	0.3550	1.12
20	200	202	204	81.38	-1.06	-1.53	0.3412	0.3566	81.23	-0.06	-0.93	0.3439	0.3568	1.53
21	160	161	161	66.42	0.10	-0.14	0.3456	0.3581	66.31	0.41	0.09	0.3467	0.3583	0.52
22	120	120	122	50.50	1.05	-1.28	0.3448	0.3537	50.39	1.28	-0.40	0.3477	0.3558	0.91
23	86	85	85	36.11	1.12	0.14	0.3496	0.3572	36.10	0.64	-0.15	0.3471	0.3570	0.74
24	53	53	56	21.08	0.99	-2.75	0.3366	0.3427	21.23	0.81	-1.07	0.3440	0.3514	1.57

4| 4 Colormatching data

2.2.1 - Task 2 - Mean value of the reference measurements MR1 and MR2

	Nominal Values Mean MR1 + MR2					Measured Values Mean MR1 + MR2					
#	L*	a*	b*	x	y	L*	a*	b*	x	y	ΔE_{00}
1	38.66	16.09	15.94	0.4439	0.3776	38.51	16.84	15.76	0.4458	0.3756	0.63
2	66.12	20.69	26.85	0.4512	0.3814	65.72	25.83	27.37	0.4544	0.3811	3.05
3	50.24	-9.25	-26.48	0.2558	0.2928	49.78	-8.85	-26.59	0.2557	0.2917	0.54
4	45.57	-19.62	27.76	0.3650	0.4766	45.15	-19.13	27.49	0.3658	0.4757	0.48
5	53.52	10.91	-35.24	0.2781	0.2591	53.22	10.63	-35.40	0.2768	0.2585	0.41
6	73.89	-51.10	5.05	0.2653	0.4206	73.73	-51.81	5.18	0.2641	0.4218	0.25
7	64.79	54.82	71.49	0.5771	0.3861	64.65	55.47	71.54	0.5787	0.3850	0.30
8	38.92	17.94	-61.26	0.2040	0.1699	38.56	18.14	-61.96	0.2019	0.1676	0.36
9	51.09	66.38	21.85	0.5545	0.3094	50.91	67.32	22.06	0.5575	0.3081	0.29
10	28.98	22.59	-24.15	0.3193	0.2380	28.76	22.02	-23.82	0.3189	0.2391	0.33
11	79.28	-31.15	81.37	0.4075	0.5356	79.20	-30.69	82.06	0.4090	0.5356	0.33
12	75.81	28.58	92.65	0.5289	0.4450	75.60	29.18	92.23	0.5299	0.4438	0.41
13	27.85	26.24	-64.98	0.1843	0.1297	27.68	25.82	-64.51	0.1842	0.1303	0.18
14	61.62	-56.01	46.49	0.3117	0.5600	61.18	-55.51	46.37	0.3123	0.5600	0.40
15	42.61	69.38	32.97	0.6144	0.3079	42.91	69.62	32.96	0.6138	0.3079	0.28
16	87.94	5.25	103.67	0.4847	0.4854	88.00	8.15	103.90	0.4879	0.4826	1.50
17	49.45	64.64	-19.14	0.4356	0.2433	49.35	65.42	-18.01	0.4410	0.2445	0.55
18	53.78	-31.76	-36.03	0.1971	0.2858	53.38	-31.30	-36.64	0.1961	0.2833	0.52
19	97.26	-0.74	1.80	0.3475	0.3621	97.16	-0.39	1.87	0.3481	0.3619	0.52
20	81.41	-1.33	-0.32	0.3430	0.3592	81.24	-0.65	-0.08	0.3445	0.3590	0.99
21	66.45	1.22	1.25	0.3508	0.3600	66.32	0.91	0.92	0.3495	0.3597	0.53
22	50.66	-0.11	-0.27	0.3448	0.3580	50.58	0.33	0.40	0.3476	0.3593	0.93
23	35.90	1.28	-0.84	0.3467	0.3535	35.90	0.86	-0.53	0.3465	0.3553	0.65
24	21.12	-1.13	-1.88	0.3319	0.3518	21.14	0.10	-0.91	0.3418	0.3538	1.96

2.2.2 - Task 2 - Color distances ΔE_{00} of the reference measurements MR1 and MR2 for evaluating repeatability

	Nominal Values				Measured Values			
	Color Distance ΔE_{00}				Color Distance ΔE_{00}			
#	MR1 vs MR2	MR1 + MR2 vs Mean $_{MR1+MR2}$			MR1 vs MR2	MR1 + MR2 vs Mean $_{MR1+MR2}$		
1	0.87	0.43	0.44	0.44	1.01	0.50	0.51	0.51
2	4.94	2.59	2.35	2.47	1.17	0.59	0.58	0.58
3	1.32	0.68	0.65	0.66	1.04	0.52	0.51	0.52
4	0.89	0.45	0.45	0.45	1.15	0.57	0.57	0.57
5	1.05	0.53	0.53	0.53	0.96	0.48	0.48	0.48
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	1.18	0.60	0.59	0.59	1.07	0.54	0.53	0.54
8	1.14	0.57	0.57	0.57	1.49	0.75	0.74	0.74
9	0.71	0.36	0.36	0.36	0.70	0.35	0.35	0.35
10	0.46	0.23	0.23	0.23	0.25	0.12	0.12	0.12
11	1.87	0.96	0.91	0.93	1.77	0.91	0.87	0.89
12	1.54	0.78	0.77	0.77	1.52	0.76	0.76	0.76
13	3.44	1.69	1.75	1.72	3.52	1.73	1.79	1.76
14	0.94	0.46	0.47	0.47	0.90	0.45	0.45	0.45
15	3.97	1.94	2.03	1.99	3.52	1.71	1.81	1.76
16	0.82	0.41	0.41	0.41	0.49	0.24	0.25	0.24
17	0.66	0.33	0.33	0.33	0.68	0.34	0.34	0.34
18	0.78	0.39	0.39	0.39	0.69	0.34	0.35	0.35
19	8.61	3.88	4.53	4.21	8.27	3.75	4.29	4.02
20	2.47	1.22	1.23	1.22	2.38	1.17	1.20	1.19
21	3.96	1.90	2.07	1.99	2.09	1.02	1.07	1.05
22	3.84	1.93	1.93	1.93	3.23	1.61	1.57	1.59
23	1.93	0.95	0.98	0.97	0.99	0.49	0.50	0.50
24	6.00	2.94	3.15	3.05	2.12	1.05	1.05	1.05

4| 4 Colormatching data

2.2.3 - Task 2 - Color distances ΔE_{00} of the reference measurements MR1 and MR2 to the target values (CC)

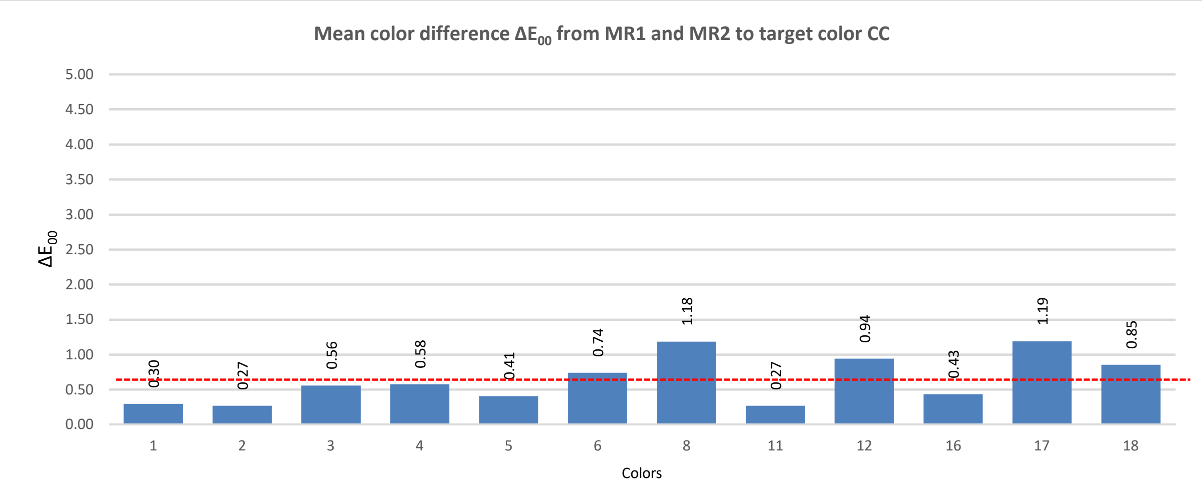
	Nominal Values											Mean
	ColorChecker CC			MR1				MR2				
#	L*	a*	b*	L*	a*	b*	ΔE_{00}	L*	a*	b*	ΔE_{00}	ΔE_{00}
1	38.60	15.61	16.13	38.71	16.57	15.75	0.87	38.60	15.61	16.13	0.00	0.44
2	65.98	24.83	27.80	65.91	16.57	25.98	4.92	66.32	24.81	27.72	0.28	2.60
3	50.00	-9.41	-26.94	50.13	-8.39	-25.86	0.86	50.35	-10.11	-27.09	0.60	0.73
4	45.66	-18.34	27.35	45.50	-19.88	27.01	0.97	45.64	-19.35	28.50	0.62	0.80
5	53.52	10.91	-35.25	53.44	9.60	-33.84	0.53	53.60	12.22	-36.63	0.53	0.53
6	73.91	-51.41	5.89	73.89	-51.10	5.05	0.46	73.89	-51.10	5.05	0.46	0.46
7	65.00	53.87	74.70	65.01	54.67	69.80	2.04	64.57	54.96	73.17	1.02	1.53
8	39.00	15.09	-58.77	39.17	16.89	-60.82	0.58	38.66	18.99	-61.70	1.58	1.08
9	50.92	65.66	23.03	51.27	67.04	21.47	1.03	50.90	65.71	22.23	0.39	0.71
10	29.05	22.89	-24.02	29.05	22.89	-24.02	0.00	28.90	22.29	-24.28	0.46	0.23
11	79.15	-32.55	80.97	79.20	-28.76	78.07	1.43	79.36	-33.53	84.66	0.80	1.11
12	75.61	29.82	89.29	75.81	27.08	92.59	2.02	75.80	30.08	92.71	0.78	1.40
13	28.32	18.51	-59.45	27.29	30.64	-68.11	4.72	28.40	21.84	-61.85	1.32	3.02
14	61.66	-55.26	46.94	61.60	-57.71	47.09	0.74	61.63	-54.30	45.88	0.34	0.54
15	42.65	68.58	33.40	42.59	72.41	30.07	2.32	42.62	66.34	35.86	1.65	1.99
16	87.45	6.29	102.03	88.19	4.82	105.23	1.12	87.69	5.67	102.11	0.36	0.74
17	49.28	66.21	-21.89	49.46	65.36	-19.95	0.75	49.44	63.91	-18.32	1.37	1.06
18	53.96	-36.06	-32.32	54.00	-32.25	-36.91	2.83	53.55	-31.26	-35.14	2.67	2.75
19	97.24	0.69	1.92	97.37	-2.41	5.72	5.33	97.14	0.93	-2.13	3.89	4.61
20	81.12	-0.49	-0.30	81.43	-1.60	0.89	1.94	81.38	-1.06	-1.53	1.42	1.68
21	66.41	0.21	-0.89	66.48	2.34	2.63	4.37	66.42	0.10	-0.14	0.75	2.56
22	50.50	0.96	-0.57	50.82	-1.26	0.74	3.46	50.50	1.05	-1.28	0.69	2.07
23	35.92	-0.32	-0.82	35.68	1.43	-1.82	2.70	36.11	1.12	0.14	2.34	2.52
24	20.95	-0.26	-1.39	21.16	-3.24	-1.01	4.03	21.08	0.99	-2.75	2.19	3.11

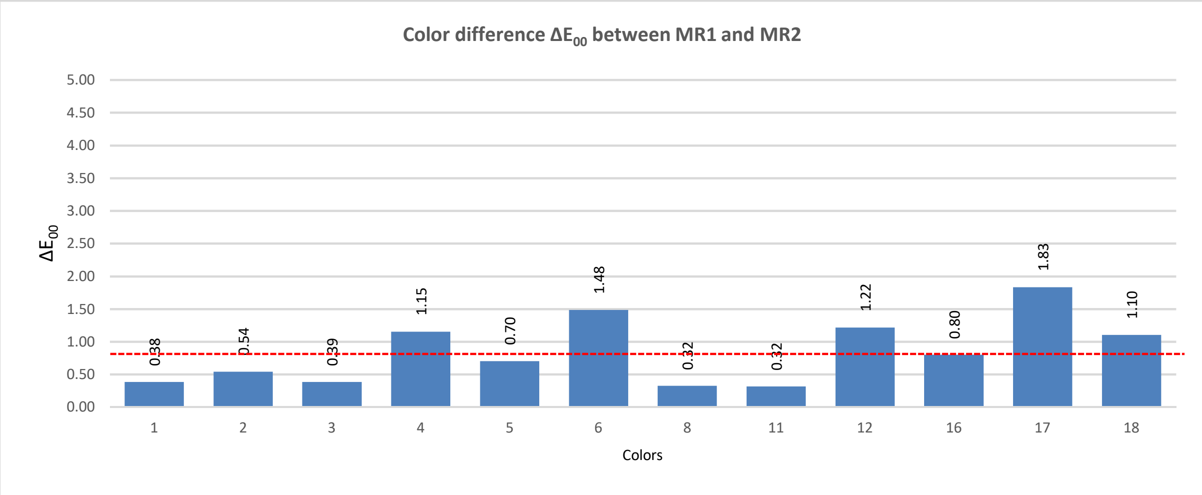
	Measured Values											Mean
	ColorChecker CC			MR1				MR2				
#	L*	a*	b*	L*	a*	b*	ΔE_{00}	L*	a*	b*	ΔE_{00}	ΔE_{00}
1	38.43	16.30	16.08	38.59	17.29	15.38	1.04	38.42	16.39	16.14	0.06	0.55
2	65.59	25.69	28.28	65.50	25.89	26.43	1.12	65.94	25.77	28.31	0.29	0.71
3	49.67	-9.15	-27.11	49.67	-8.34	-25.72	0.81	49.89	-9.36	-27.46	0.30	0.55
4	45.22	-17.80	27.00	45.07	-19.59	26.64	1.13	45.22	-18.67	28.33	0.64	0.88
5	53.28	10.77	-35.50	53.14	9.43	-34.11	0.55	53.29	11.83	-36.68	0.42	0.48
6	73.76	-52.14	5.70	73.73	-51.81	5.18	0.29	73.73	-51.81	5.18	0.29	0.29
7	64.72	54.74	74.52	64.89	55.40	70.11	1.82	64.40	55.53	72.96	0.89	1.35
8	38.62	15.46	-59.59	38.84	16.82	-61.54	0.44	38.28	19.45	-62.37	1.67	1.05
9	50.67	66.52	23.04	51.05	67.98	21.63	0.99	50.77	66.66	22.49	0.30	0.64
10	28.75	22.26	-23.93	28.73	22.24	-23.85	0.04	28.78	21.79	-23.78	0.24	0.14
11	79.09	-32.02	81.74	79.15	-28.41	79.01	1.37	79.25	-32.96	85.11	0.72	1.05
12	75.60	30.09	89.02	75.60	27.70	92.19	1.82	75.60	30.65	92.26	0.67	1.24
13	28.02	17.93	-58.45	27.12	30.48	-68.10	4.70	28.24	21.15	-60.91	1.26	2.98
14	61.35	-54.75	46.89	61.15	-57.10	46.77	0.78	61.20	-53.92	45.97	0.32	0.55
15	42.90	69.01	33.24	42.84	72.92	30.76	1.98	42.97	66.31	35.16	1.53	1.76
16	87.75	7.99	102.38	87.87	8.43	105.07	0.50	88.13	7.87	102.73	0.26	0.38
17	49.32	67.05	-21.28	49.34	65.97	-18.88	0.90	49.35	64.87	-17.13	1.57	1.24
18	53.49	-35.33	-33.26	53.55	-31.56	-37.49	2.67	53.21	-31.03	-35.78	2.37	2.52
19	97.14	0.83	1.09	97.34	-2.33	5.18	5.67	96.97	1.55	-1.44	2.62	4.14
20	81.05	-0.04	-0.30	81.25	-1.24	0.78	2.03	81.23	-0.06	-0.93	0.63	1.33
21	66.35	0.92	-0.45	66.32	1.41	1.75	2.20	66.31	0.41	0.09	0.90	1.55
22	50.46	1.10	0.07	50.76	-0.62	1.20	2.79	50.39	1.28	-0.40	0.52	1.65
23	36.01	0.10	-0.27	35.70	1.07	-0.90	1.54	36.10	0.64	-0.15	0.80	1.17
24	21.09	0.67	-0.63	21.05	-0.61	-0.75	1.90	21.23	0.81	-1.07	0.48	1.19

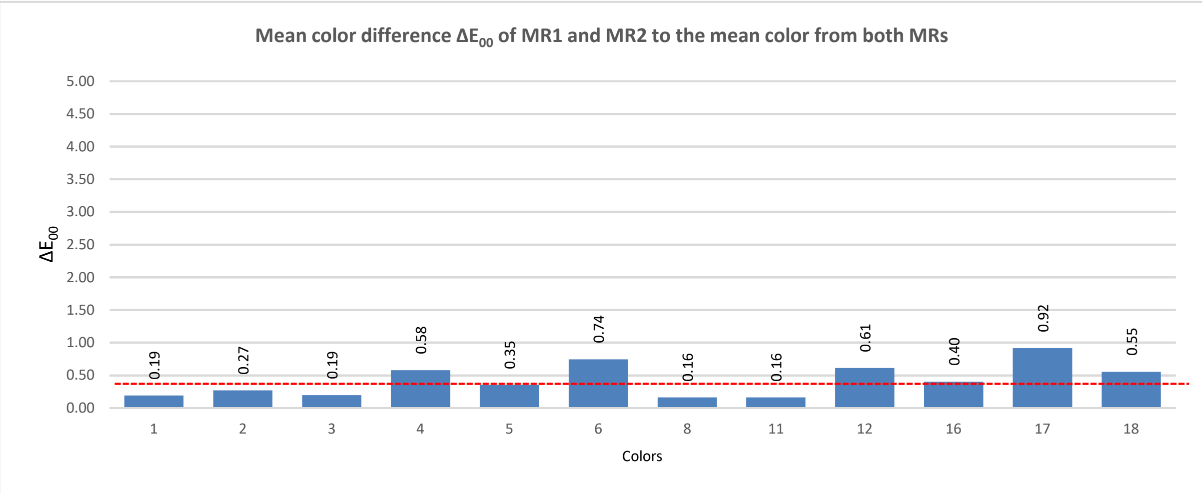
4| 4 Colormatching data

3.1 - Task 1 - Nominal spectral values

	Determined color differences				Distribution within defined limit values							
ΔE_{00}	M	Min	Max	SD	< 0,2	< 0,5	< 1	< 2	< 4	< 5	> 5	> M
MR 1 → CC	0.96	0.43	2.08	0.4871	0	2	5	4	1	0	0	5
MR 2 → CC	0.33	0.00	1.09	0.3648	6	1	4	1	0	0	0	4
MCD → CC	0.64	0.27	1.19	0.3217	0	5	5	2	0	0	0	5
MR1 → MR 2	0.85	0.32	1.83	0.4801	0	4	3	5	0	0	0	5
MCD → $M_{MR1+MR2}$	0.43	0.16	0.92	0.2401	4	3	5	0	0	0	0	5



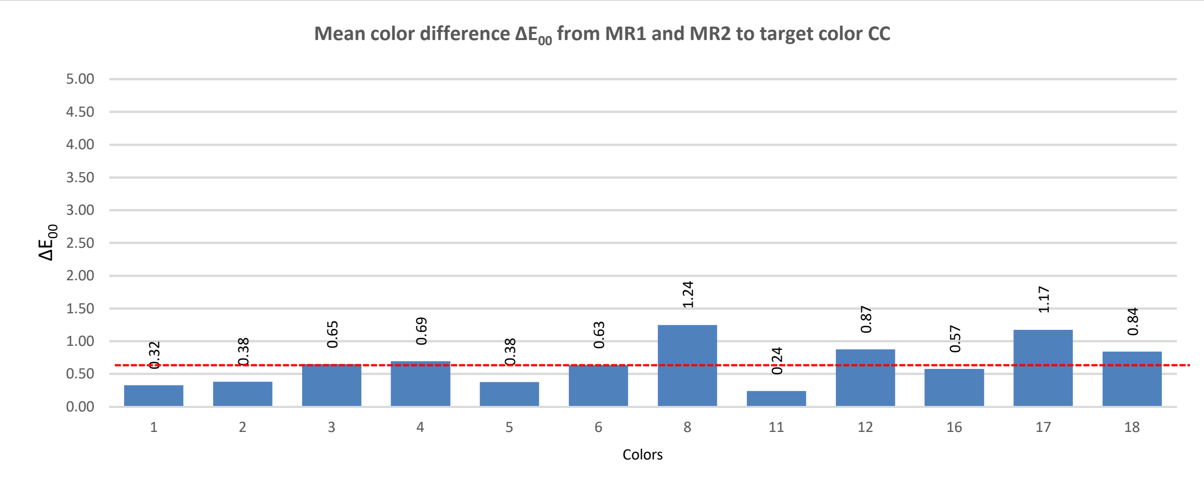


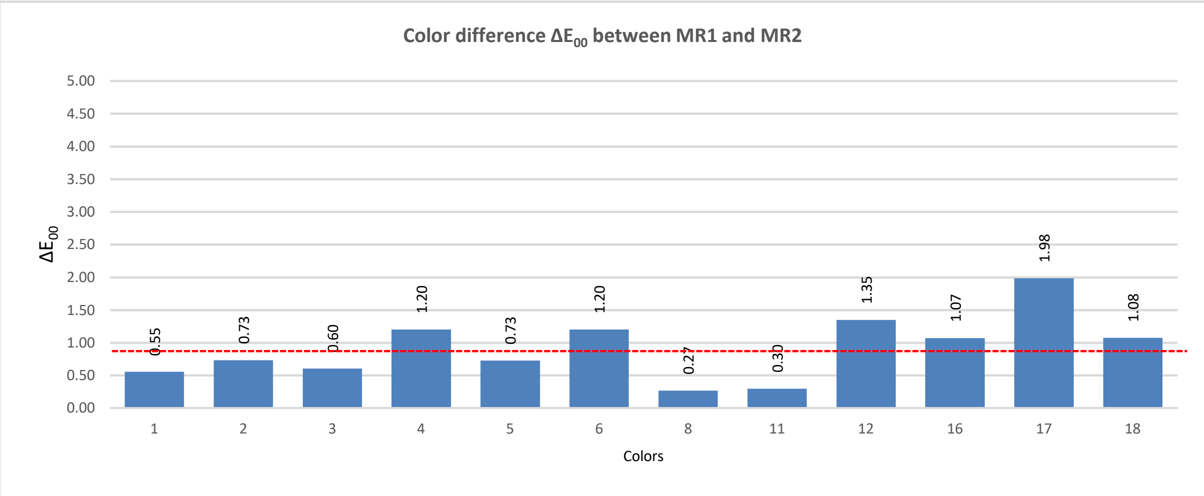


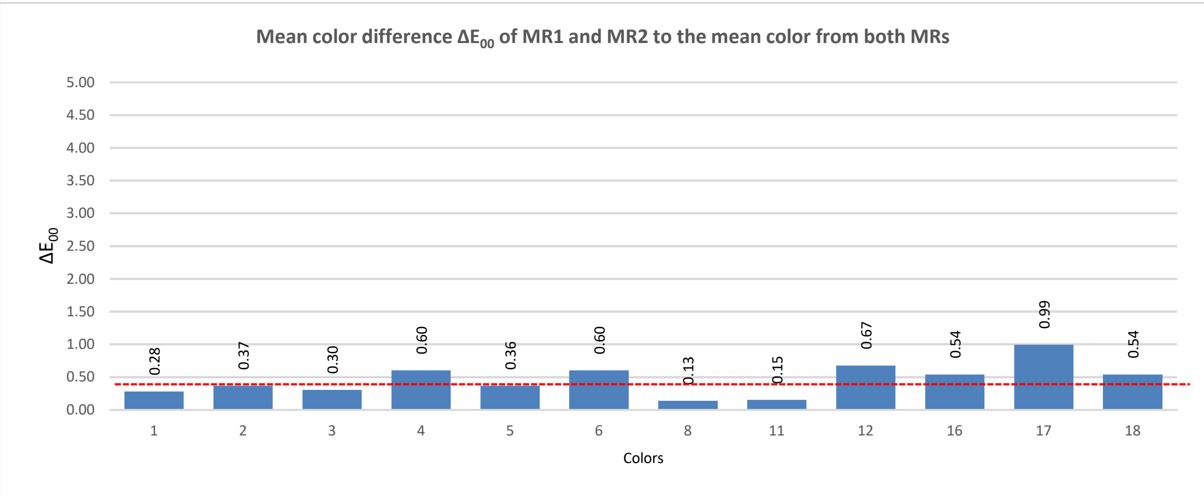
4| 4 Colormatching data

3.1 - Task 1 - Measured spectral values

	Determined color differences				Distribution within defined limit values							
ΔE_{00}	M	Min	Max	SD	< 0,2	< 0,5	< 1	< 2	< 4	< 5	> 5	> M
MR 1 → CC	0.98	0.38	2.15	0.4707	0	2	4	5	1	0	0	6
MR 2 → CC	0.35	0.05	1.27	0.3838	7	2	1	2	0	0	0	4
MCD → CC	0.67	0.24	1.24	0.3080	0	4	8	2	0	0	0	5
MR1 → MR 2	0.92	0.27	1.98	0.4686	0	2	4	6	0	0	0	6
MCD → $M_{MR1+MR2}$	0.46	0.13	0.99	0.2344	2	4	6	0	0	0	0	6



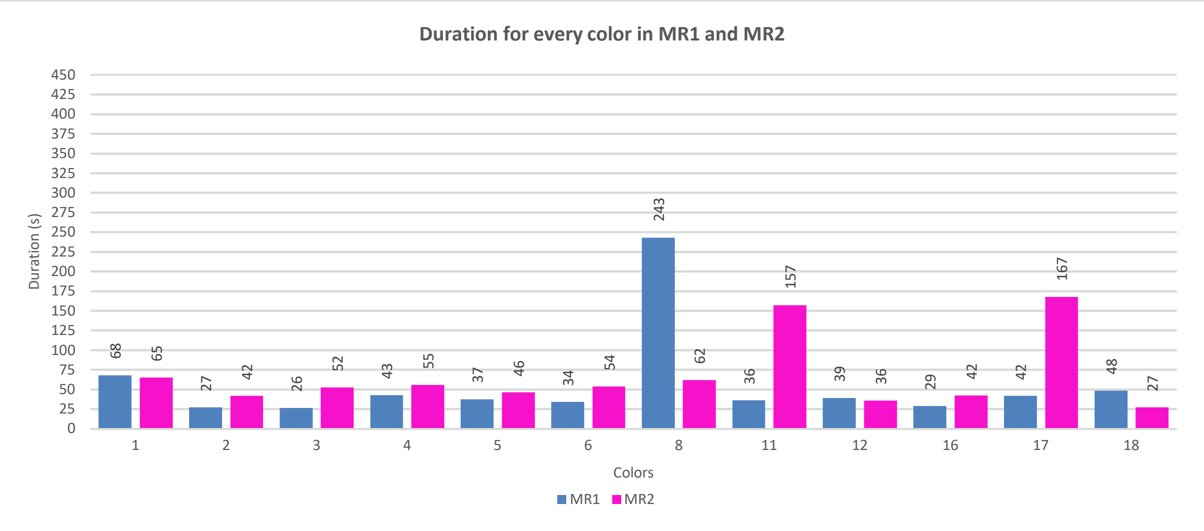


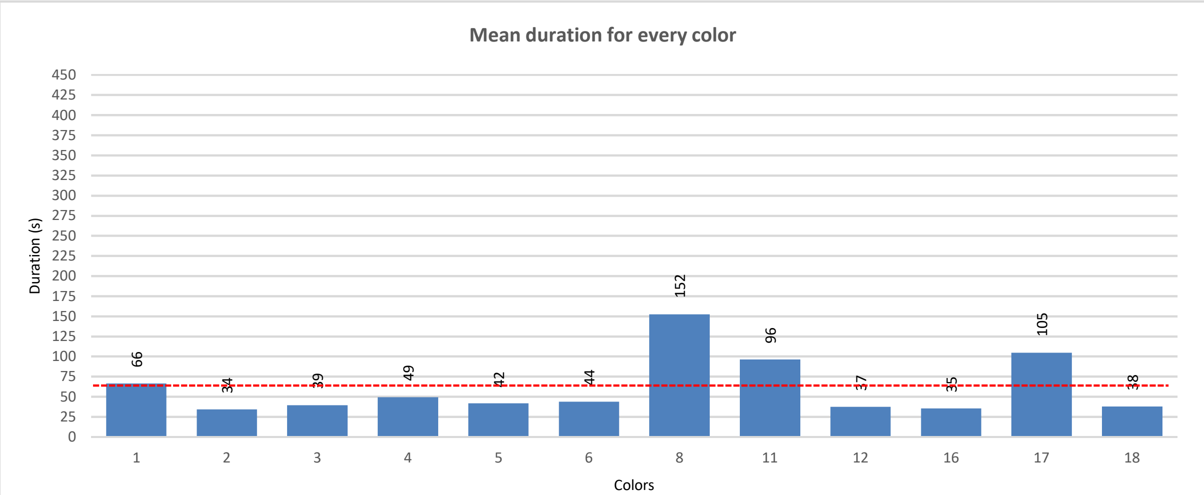


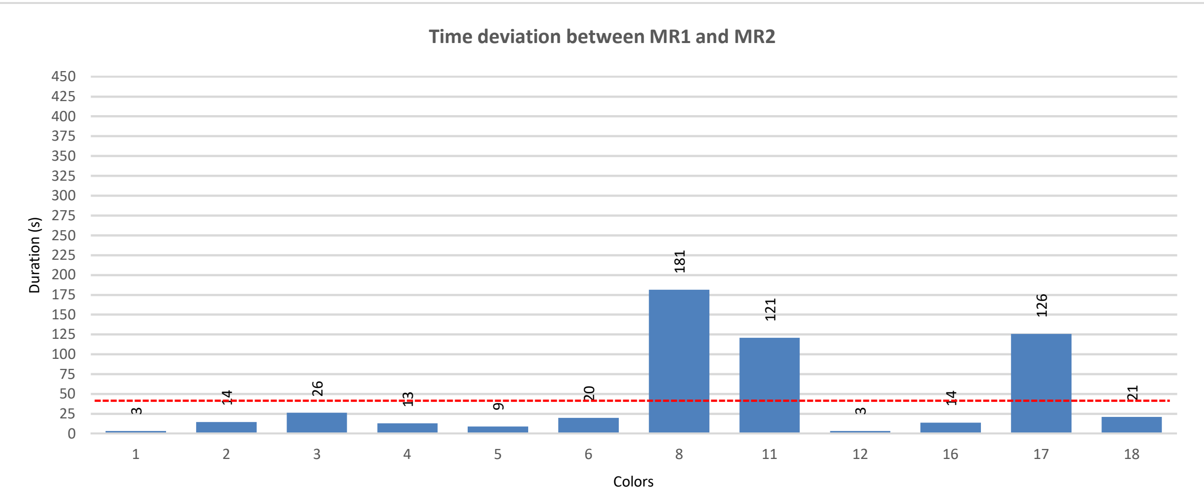
4| 4 Colormatching data

3.1 - Task 1 - Duration

Time in sec.	Duration				Distribution within defined limit values				
	Total	M	Min	Max	< 30	< 60	< 90	> 90	> M
MR 1	672	56	26	243	3	7	1	1	2
MR 2	805	67	27	167	1	7	2	2	2
Mean	738	62	34	152	0	8	1	3	4
MR1 → MR 2	- -	46	3	181	9	0	0	3	3



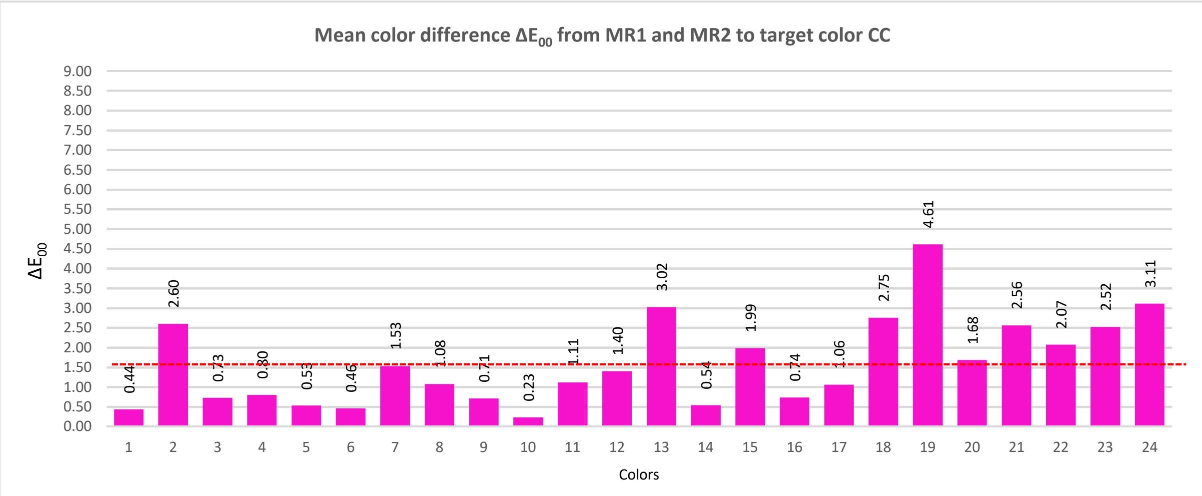


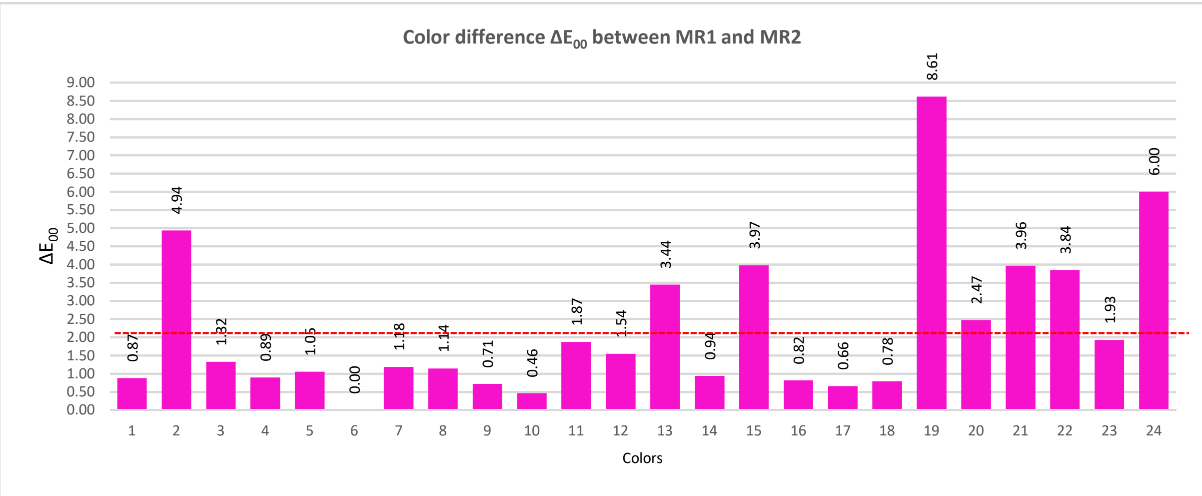


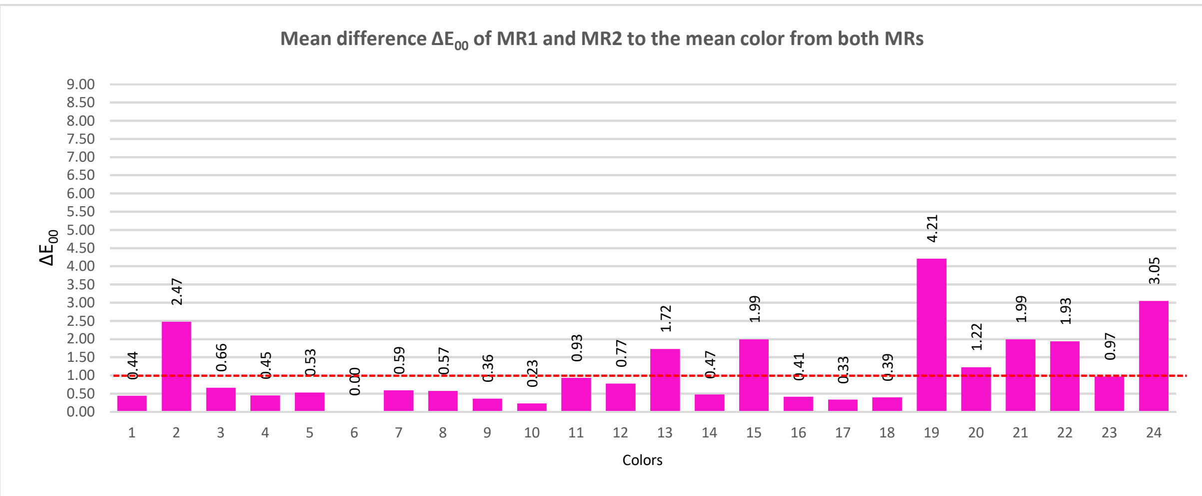
4| 4 Colormatching data

3.2 - Task 2 - Nominal spectral values

	Determined color differences				Distribution within defined limit values							
ΔE_{00}	M	Min	Max	SD	< 0,2	< 0,5	< 1	< 2	< 4	< 5	> 5	> M
MR 1 → CC	2.08	0.00	5.33	1.5729	1	1	7	4	6	4	1	9
MR 2 → CC	1.10	0.00	3.89	0.8978	1	6	7	6	4	0	0	9
MCD → CC	1.59	0.23	4.61	1.0877	0	3	6	7	7	1	0	10
MR1 → MR 2	2.23	0.00	8.61	2.0404	1	1	7	7	5	1	2	8
MCD → $M_{MR1+MR2}$	1.11	0.00	4.21	1.0113	1	8	7	5	2	1	0	8



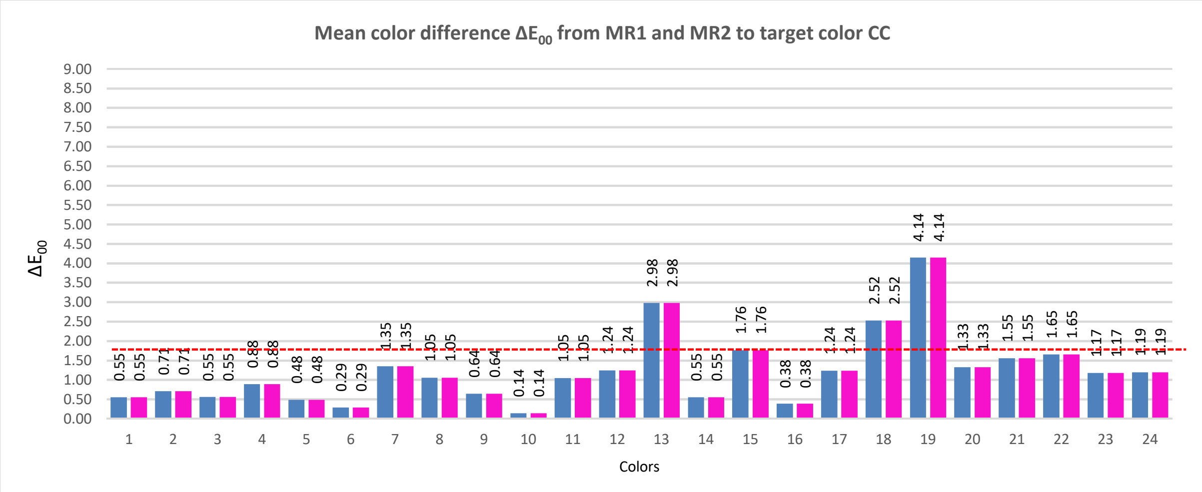


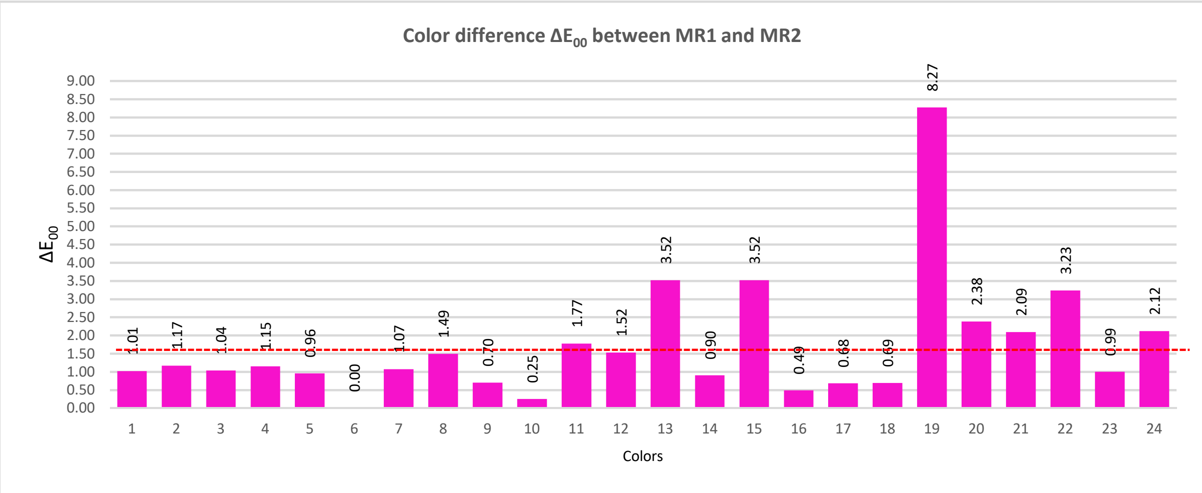


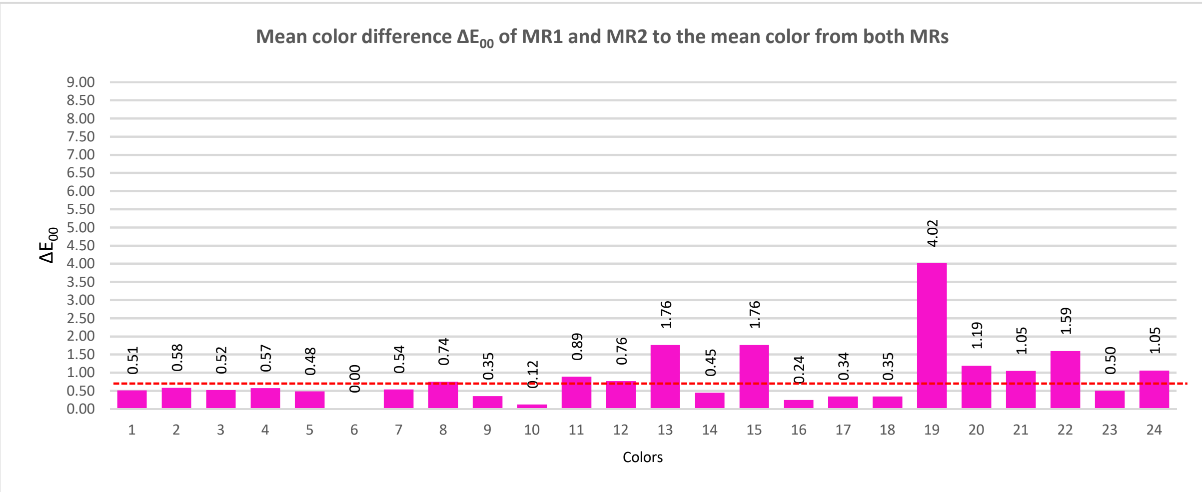
4| 4 Colormatching data

3.2 - Task 2 - Measured spectral values

	Determined color differences				Distribution within defined limit values							
ΔE_{00}	M	Min	Max	SD	< 0,2	< 0,5	< 1	< 2	< 4	< 5	> 5	> M
MR 1 → CC	1.63	0.04	5.67	1.2976	1	2	6	9	4	1	1	10
MR 2 → CC	0.82	0.06	2.62	0.6673	1	8	9	4	2	0	0	8
MCD → CC	1.23	0.14	4.14	0.8977	1	3	10	7	2	1	0	10
MR1 → MR 2	1.71	0.00	8.27	1.6595	1	2	6	8	6	0	1	8
MCD → $M_{MR1+MR2}$	0.85	0.00	4.02	0.8095	2	5	10	6	0	1	0	8



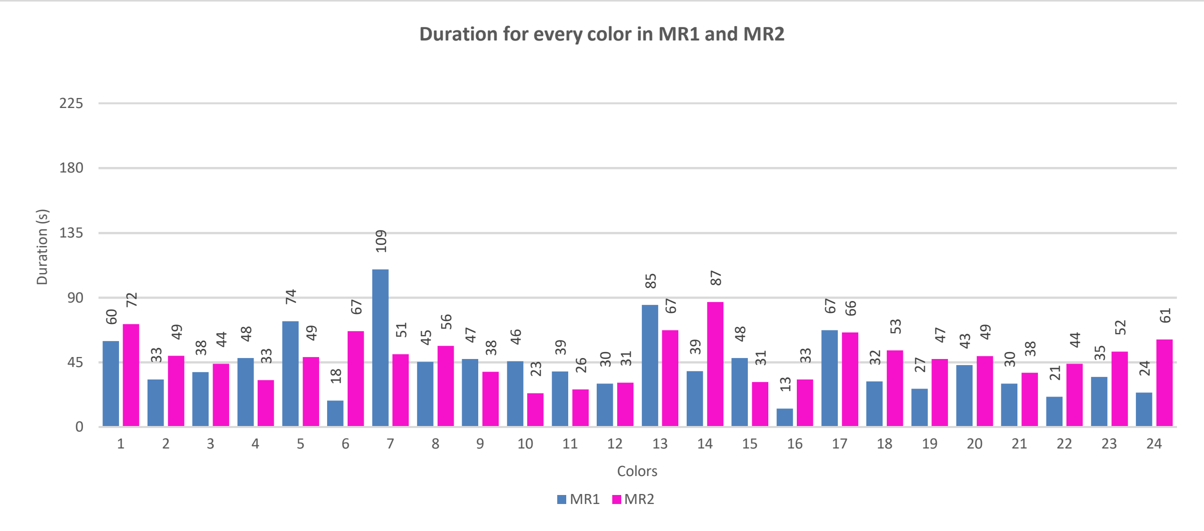


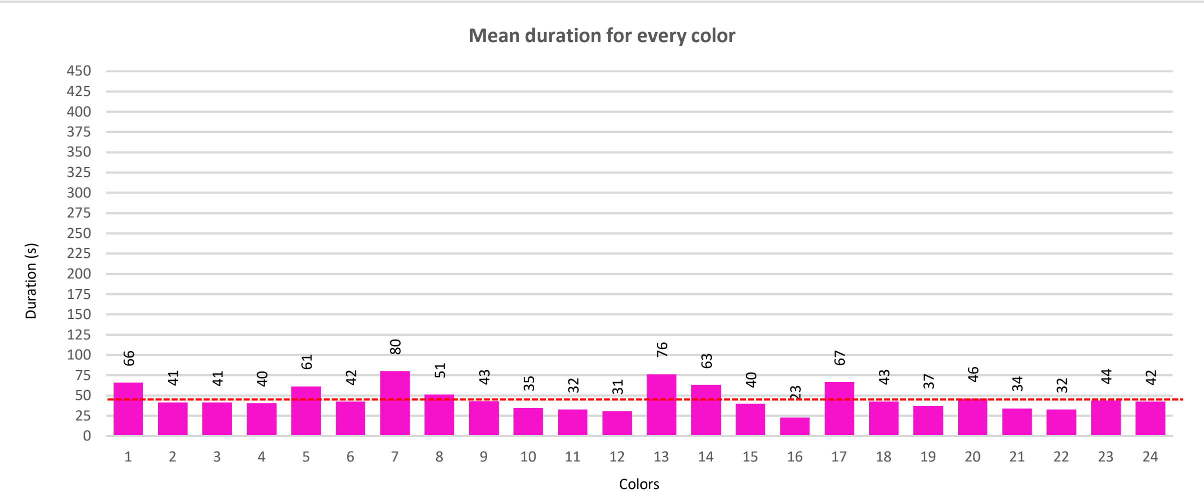


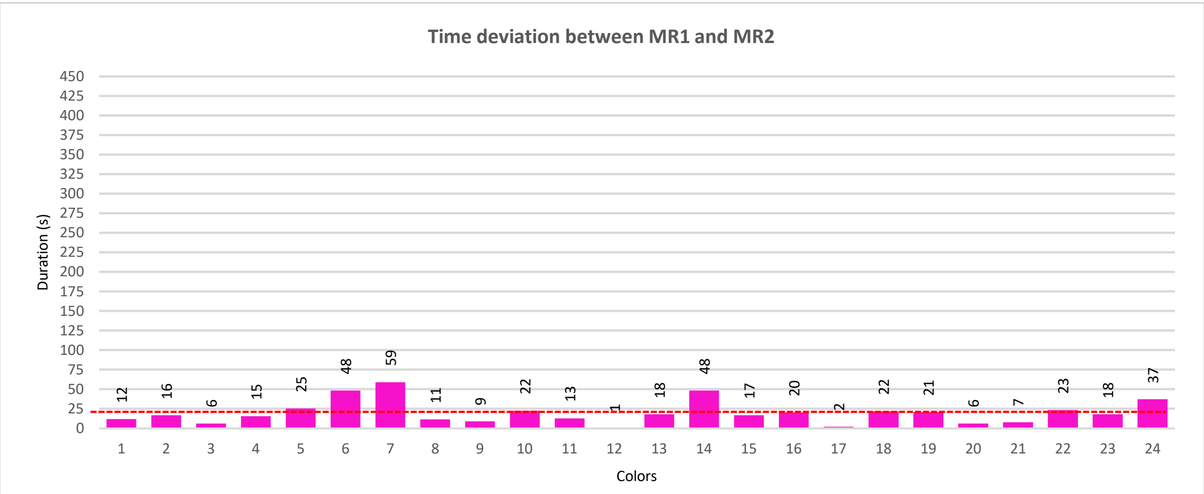
4| 4 Colormatching data

3.2 - Task 2 - Duration

	Duration				Distribution within defined limit values				
Time in sec.	Total	M	Min	Max	< 30	< 60	< 90	> 90	> M
MR 1	1051	44	13	109	8	12	3	1	8
MR 2	1167	49	23	87	2	15	7	0	10
Mean	1109	46	23	80	1	18	5	0	6
MR1 → MR 2	- -	20	1	59	20	4	0	0	9

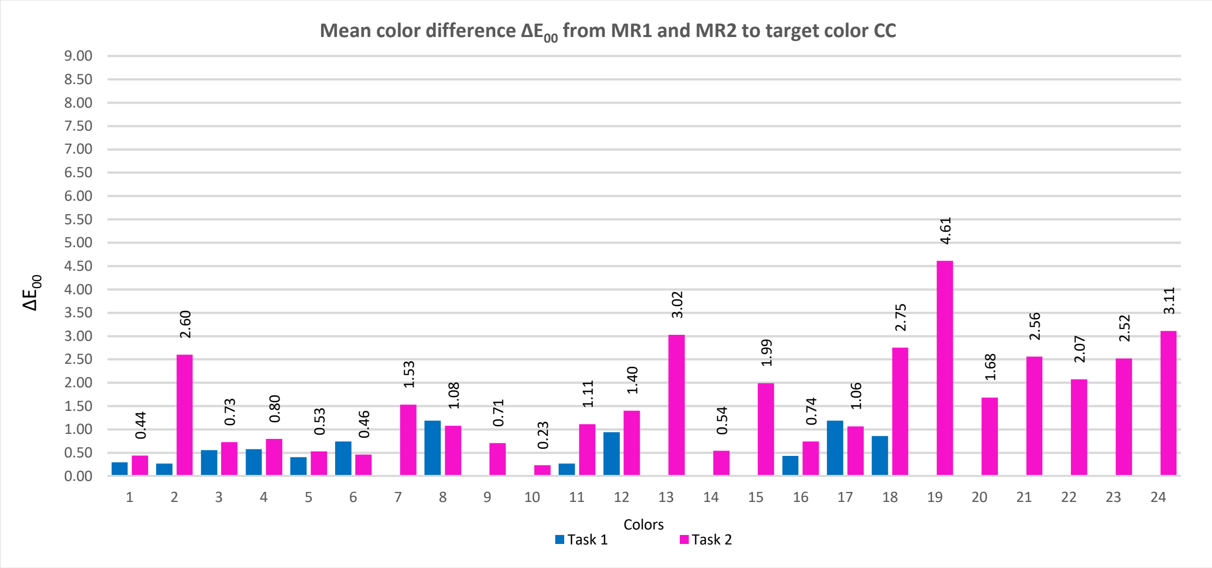


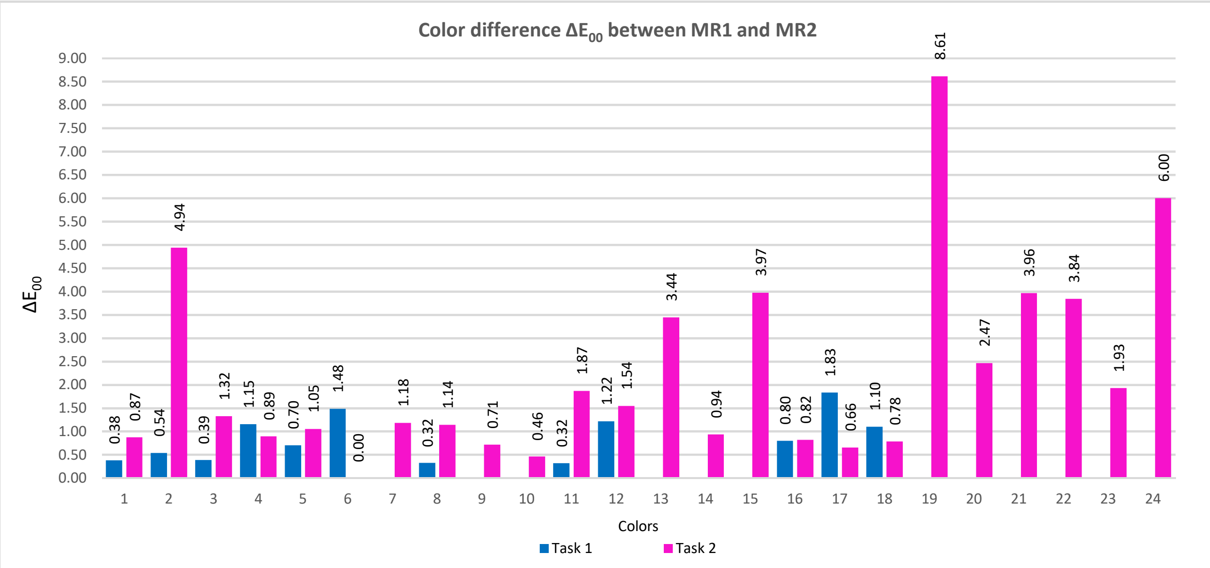


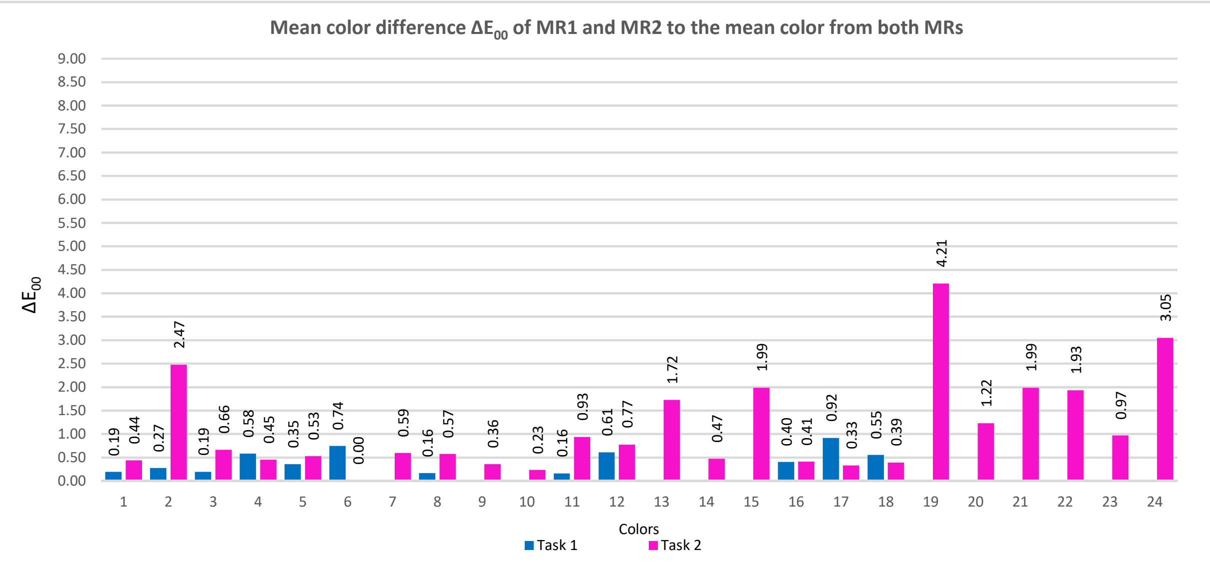


4| 4 Colormatching data

3.3 - Joint visualization - Nominal spectral values

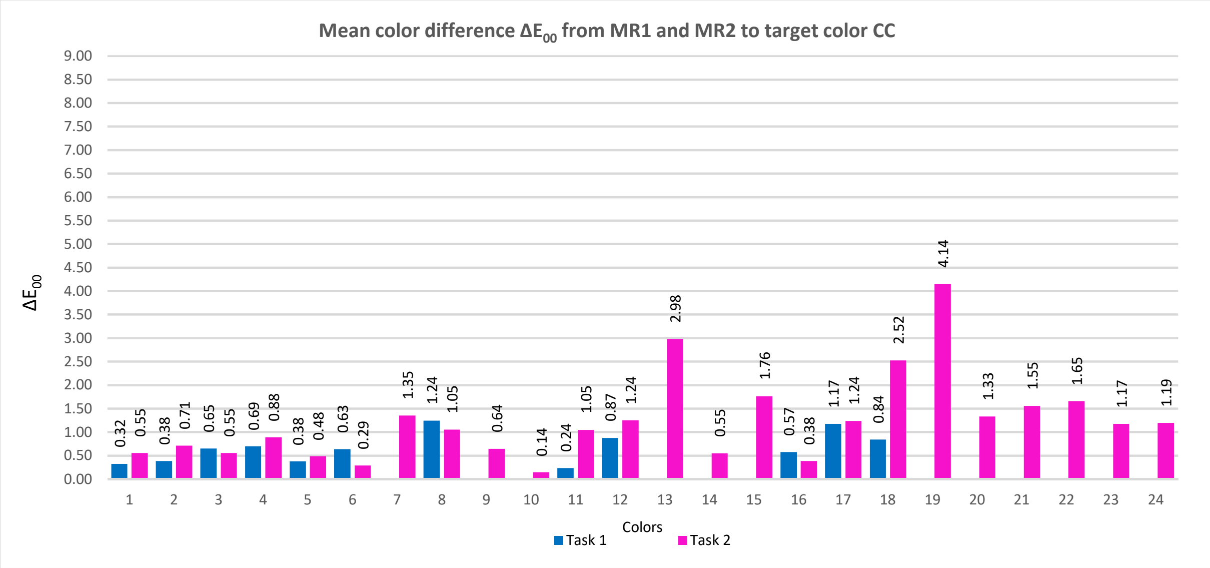


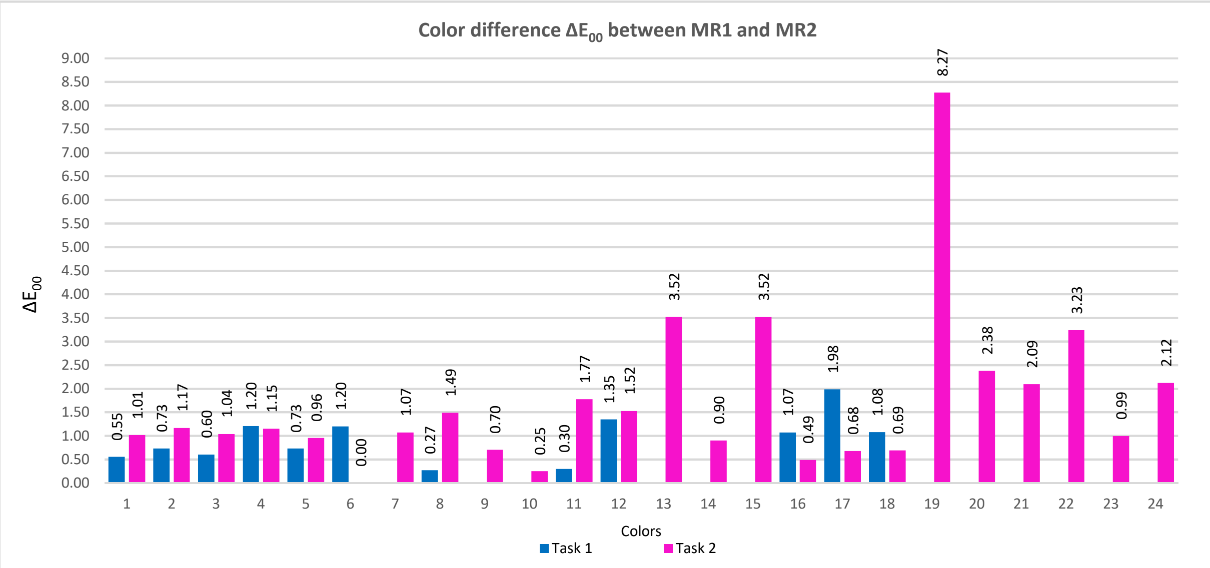


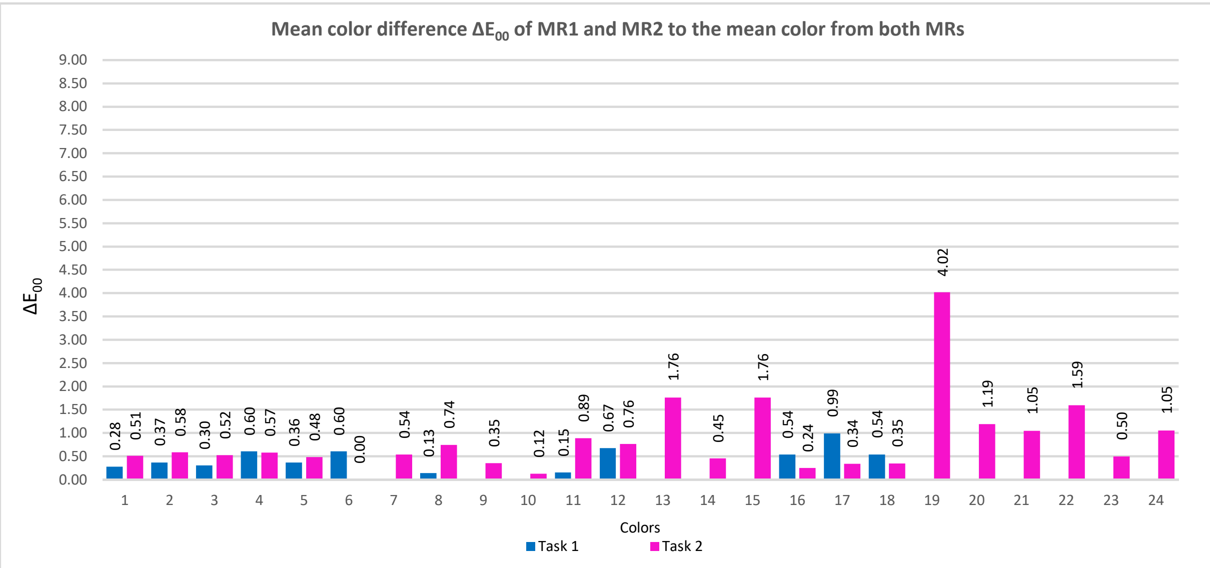


4| 4 Colormatching data

3.3 - Joint visualization - Measured spectral values

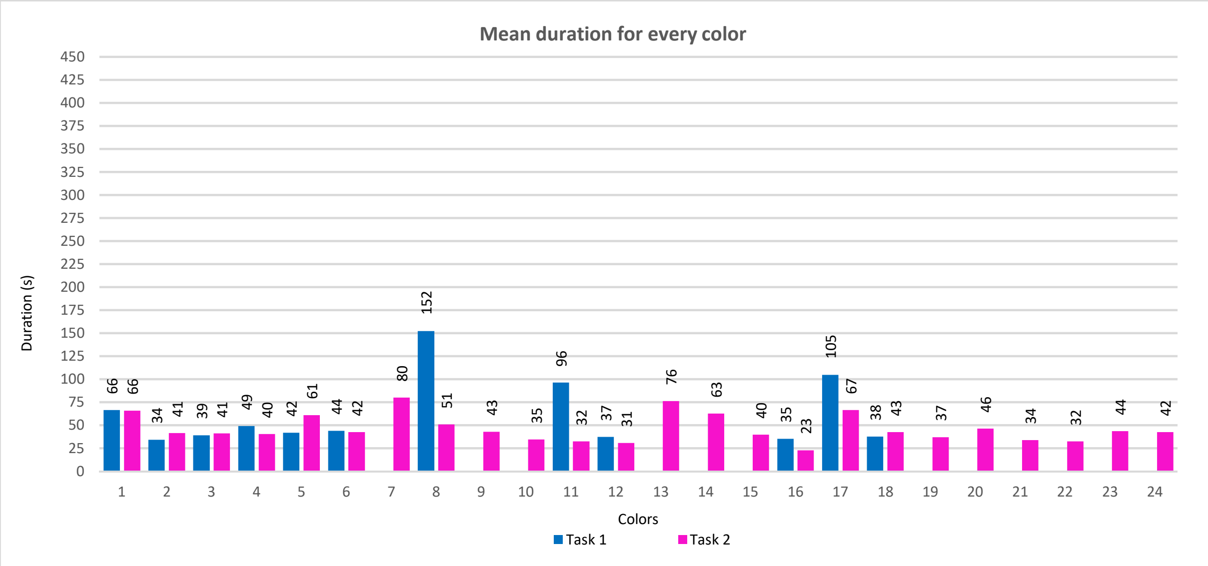


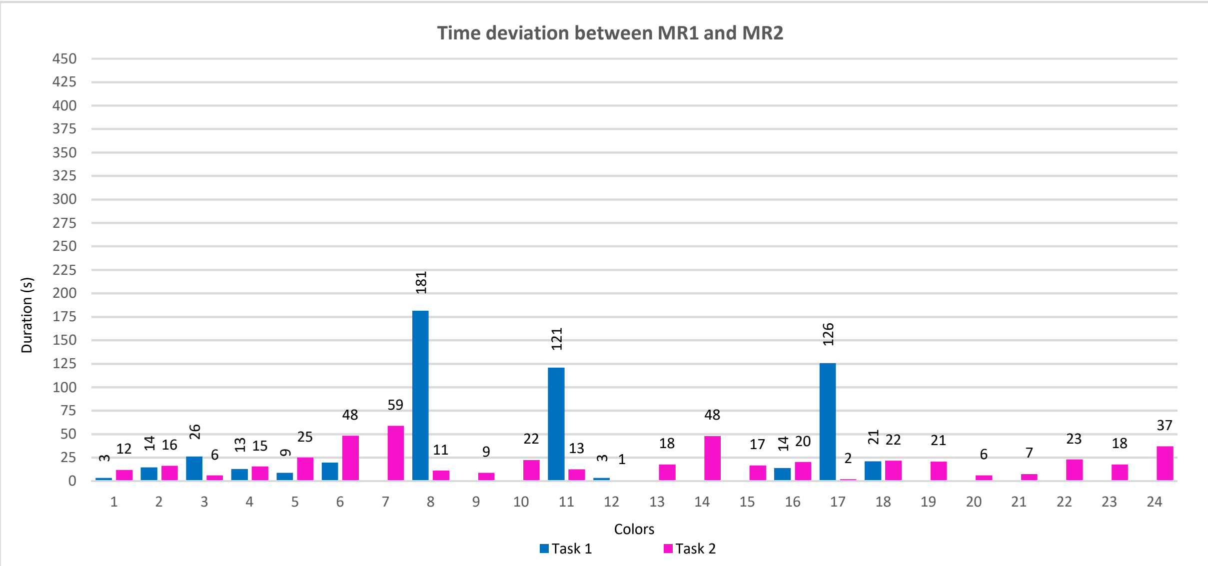




4| 4 Colormatching data

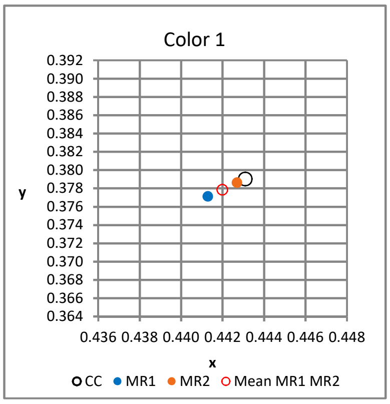
3.3 - Joint visualization - Duration

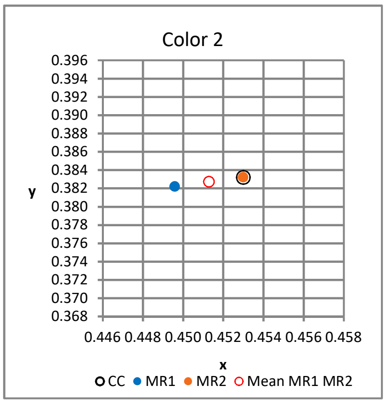


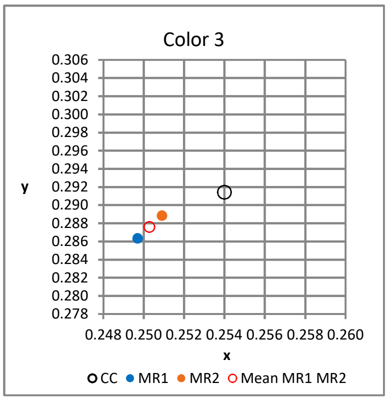


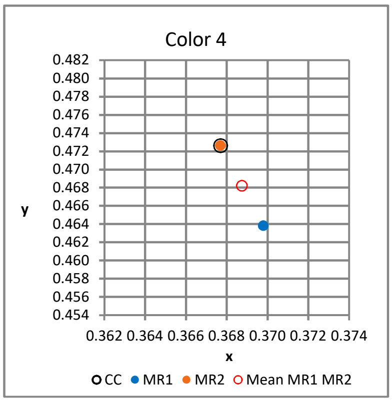
4| 4 Colormatching data

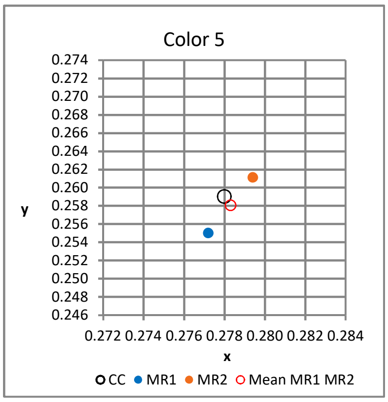
3.4 - Task 1 - Nominal values: Color coordinates in the CIExy color system

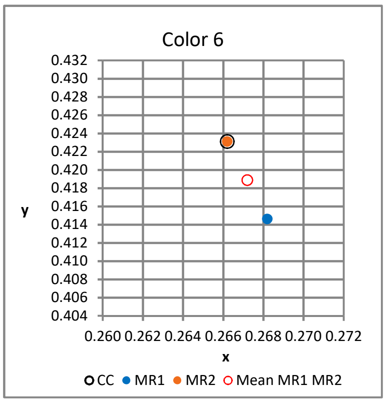


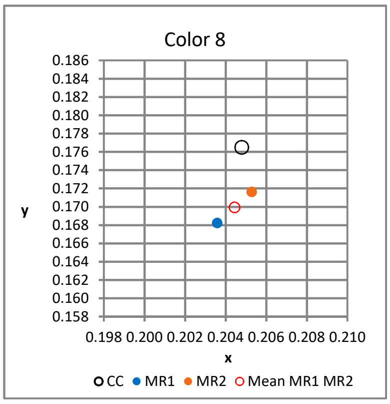


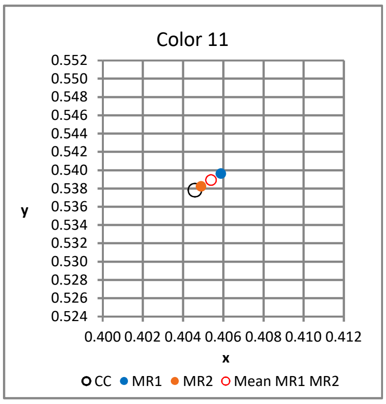


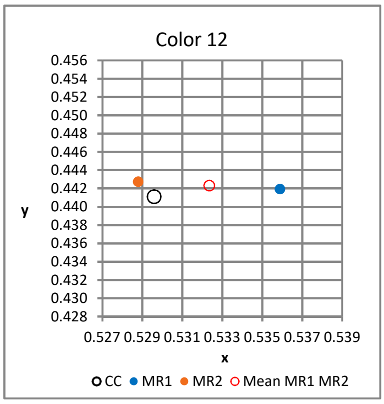


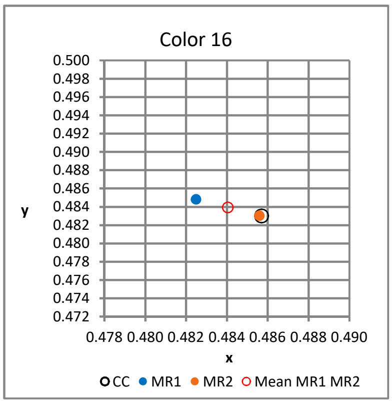


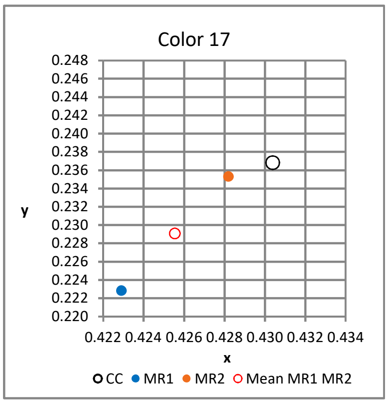


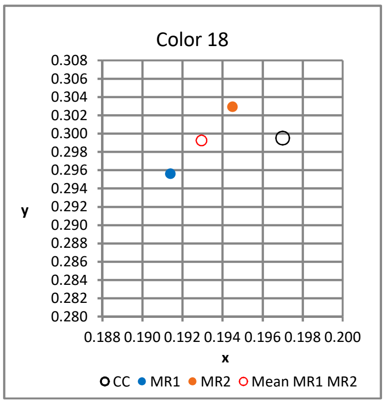






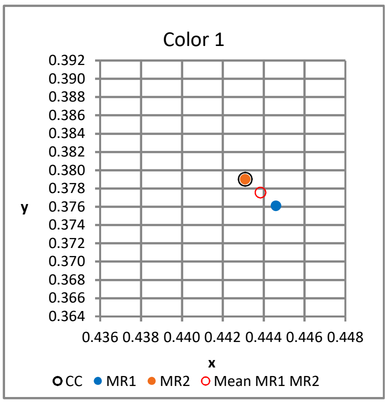


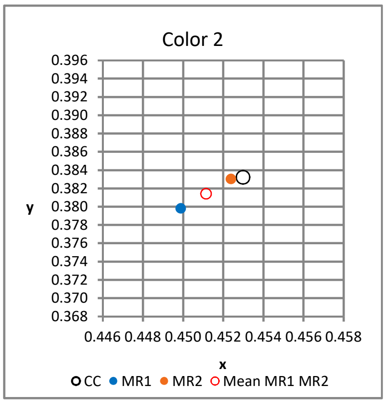


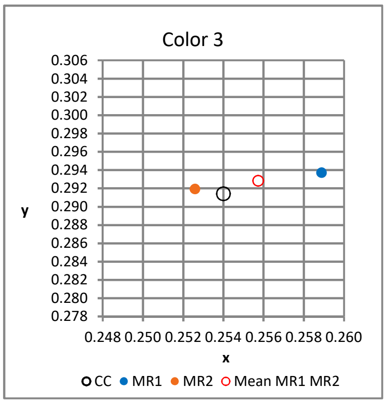


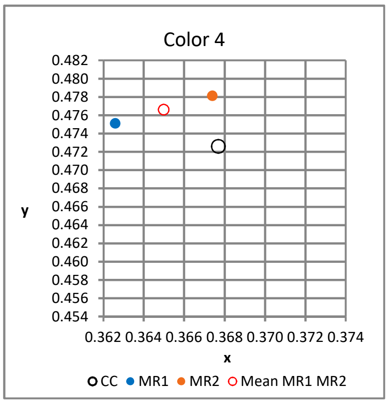
4| 4 Colormatching data

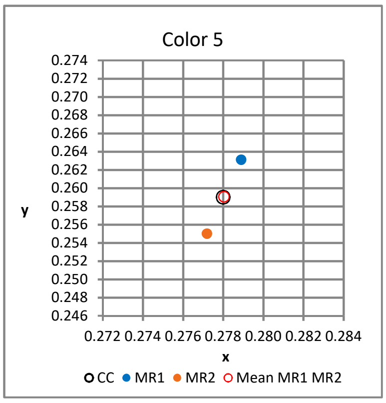
3.4 - Task 2 - Nominal values: Color coordinates in the CIExy color system

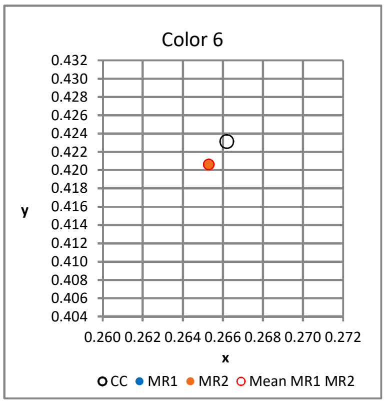


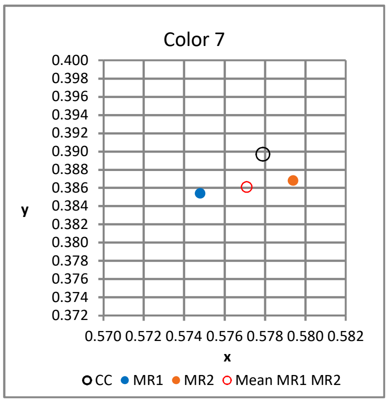


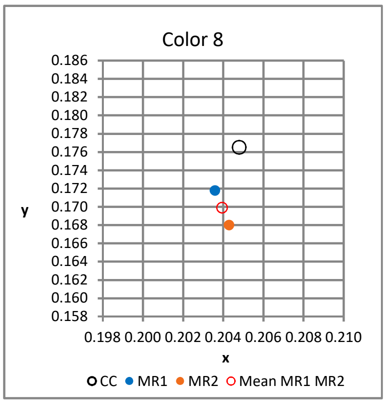


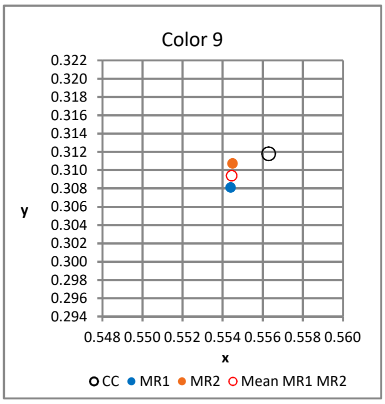


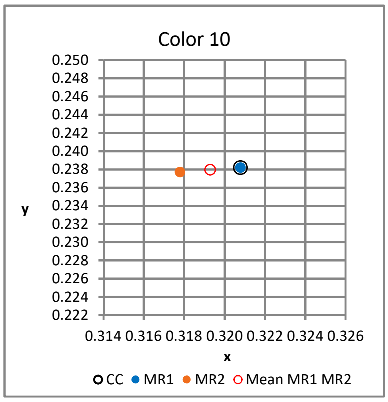


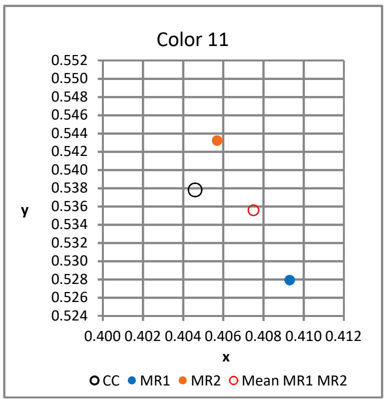


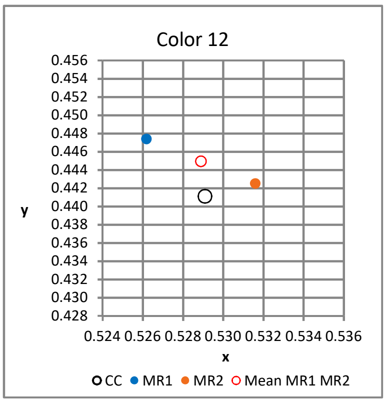




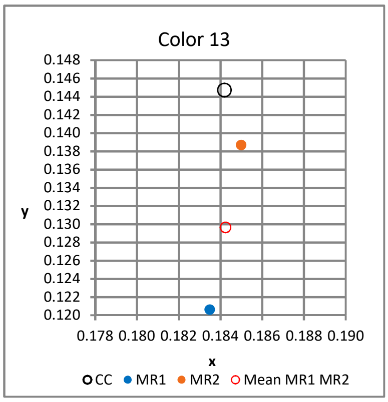


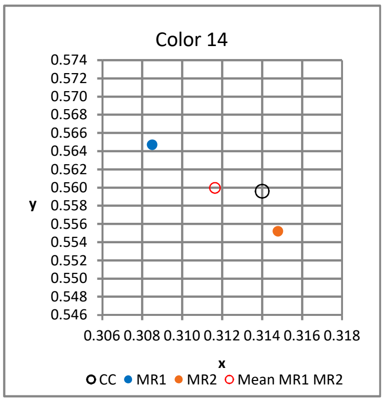


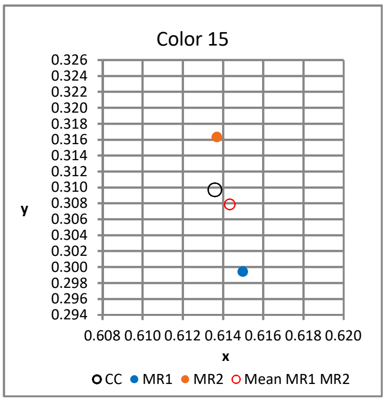


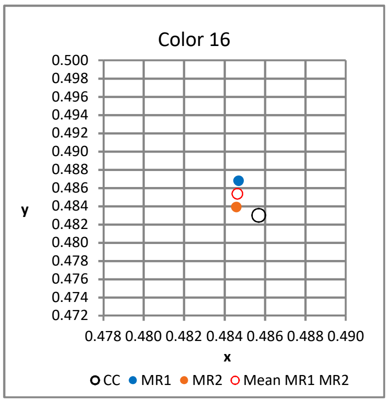


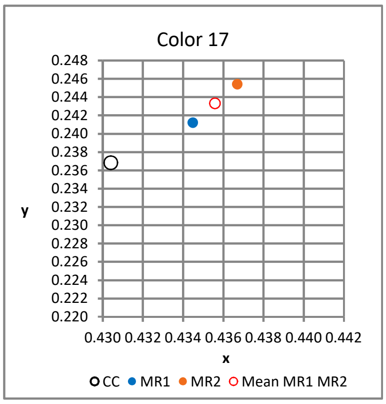
4| 4 Colormatching data

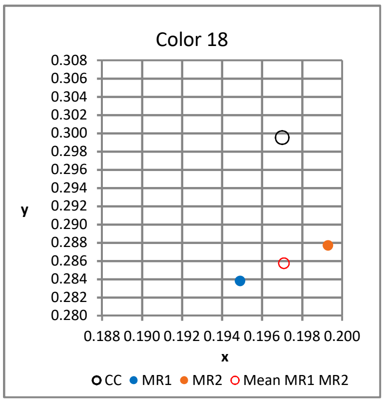


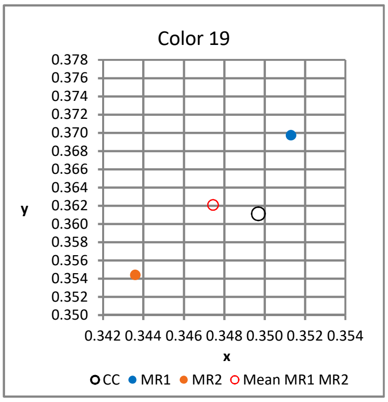


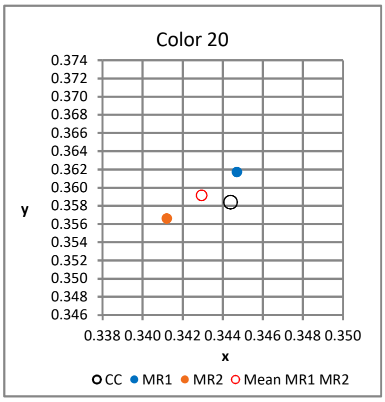


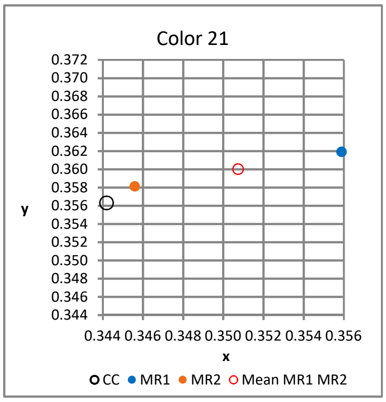


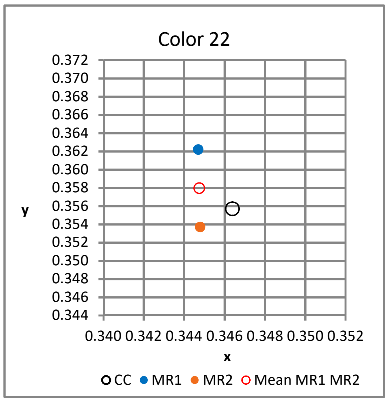


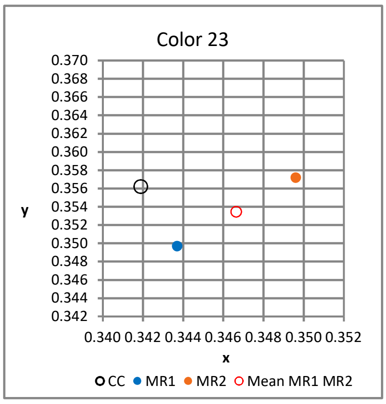


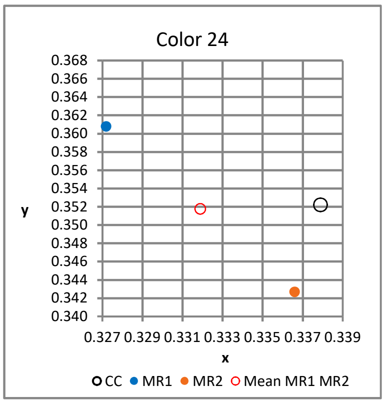






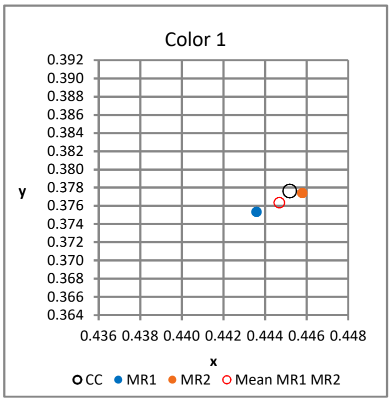


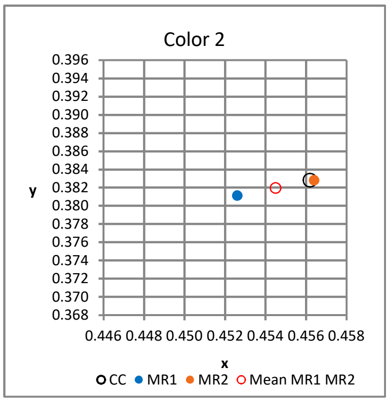


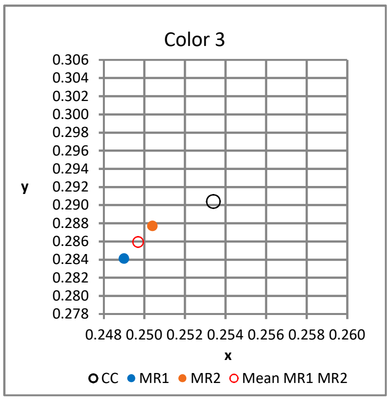


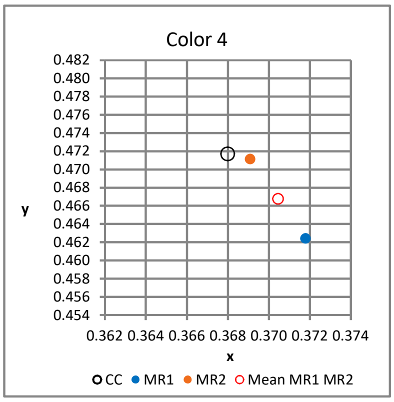
4| 4 Colormatching data

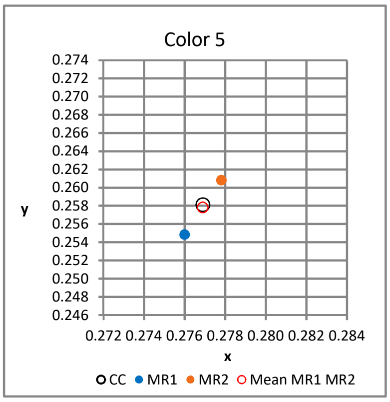
3.5 - Task 1 - Measured values: Color coordinates in the CIExy color system

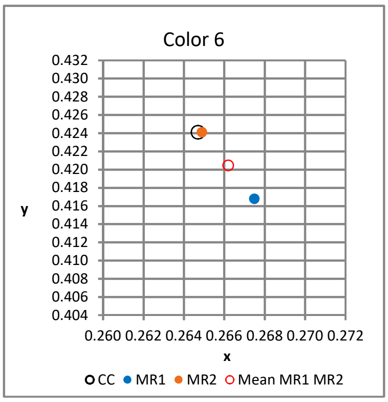


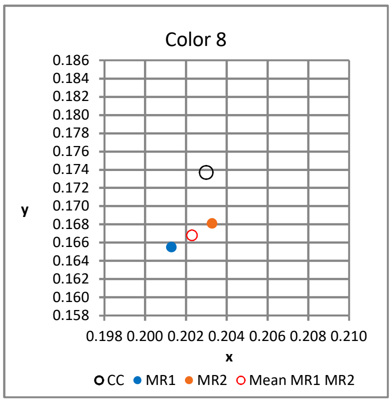


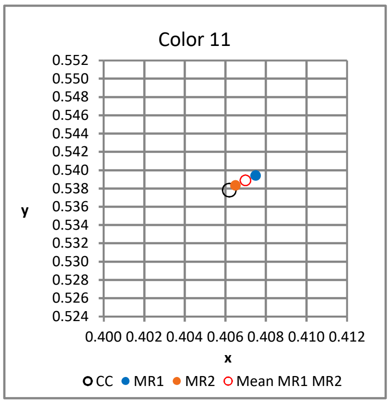


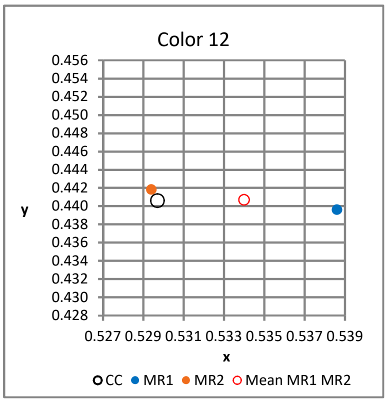


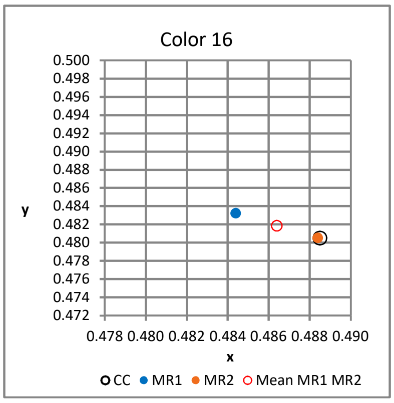


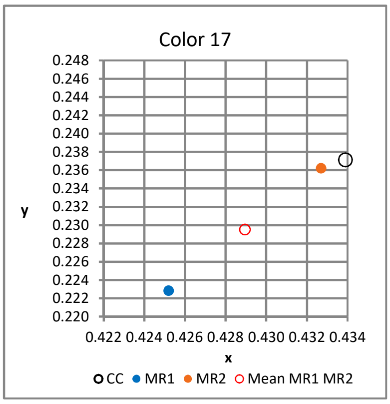


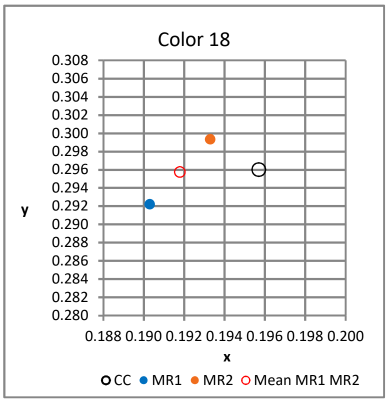






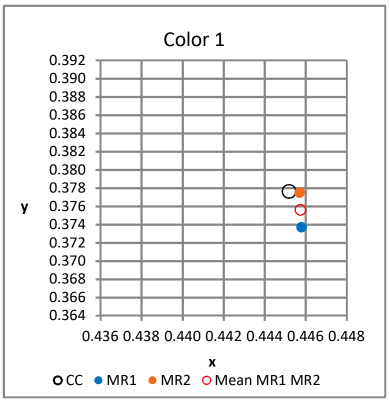


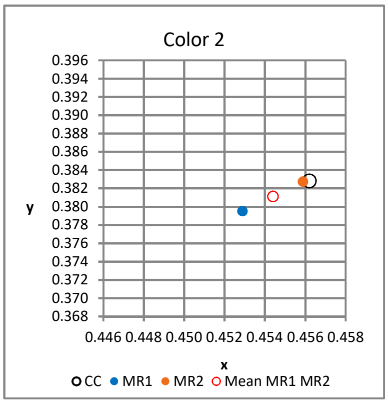


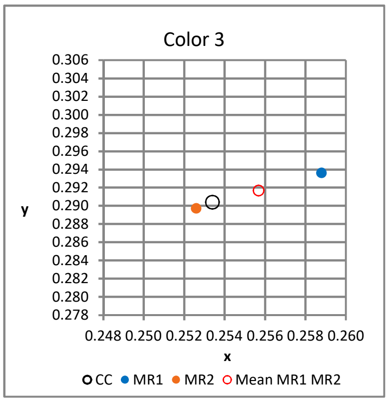


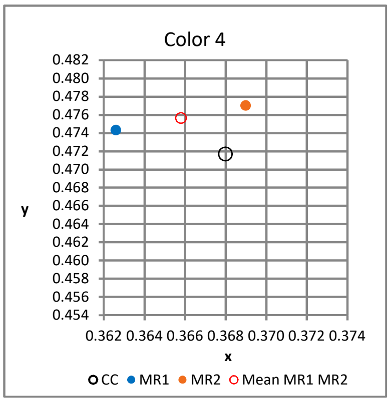
4| 4 Colormatching data

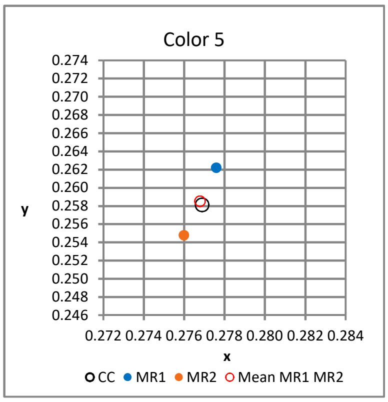
3.5 - Task 2 - Measured values: Color coordinates in the CIExy color system

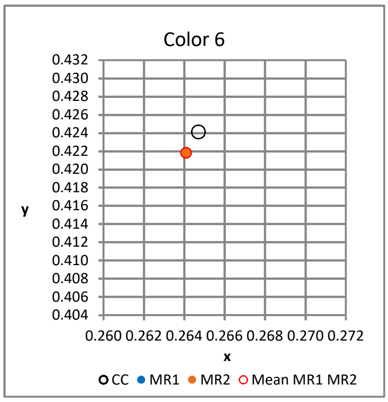


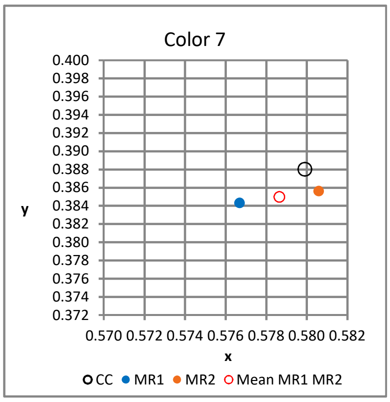


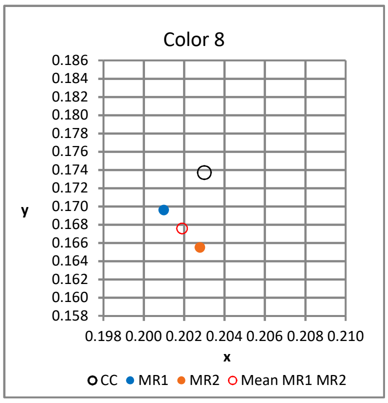


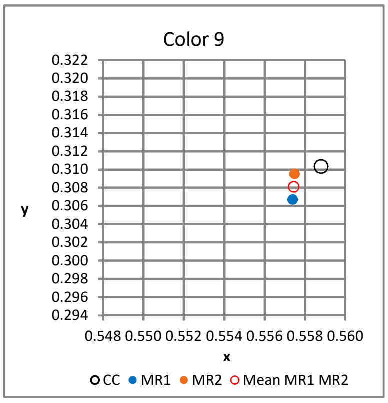


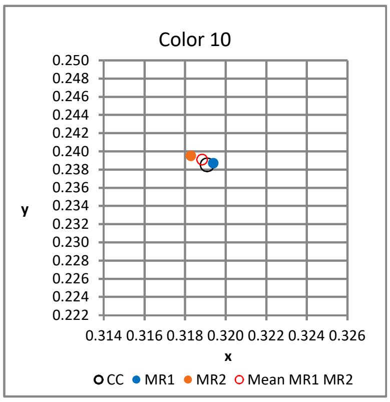


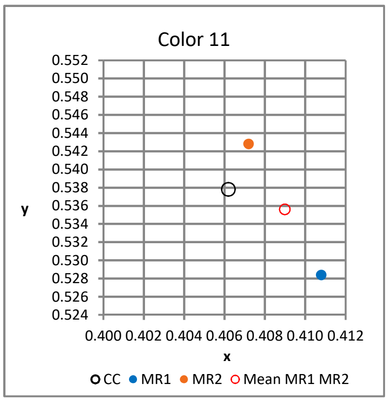


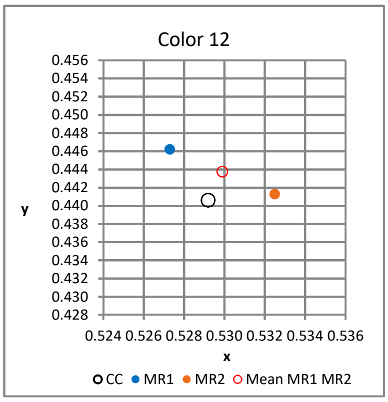




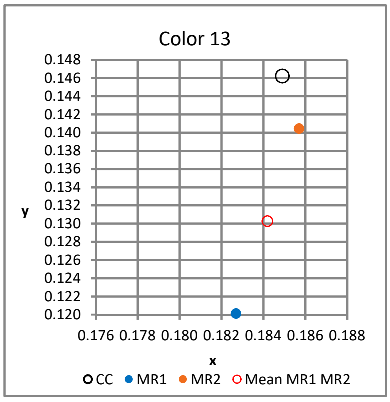


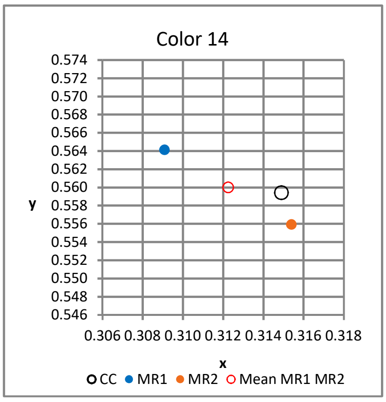


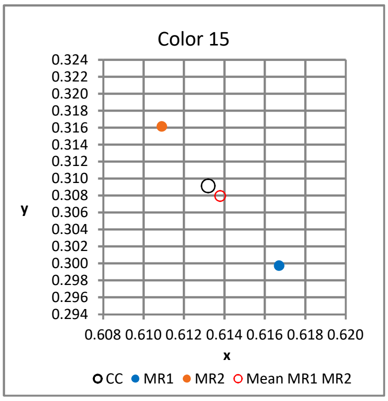


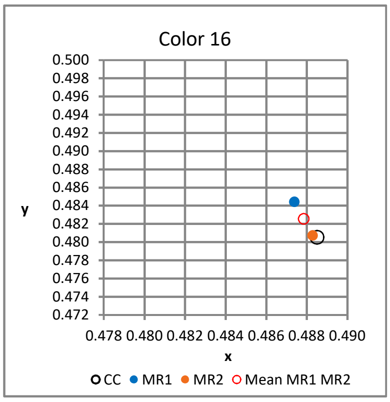


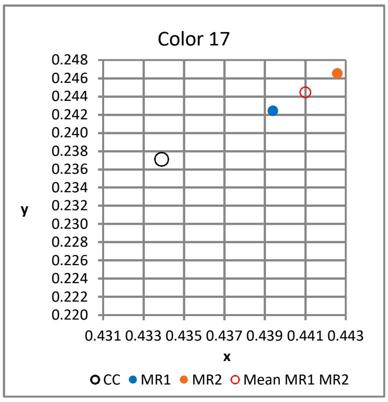
4| 4 Colormatching data

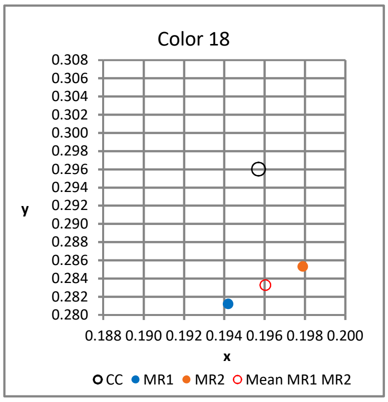


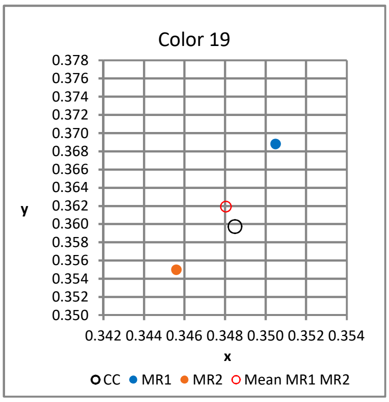


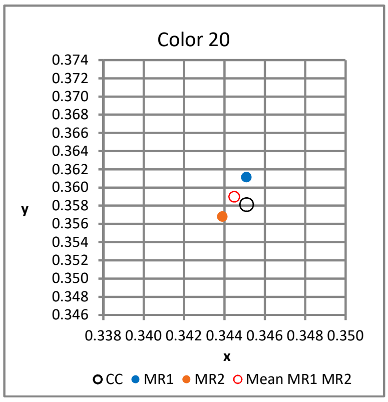


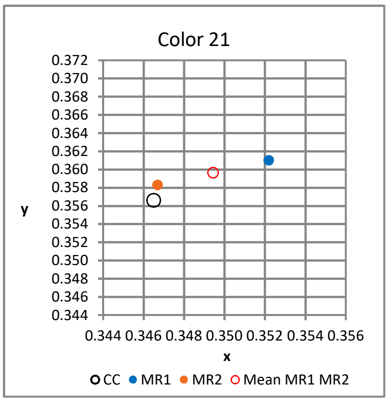


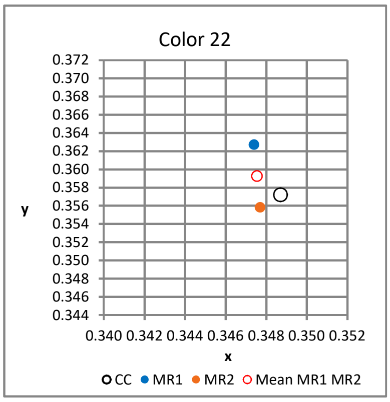


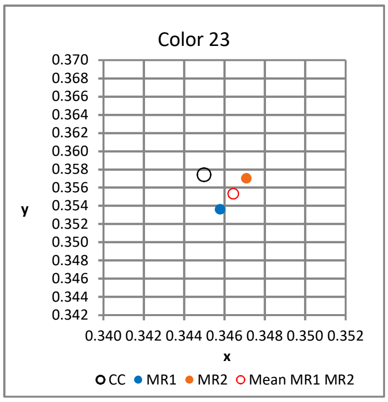


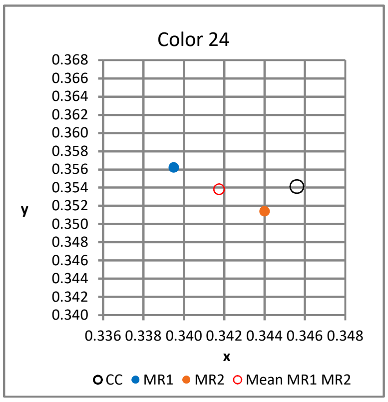












4| 4 Colormatching data

3.6 - Task 1 - Nominal values - summary and rating

	MR1 → CC	
Color	ΔE_{00}	Rating
1	0.49	1
2	0.54	2
3	0.68	2
4	1.15	3
5	0.53	2
6	1.48	3
8	1.27	3
11	0.43	1
12	1.34	3
16	0.82	2
17	2.08	4
18	0.71	1
Mean	0.96	2.25

	MR2 → CC	
Color	ΔE_{00}	Rating
1	0.11	0
2	0.00	0
3	0.43	1
4	0.00	0
5	0.29	1
6	0.00	0
8	1.09	3
11	0.11	0
12	0.54	2
16	0.05	0
17	0.29	1
18	1.00	3
Mean	0.33	0.92

	MCD → CC	
Color	ΔE_{00}	Rating
1	0.30	1
2	0.27	1
3	0.56	2
4	0.58	2
5	0.41	1
6	0.74	2
8	1.18	3
11	0.27	1
12	0.94	2
16	0.43	1
17	1.19	3
18	0.85	2
Mean	0.64	1.75

	MR1 → MR 2	
Color	ΔE_{00}	Rating
1	0.38	1
2	0.54	2
3	0.39	1
4	1.15	3
5	0.70	2
6	1.48	3
8	0.32	1
11	0.32	1
12	1.22	3
16	0.80	2
17	1.83	3
18	1.10	3
Mean	0.85	2.08

	MCD → $M_{MR1+MR2}$	
Color	ΔE_{00}	Rating
1	0.19	0
2	0.27	1
3	0.19	0
4	0.58	2
5	0.35	1
6	0.74	2
8	0.16	0
11	0.16	0
12	0.61	2
16	0.40	1
17	0.92	2
18	0.55	2
Mean	0.43	1.08

3.6 - Task 2 - Nominal values - summary and rating

	MR1 → CC	
Color	ΔE_{00}	Rating
1	0.87	2
2	4.92	5
3	0.86	2
4	0.97	2
5	0.53	2
6	0.46	1
7	2.04	4
8	0.58	2
9	1.03	3
10	0.00	0
11	1.43	3
12	2.02	4
13	4.72	5
14	0.74	2
15	2.32	4
16	1.12	3
17	0.75	2
18	2.83	4
19	5.33	6
20	1.94	3
21	4.37	5
22	3.46	4
23	2.70	4
24	4.03	5
Mean	2.08	3.21

	MR2 → CC	
Color	ΔE_{00}	Rating
1	0.00	0
2	0.28	1
3	0.60	2
4	0.62	2
5	0.53	2
6	0.46	1
7	1.02	3
8	1.58	3
9	0.39	1
10	0.46	1
11	0.80	2
12	0.78	2
13	1.32	3
14	0.34	1
15	1.65	3
16	0.36	1
17	1.37	3
18	2.67	4
19	3.89	4
20	1.42	3
21	0.75	2
22	0.69	2
23	2.34	4
24	2.19	4
Mean	1.10	2.25

	MCD → CC	
Color	ΔE_{00}	Rating
1	0.44	1
2	2.60	4
3	0.73	2
4	0.80	2
5	0.53	2
6	0.46	1
7	1.53	3
8	1.08	3
9	0.71	2
10	0.23	1
11	1.11	3
12	1.40	3
13	3.02	4
14	0.54	2
15	1.99	3
16	0.74	2
17	1.06	3
18	2.75	4
19	4.61	5
20	1.68	3
21	2.56	4
22	2.07	4
23	2.52	4
24	3.11	4
Mean	1.59	2.88

	MR1 → MR 2	
Color	ΔE_{00}	Rating
1	0.87	2
2	4.94	5
3	1.32	3
4	0.89	2
5	1.05	3
6	0.00	0
7	1.18	3
8	1.14	3
9	0.71	2
10	0.46	1
11	1.87	3
12	1.54	3
13	3.44	4
14	0.94	2
15	3.97	4
16	0.82	2
17	0.66	2
18	0.78	2
19	8.61	6
20	2.47	4
21	3.96	4
22	3.84	4
23	1.93	3
24	6.00	6
Mean	2.23	3.04

	MCD → $M_{MR1+MR2}$	
Color	ΔE_{00}	Rating
1	0.44	1
2	2.47	4
3	0.66	2
4	0.45	1
5	0.53	2
6	0.00	0
7	0.59	2
8	0.57	2
9	0.36	1
10	0.23	1
11	0.93	2
12	0.77	2
13	1.72	3
14	0.47	1
15	1.99	3
16	0.41	1
17	0.33	1
18	0.39	1
19	4.21	5
20	1.22	3
21	1.99	3
22	1.93	3
23	0.97	2
24	3.05	4
Mean	1.11	2.08

4| 4 Colormatching data

3.7 - Task 1 - Measured values - summary and rating

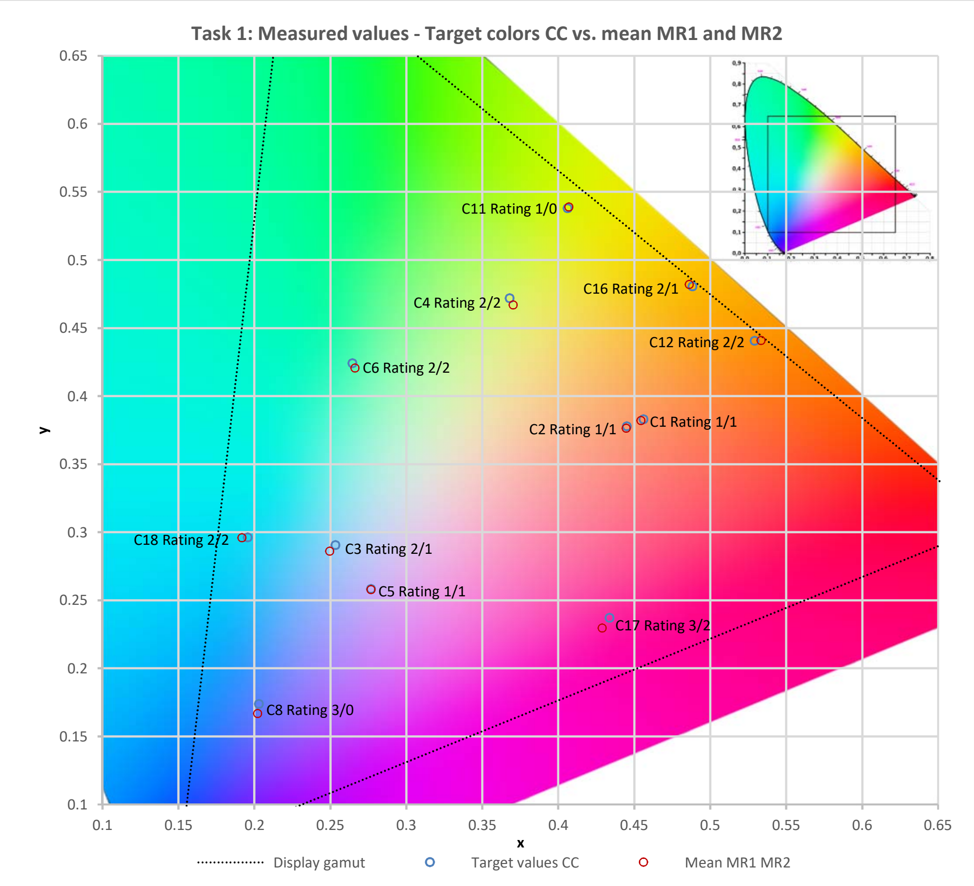
	MR1 → CC		MR2 → CC		MCD → CC		MR1 → MR 2		MCD → $M_{MR1+MR2}$	
Color	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
1	0.57	2	0.08	0	0.32	1	0.55	2	0.28	1
2	0.71	2	0.05	0	0.38	1	0.73	2	0.37	1
3	0.83	2	0.46	1	0.65	2	0.60	2	0.30	1
4	1.28	3	0.10	0	0.69	2	1.20	3	0.60	2
5	0.46	1	0.29	1	0.38	1	0.73	2	0.36	1
6	1.12	3	0.15	0	0.63	2	1.20	3	0.60	2
8	1.22	3	1.27	3	1.24	3	0.27	1	0.13	0
11	0.38	1	0.09	0	0.24	1	0.30	1	0.15	0
12	1.31	3	0.44	1	0.87	2	1.35	3	0.67	2
16	1.10	3	0.05	0	0.57	2	1.07	3	0.54	2
17	2.15	4	0.19	0	1.17	3	1.98	3	0.99	2
18	0.66	2	1.02	3	0.84	2	1.08	3	0.54	2
Mean	0.98	2.42	0.35	0.75	0.67	1.83	0.92	2.33	0.46	1.33

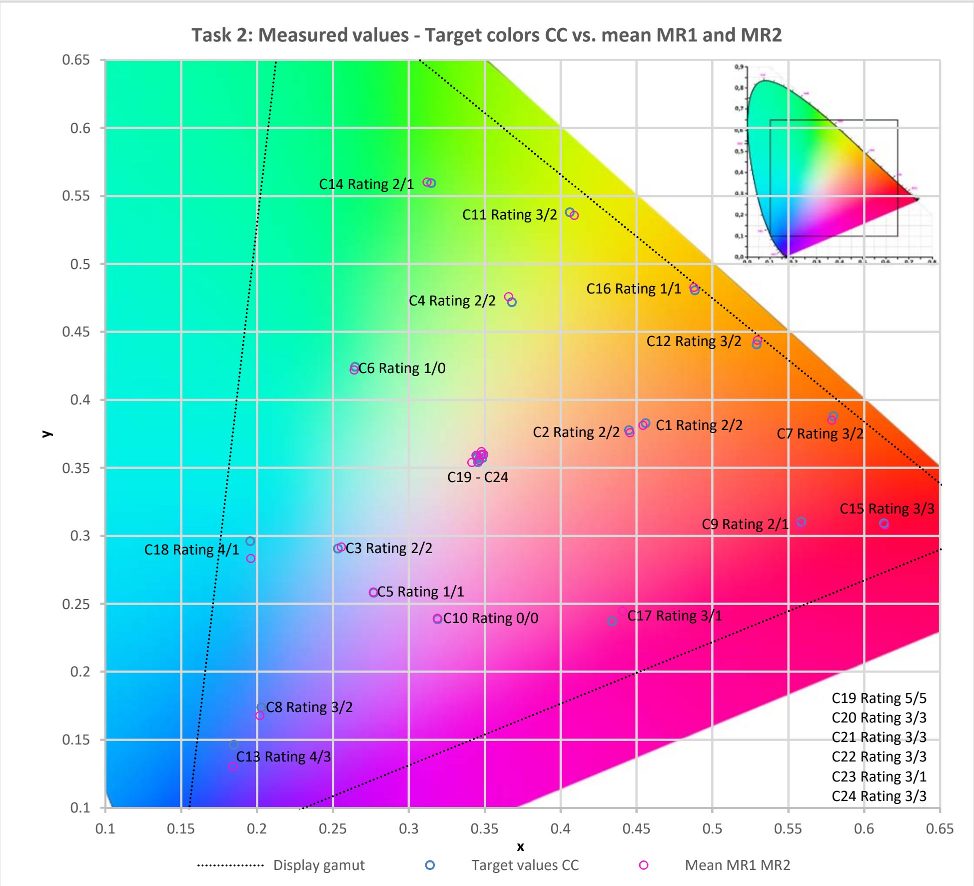
3.7 - Task 2 - Measured values - summary and rating

	MR1 → CC		MR2 → CC		MCD → CC		MR1 → MR 2		MCD → $M_{MR1+MR2}$	
Color	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
1	1.04	3	0.06	0	0.55	2	1.01	3	0.51	2
2	1.12	3	0.29	1	0.71	2	1.17	3	0.58	2
3	0.81	2	0.30	1	0.55	2	1.04	3	0.52	2
4	1.13	3	0.64	2	0.88	2	1.15	3	0.57	2
5	0.55	2	0.42	1	0.48	1	0.96	2	0.48	1
6	0.29	1	0.29	1	0.29	1	0.00	0	0.00	0
7	1.82	3	0.89	2	1.35	3	1.07	3	0.54	2
8	0.44	1	1.67	3	1.05	3	1.49	3	0.74	2
9	0.99	2	0.30	1	0.64	2	0.70	2	0.35	1
10	0.04	0	0.24	1	0.14	0	0.25	1	0.12	0
11	1.37	3	0.72	2	1.05	3	1.77	3	0.89	2
12	1.82	3	0.67	2	1.24	3	1.52	3	0.76	2
13	4.70	5	1.26	3	2.98	4	3.52	4	1.76	3
14	0.78	2	0.32	1	0.55	2	0.90	2	0.45	1
15	1.98	3	1.53	3	1.76	3	3.52	4	1.76	3
16	0.50	2	0.26	1	0.38	1	0.49	1	0.24	1
17	0.90	2	1.57	3	1.24	3	0.68	2	0.34	1
18	2.67	4	2.37	4	2.52	4	0.69	2	0.35	1
19	5.67	6	2.62	4	4.14	5	8.27	6	4.02	5
20	2.03	4	0.63	2	1.33	3	2.38	4	1.19	3
21	2.20	4	0.90	2	1.55	3	2.09	4	1.05	3
22	2.79	4	0.52	2	1.65	3	3.23	4	1.59	3
23	1.54	3	0.80	2	1.17	3	0.99	2	0.50	2
24	1.90	3	0.48	1	1.19	3	2.12	4	1.05	3
Mean	1.63	2.83	0.82	1.88	1.23	2.54	1.71	2.83	0.85	1.96

4| 4 Colormatching data

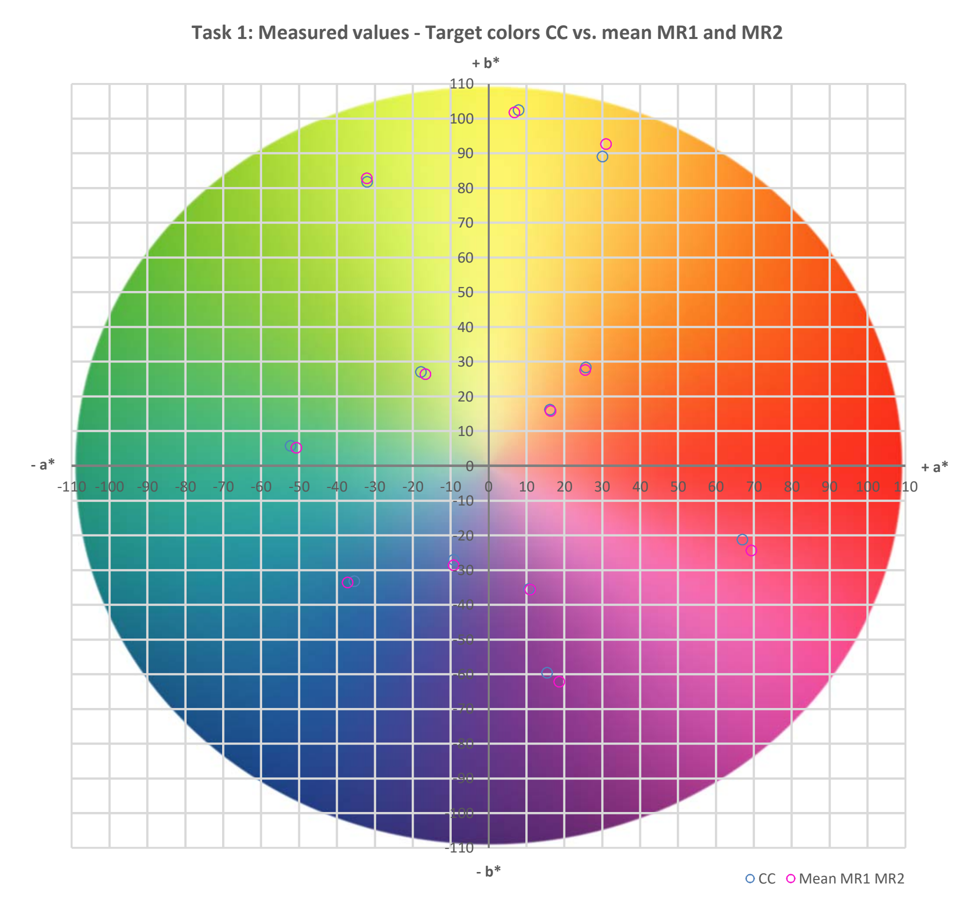
3.8 - Measured values - visualization in CIExy-Diagram

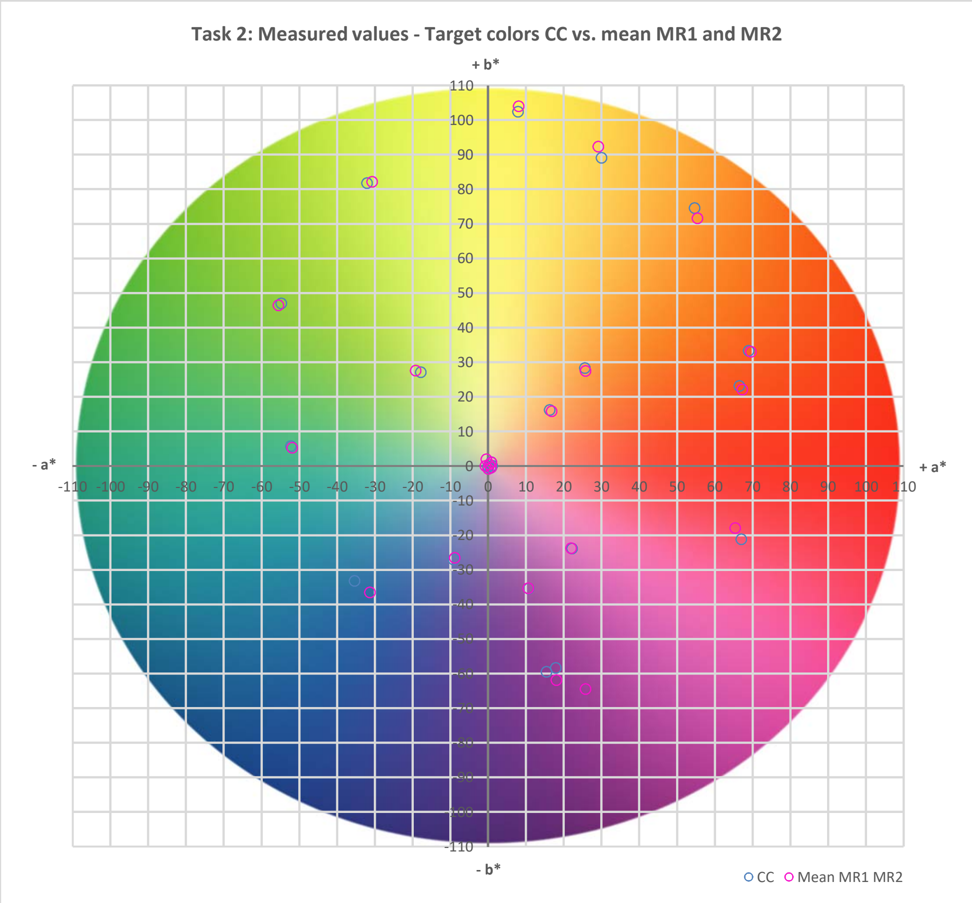




4| 4 Colormatching data

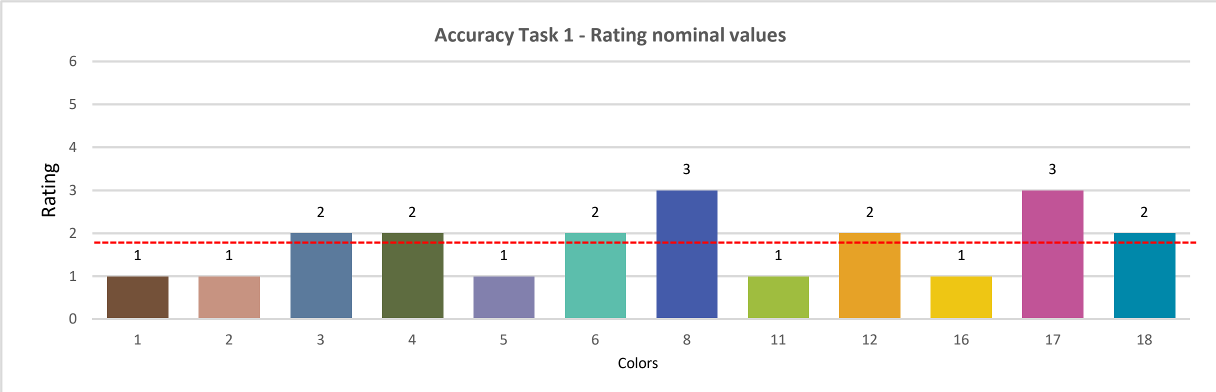
3.8 - Measured values - visualization in CIE a*b*-plane

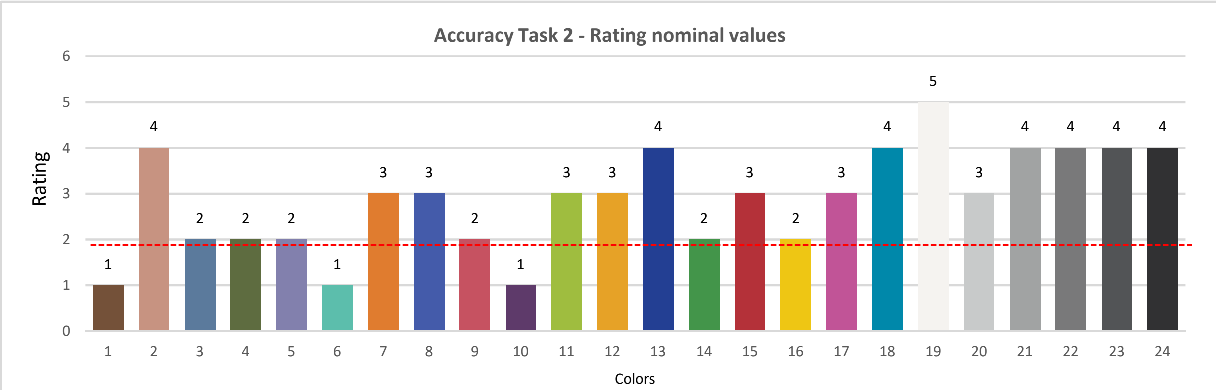


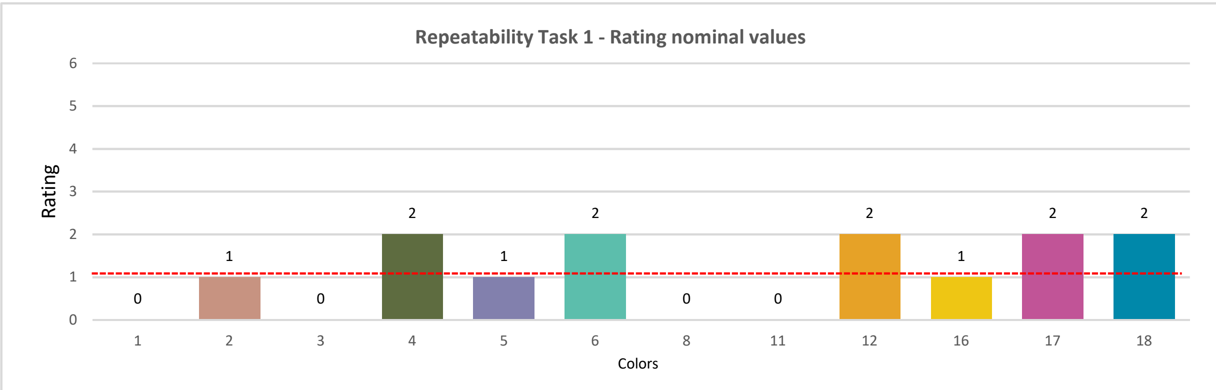


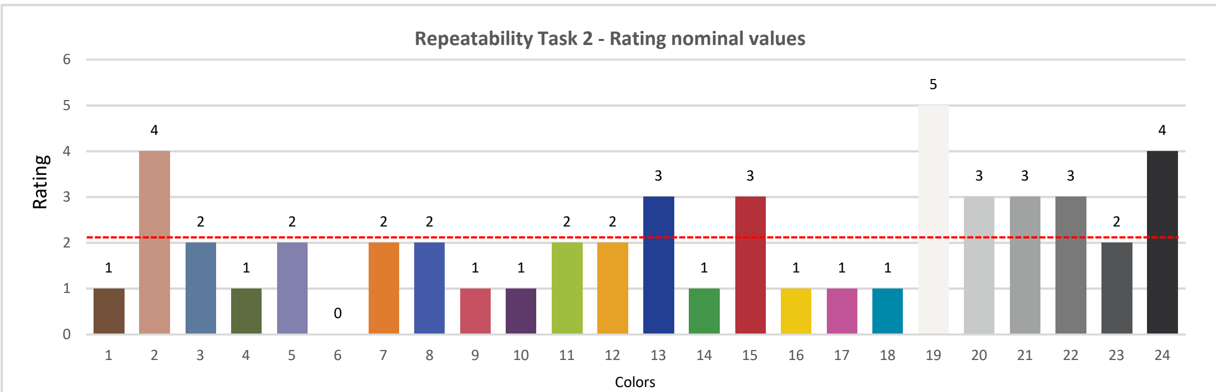
4| 4 Colormatching data

3.9 - Nominal values - Rating of the colors



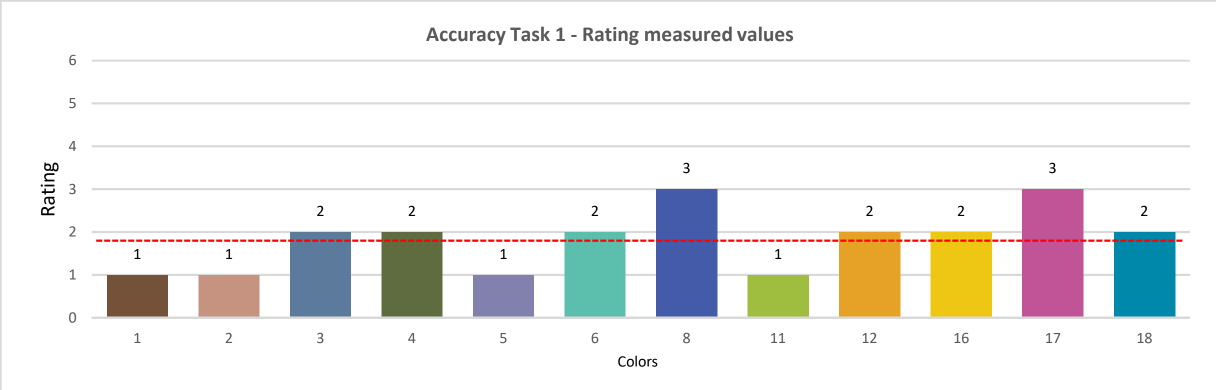


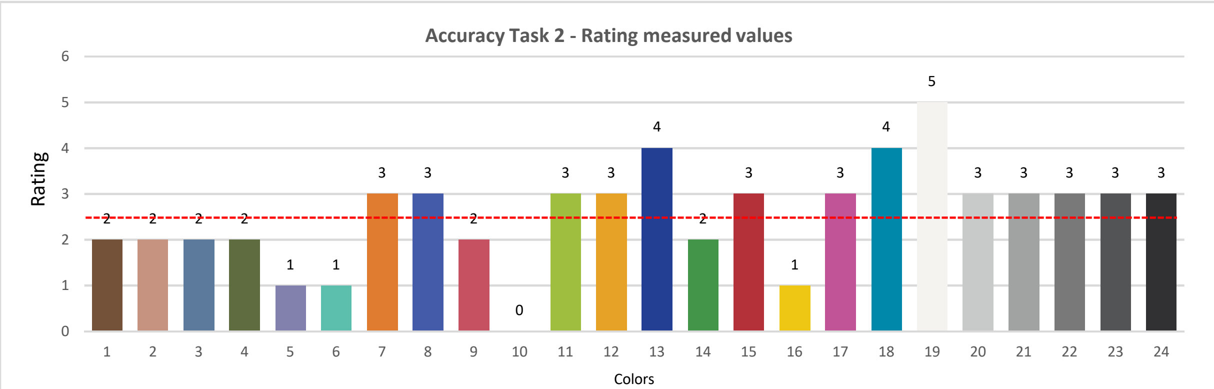


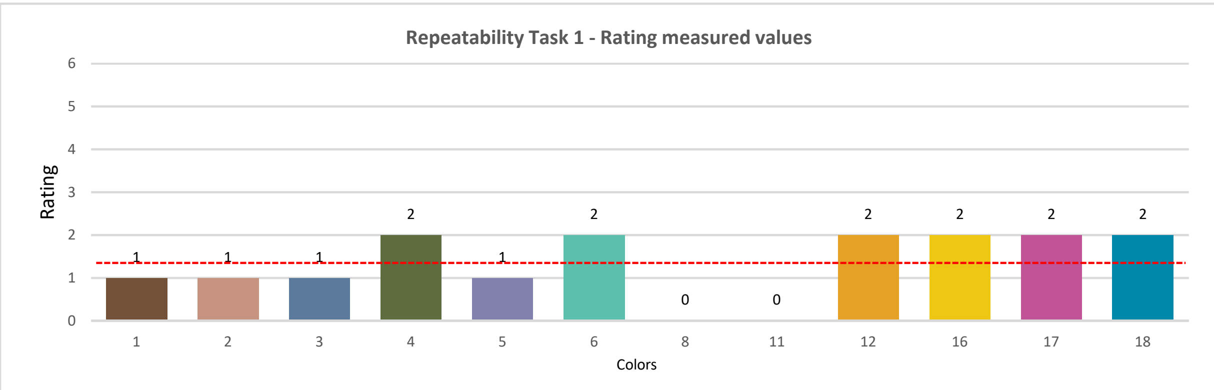


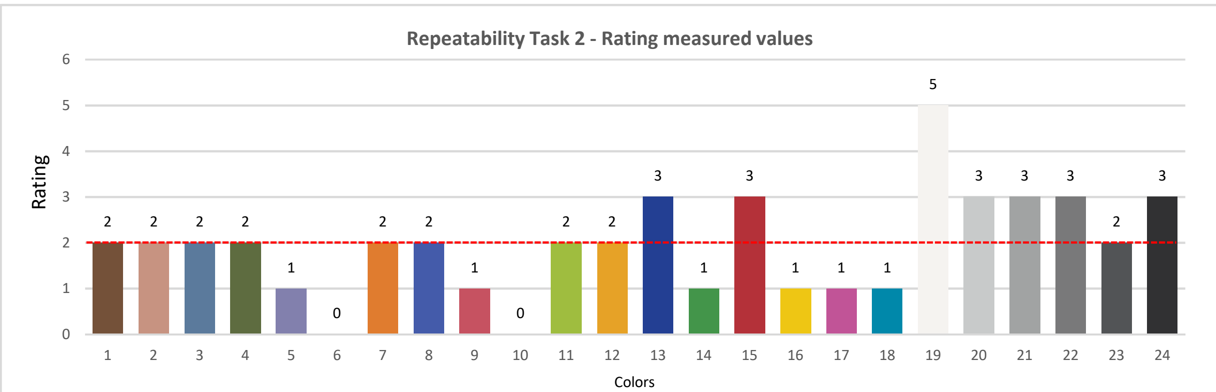
4| 4 Colormatching data

3.9 - Measured values - Rating of the colors





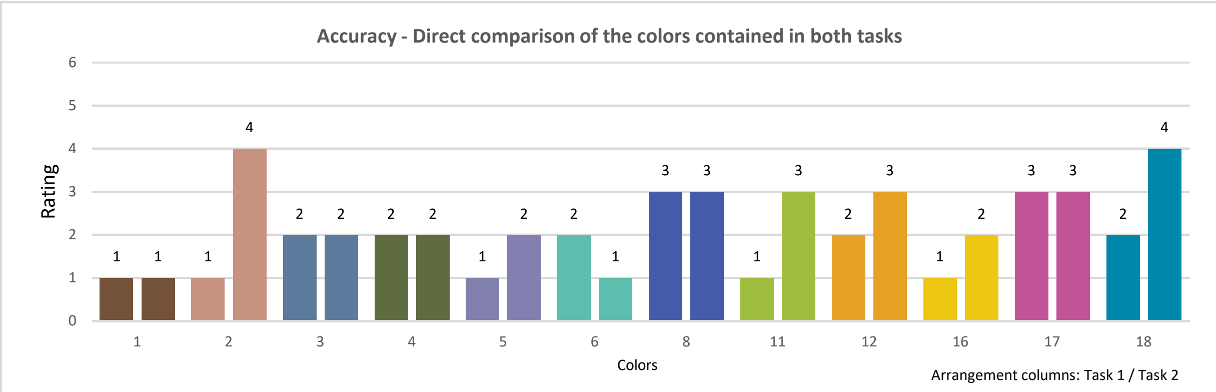


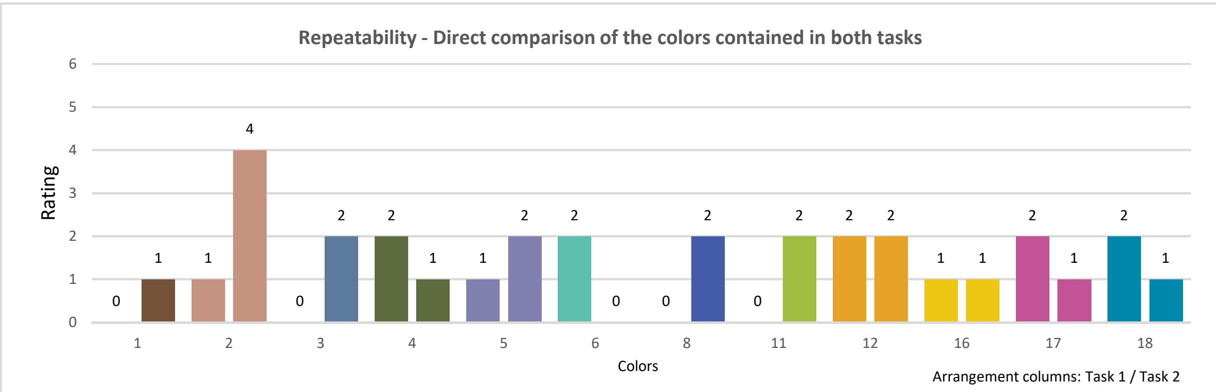


4| 4 Colormatching data

3.9 - Nominal values - Direct comparison of the colors contained in both tasks

	MCD → CC				MR1 → MR 2				MCD → $M_{MR1+MR2}$			
	Task1		Task2		Task1		Task2		Task1		Task2	
Color	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
1	0.30	1	0.44	1	0.38	1	0.87	2	0.19	0	0.44	1
2	0.27	1	2.60	4	0.54	2	4.94	5	0.27	1	2.47	4
3	0.56	2	0.73	2	0.39	1	1.32	3	0.19	0	0.66	2
4	0.58	2	0.80	2	1.15	3	0.89	2	0.58	2	0.45	1
5	0.41	1	0.53	2	0.70	2	1.05	3	0.35	1	0.53	2
6	0.74	2	0.46	1	1.48	3	0.00	0	0.74	2	0.00	0
8	1.18	3	1.08	3	0.32	1	1.14	3	0.16	0	0.57	2
11	0.27	1	1.11	3	0.32	1	1.87	3	0.16	0	0.93	2
12	0.94	2	1.40	3	1.22	3	1.54	3	0.61	2	0.77	2
16	0.43	1	0.74	2	0.80	2	0.82	2	0.40	1	0.41	1
17	1.19	3	1.06	3	1.83	3	0.66	2	0.92	2	0.33	1
18	0.85	2	2.75	4	1.10	3	0.78	2	0.55	2	0.39	1
Mean	0.64	1.75	1.14	2.50	0.85	2.08	1.32	2.50	0.43	1.08	0.66	1.58

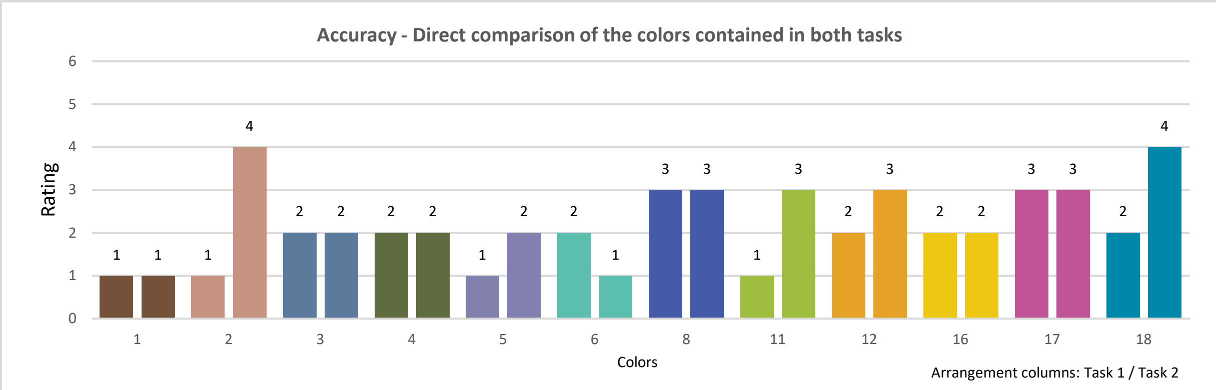


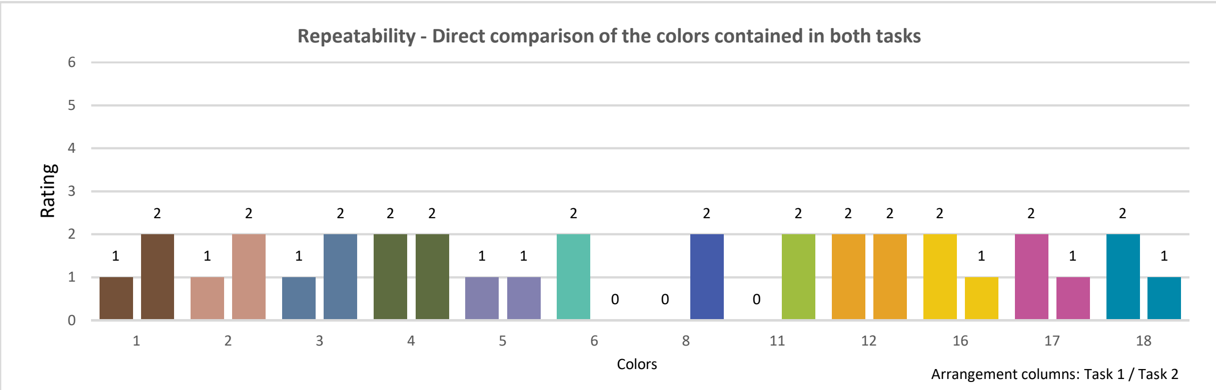


4| 4 Colormatching data

3.9 - Measured values - Direct comparison of the colors contained in both tasks

	MCD → CC				MR1 → MR 2				MCD → $M_{MR1+MR2}$			
	Task1		Task2		Task1		Task2		Task1		Task2	
Color	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
1	0.32	1	0.55	2	0.55	2	1.01	3	0.28	1	0.51	2
2	0.38	1	0.71	2	0.73	2	1.17	3	0.37	1	0.58	2
3	0.65	2	0.55	2	0.60	2	1.04	3	0.30	1	0.52	2
4	0.69	2	0.88	2	1.20	3	1.15	3	0.60	2	0.57	2
5	0.38	1	0.48	1	0.73	2	0.96	2	0.36	1	0.48	1
6	0.63	2	0.29	1	1.20	3	0.00	0	0.60	2	0.00	0
8	1.24	3	1.05	3	0.27	1	1.49	3	0.13	0	0.74	2
11	0.24	1	1.05	3	0.30	1	1.77	3	0.15	0	0.89	2
12	0.87	2	1.24	3	1.35	3	1.52	3	0.67	2	0.76	2
16	0.57	2	0.38	1	1.07	3	0.49	1	0.54	2	0.24	1
17	1.17	3	1.24	3	1.98	3	0.68	1	0.99	2	0.34	1
18	0.84	2	2.52	4	1.08	3	0.69	2	0.54	2	0.35	1
Mean	0.67	1.83	0.91	2.25	0.92	2.33	1.00	2.25	0.46	1.33	0.50	1.50





4| 4 Colormatching data

3.9 - Task 1 - Ranking of the colors

	Accuray		MR1 → MR 2		Repeatability	
Mean Task 1	**ΔE_{00}**	**Rating**	**ΔE_{00}**	**Rating**	**ΔE_{00}**	**Rating**
Nominal values	0.64	1.8	0.85	2.1	0.43	1.1
Measured values	0.67	1.8	0.92	2.3	0.46	1.3

	Rating chromatic colors											
Nominal values	11	2	1	5	16	3	4	6	18	12	8	17
Accuray	1	1	1	1	1	2	2	2	2	2	3	3
Repeatability	0	1	0	1	1	0	2	2	2	2	0	2

	Rating chromatic colors											
Measured values	11	1	5	2	16	6	3	4	18	12	17	8
Accuray	1	1	1	1	2	2	2	2	2	2	3	3
Repeatability	0	1	1	1	2	2	1	2	2	2	2	0

3.9 - Task 2 - Ranking of the colors

	Accuray		MR1 → MR 2		Repeatability	
Mean Task 2	**ΔE_{00}**	**Rating**	**ΔE_{00}**	**Rating**	**ΔE_{00}**	**Rating**
Nominal values	1.59	2.9	2.23	3.0	1.11	2.1
Measured values	1.23	2.5	1.71	2.8	0.85	2.0

	Accuray		MR1 → MR 2		Repeatability	
Measured values	**ΔE_{00}**	**Rating**	**ΔE_{00}**	**Rating**	**ΔE_{00}**	**Rating**
Chromatic colors	1.02	2.3	1.22	2.5	0.61	1.6
Achromatic colors	1.84	3.3	3.18	4.0	1.57	3.2

	Rating chromatic colors																		Rating achromatic colors					
Nominal values	10	1	6	5	14	9	3	16	4	17	8	11	12	7	15	2	18	13	20	22	23	21	24	19
Accuray	1	1	1	2	2	2	2	2	2	3	3	3	3	3	3	4	4	4	3	4	4	4	4	5
Repeatability	1	1	0	2	1	1	2	1	1	1	2	2	2	2	3	4	1	3	3	3	2	3	4	5

	Rating chromatic colors																		Rating achromatic colors					
Measured values	10	6	16	5	14	1	3	9	2	4	11	8	17	12	7	15	18	13	23	24	20	21	22	19
Accuray	0	1	1	1	2	2	2	2	2	2	3	3	3	3	3	3	4	4	3	3	3	3	3	5
Repeatability	0	0	1	1	1	2	2	1	2	2	2	2	1	2	2	1	1	3	2	3	3	3	3	5

3.9 - Direct comparison of the colors contained in both tasks

	Accuray		MR1 → MR 2		Repeatability	
Mean	**ΔE_{00}**	**Rating**	**ΔE_{00}**	**Rating**	**ΔE_{00}**	**Rating**
Nominal values	0.64	1.8	0.85	2.1	0.43	1.1
Nominal values	1.14	2.5	1.32	2.5	0.66	1.6
Measured values	0.67	1.8	0.92	2.3	0.46	1.3
Measured values	0.91	2.3	1.00	2.3	0.50	1.5

	Rating chromatic colors											
Nominal values	1	2	3	4	5	6	8	11	12	16	17	18
Accuray	1	1	2	2	1	2	3	1	2	1	3	2
Accuray	1	4	2	2	2	1	3	3	3	2	3	4
Repeatability	0	1	0	2	1	2	0	0	2	1	2	2
Repeatability	1	4	2	1	2	0	2	2	2	1	1	1

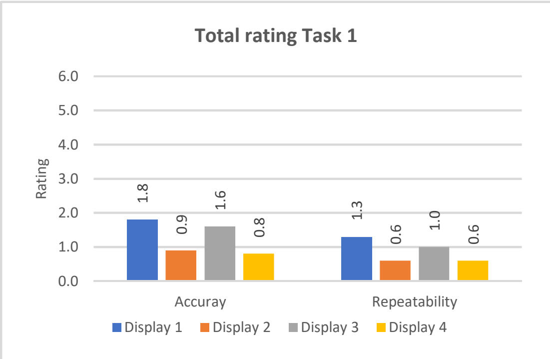
	Rating chromatic colors											
Measured values	1	2	3	4	5	6	8	11	12	16	17	18
Accuray	1	1	2	2	1	2	3	1	2	2	3	2
Accuray	2	2	2	2	1	1	3	3	3	1	3	4
Repeatability	1	1	1	2	1	2	0	0	2	2	2	2
Repeatability	2	2	2	2	1	0	2	2	2	1	1	1

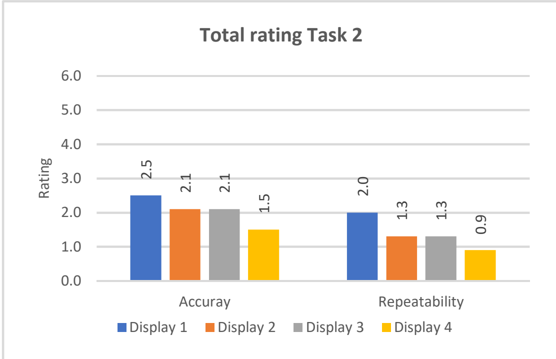
4| 5 User-related summary of the results of the color matching tests performed

1.1 - Total rating of Task 1 and Task 2 for each display used

Task 1	**Accuray**		**MR1 → MR2**		**Repeatability**	
Measured values	**ΔE_{00}**	**Rating**	**ΔE_{00}**	**Rating**	**ΔE_{00}**	**Rating**
Display 1	0.67	1.8	0.92	2.3	0.46	1.3
Display 2	0.32	0.9	0.48	1.3	0.24	0.6
Display 3	0.49	1.6	0.71	1.8	0.36	1.0
Display 4	0.29	0.8	0.40	1.3	0.20	0.6

Task 2	**Accuray**		**MR1 → MR2**		**Repeatability**	
Measured values	**ΔE_{00}**	**Rating**	**ΔE_{00}**	**Rating**	**ΔE_{00}**	**Rating**
Display 1	1.23	2.5	1.71	2.8	0.85	2.0
Display 2	0.81	2.1	0.92	2.0	0.46	1.3
Display 3	0.83	2.1	1.03	2.2	0.51	1.3
Display 4	0.52	1.5	0.68	1.8	0.34	0.9





1.2 - Ranking of results per color

Display 1	**Rating chromatic colors**											
Task 1	11	1	5	2	16	6	3	4	18	12	17	8
Accuray	1	1	1	1	2	2	2	2	2	2	3	3
Repeatability	0	1	1	1	2	2	1	2	2	2	2	0

Display 1	**Rating chromatic colors**																		**Rating achromatic colors**					
Task 2	10	6	16	5	14	1	3	9	2	4	11	8	17	12	7	12	18	13	23	24	20	21	22	19
Accuray	0	1	1	1	2	2	2	2	2	2	3	3	3	3	3	3	4	4	3	3	3	3	3	5
Repeatability	0	0	1	1	1	2	2	1	2	2	2	2	1	2	2	1	1	3	2	3	3	3	3	5

Display 2	**Rating chromatic colors**											
Task 1	4	1	5	3	16	6	12	18	11	2	8	17
Accuray	0	0	0	1	1	1	1	1	1	1	2	2
Repeatability	0	0	0	0	0	1	0	1	1	1	1	2

Display 2	**Rating chromatic colors**																		**Rating achromatic colors**					
Task 2	9	4	18	11	3	2	1	5	6	17	10	16	12	8	15	7	14	13	20	21	22	24	23	19
Accuray	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	3	3	4	2	2	2	2	3	3
Repeatability	1	0	1	1	1	2	0	2	2	1	2	2	2	2	2	2	3	2	1	0	0	0	1	1

Display 3	**Rating chromatic colors**											
Task 1	11	4	18	2	16	5	1	6	12	3	8	17
Accuray	1	1	1	1	1	1	2	2	2	2	2	3
Repeatability	0	1	0	1	0	1	1	0	1	2	2	3

Display 3	**Rating chromatic colors**																		**Rating achromatic colors**					
Task 2	9	1	11	12	4	5	7	2	16	18	3	15	8	17	6	10	13	14	20	23	21	22	19	24
Accuray	1	1	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3	4	1	2	2	2	2	3
Repeatability	0	1	1	1	1	1	0	2	1	0	1	2	2	3	3	1	1	3	0	1	1	2	2	2

Display 4	**Rating chromatic colors**											
Task 1	1	11	16	5	8	6	2	4	12	3	18	17
Accuray	0	0	0	1	1	1	1	1	1	1	1	2
Repeatability	0	0	0	1	1	1	0	1	1	0	1	1

Display 4	**Rating chromatic colors**																		**Rating achromatic colors**					
Task 2	4	7	6	5	9	14	1	3	11	12	15	2	8	16	18	10	17	13	24	20	22	19	23	21
Accuray	0	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2
Repeatability	0	1	1	1	1	0	1	1	1	1	1	1	1	1	2	2	1	0	1	1	0	0	1	2

* The ranking is based on the rating of the results for accuracy.

4| 5 User-related summary of the results of the color matching tests performed

1.3 - Task 1 - Comparison of the rating for accuracy

Display 1

Color		MCD → CC	
		ΔE_{00}	Rating
	1	0.32	1
	2	0.38	1
	3	0.65	2
	4	0.69	2
	5	0.38	1
	6	0.63	2
	8	1.24	3
	11	0.24	1
	12	0.87	2
	16	0.57	2
	17	1.17	3
	18	0.84	2
Mean		0.67	1.83

Display 2

Color		MCD → CC	
		ΔE_{00}	Rating
	1	0.11	0
	2	0.46	1
	3	0.22	1
	4	0.10	0
	5	0.15	0
	6	0.25	1
	8	0.53	2
	11	0.40	1
	12	0.27	1
	16	0.24	1
	17	0.76	2
	18	0.32	1
Mean		0.32	0.92

Display 3

Color		MCD → CC	
		ΔE_{00}	Rating
	1	0.54	2
	2	0.36	1
	3	0.64	2
	4	0.27	1
	5	0.48	1
	6	0.54	2
	8	0.64	2
	11	0.20	1
	12	0.56	2
	16	0.36	1
	17	1.04	3
	18	0.31	1
Mean		0.49	1.58

Display 4

Color		MCD → CC	
		ΔE_{00}	Rating
	1	0.07	0
	2	0.28	1
	3	0.37	1
	4	0.28	1
	5	0.25	1
	6	0.27	1
	8	0.27	1
	11	0.12	0
	12	0.36	1
	16	0.16	0
	17	0.59	2
	18	0.48	1
Mean		0.29	0.83

1.3 - Task 2 - Comparison of the rating for accuracy

Display 1

Color		MCD → CC	
		ΔE_{00}	Rating
	1	0.55	2
	2	0.71	2
	3	0.55	2
	4	0.88	2
	5	0.48	1
	6	0.29	1
	7	1.35	3
	8	1.05	3
	9	0.64	2
	10	0.14	0
	11	1.05	3
	12	1.24	3
	13	2.98	4
	14	0.55	2
	15	1.76	3
	16	0.38	1
	17	1.24	3
	18	2.52	4
	19	4.14	5
	20	1.33	3
	21	1.55	3
	22	1.65	3
	23	1.17	3
	24	1.19	3
Mean		1.23	2.54

Display 2

Color		MCD → CC	
		ΔE_{00}	Rating
	1	0.60	2
	2	0.59	2
	3	0.56	2
	4	0.38	1
	5	0.63	2
	6	0.63	2
	7	1.01	3
	8	0.89	2
	9	0.34	1
	10	0.76	2
	11	0.54	2
	12	0.80	2
	13	2.29	4
	14	1.27	3
	15	0.95	2
	16	0.79	2
	17	0.69	2
	18	0.41	1
	19	1.23	3
	20	0.57	2
	21	0.77	2
	22	0.77	2
	23	1.20	3
	24	0.86	2
Mean		0.81	2.13

Display 3

Color		MCD → CC	
		ΔE_{00}	Rating
	1	0.32	1
	2	0.61	2
	3	0.77	2
	4	0.50	2
	5	0.53	2
	6	1.21	3
	7	0.54	2
	8	1.04	3
	9	0.22	1
	10	1.28	3
	11	0.40	1
	12	0.44	1
	13	1.64	3
	14	2.67	4
	15	0.81	2
	16	0.62	2
	17	1.10	3
	18	0.71	2
	19	0.91	2
	20	0.29	1
	21	0.80	2
	22	0.83	2
	23	0.62	2
	24	1.11	3
Mean		0.83	2.13

Display 4

Color		MCD → CC	
		ΔE_{00}	Rating
	1	0.36	1
	2	0.50	2
	3	0.38	1
	4	0.03	0
	5	0.34	1
	6	0.33	1
	7	0.33	1
	8	0.51	2
	9	0.35	1
	10	0.68	2
	11	0.39	1
	12	0.47	1
	13	0.89	2
	14	0.36	1
	15	0.48	1
	16	0.52	2
	17	0.78	2
	18	0.59	2
	19	0.65	2
	20	0.60	2
	21	0.95	2
	22	0.61	2
	23	0.83	2
	24	0.50	2
Mean		0.52	1.50

4| 5 User-related summary of the results of the color matching tests performed

1.4 - Task 1 - Comparison of the rating for the color difference MR1 → MR2

	Display 1		Display 2		Display 3		Display 4	
	MR1 → MR2		MR1 → MR2		MR1 → MR2		MR1 → MR2	
Color	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
1	0.55	2	0.02	0	0.96	2	0.01	0
2	0.73	2	0.87	2	0.57	2	0.31	1
3	0.60	2	0.30	1	1.01	3	0.33	1
4	1.20	3	0.19	0	0.53	2	0.56	2
5	0.73	2	0.29	1	0.84	2	0.40	1
6	1.20	3	0.50	2	0.01	0	0.51	2
8	0.27	1	0.72	2	1.26	3	0.50	2
11	0.30	1	0.80	2	0.23	1	0.24	1
12	1.35	3	0.34	1	0.79	2	0.67	2
16	1.07	3	0.30	1	0.27	1	0.29	1
17	1.98	3	1.02	3	2.07	4	0.49	1
18	1.08	3	0.44	1	0.01	0	0.45	1
Mean	0.92	2.33	0.48	1.33	0.71	1.83	0.40	1.25

1.4 - Task 2 - Comparison of the rating for the color difference MR1 → MR2

	Display 1		Display 2		Display 3		Display 4	
	MR1 → MR2		MR1 → MR2		MR1 → MR2		MR1 → MR2	
Color	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
1	1.01	3	0.02	0	0.56	2	0.56	2
2	1.17	3	0.99	2	1.11	3	0.63	2
3	1.04	3	0.65	2	0.92	2	0.67	2
4	1.15	3	0.18	0	0.42	1	0.00	0
5	0.96	2	1.24	3	0.63	2	0.61	2
6	0.00	0	1.00	3	2.28	4	0.60	2
7	1.07	3	1.99	3	0.20	0	0.54	2
8	1.49	3	1.77	3	1.92	3	0.65	2
9	0.70	2	0.63	2	0.07	0	0.70	2
10	0.25	1	1.51	3	0.85	2	1.36	3
11	1.77	3	0.94	2	0.49	1	0.75	2
12	1.52	3	1.08	3	0.70	2	0.45	1
13	3.52	4	0.56	2	0.69	2	0.12	0
14	0.90	2	2.52	4	3.37	4	0.37	1
15	3.52	4	1.88	3	1.28	3	0.52	2
16	0.49	1	1.03	3	0.59	2	0.95	2
17	0.68	2	0.54	2	2.18	4	0.62	2
18	0.69	2	0.83	2	0.34	1	1.17	3
19	8.27	6	0.78	2	1.77	3	0.29	1
20	2.38	4	0.87	2	0.26	1	0.90	2
21	2.09	4	0.18	0	0.77	2	1.84	3
22	3.23	4	0.26	1	1.25	3	0.35	1
23	0.99	2	0.56	2	0.86	2	0.64	2
24	2.12	4	0.01	0	1.17	3	0.96	2
Mean	1.71	2.83	0.92	2.04	1.03	2.17	0.68	1.79

4| 5 User-related summary of the results of the color matching tests performed

1.5 - Task 1 - Comparison of the rating for repeatability

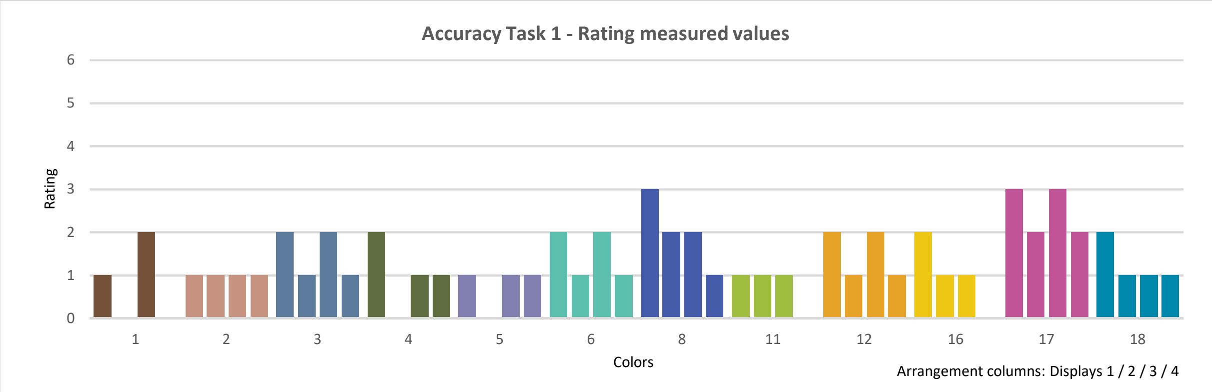
	Display 1		Display 2		Display 3		Display 4	
	MCD → $M_{MR1+MR2}$		MCD → $M_{MR1+MR2}$		MCD → $M_{MR1+MR2}$		MCD → $M_{MR1+MR2}$	
Color	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
1	0.28	1	0.01	0	0.48	1	0.00	0
2	0.37	1	0.44	1	0.28	1	0.15	0
3	0.30	1	0.15	0	0.51	2	0.16	0
4	0.60	2	0.10	0	0.26	1	0.28	1
5	0.36	1	0.14	0	0.42	1	0.20	1
6	0.60	2	0.25	1	0.01	0	0.26	1
8	0.13	0	0.36	1	0.63	2	0.25	1
11	0.15	0	0.40	1	0.12	0	0.12	0
12	0.67	2	0.17	0	0.40	1	0.34	1
16	0.54	2	0.15	0	0.13	0	0.14	0
17	0.99	2	0.51	2	1.04	3	0.24	1
18	0.54	2	0.22	1	0.01	0	0.22	1
Mean	0.46	1.33	0.24	0.58	0.36	1.00	0.20	0.58

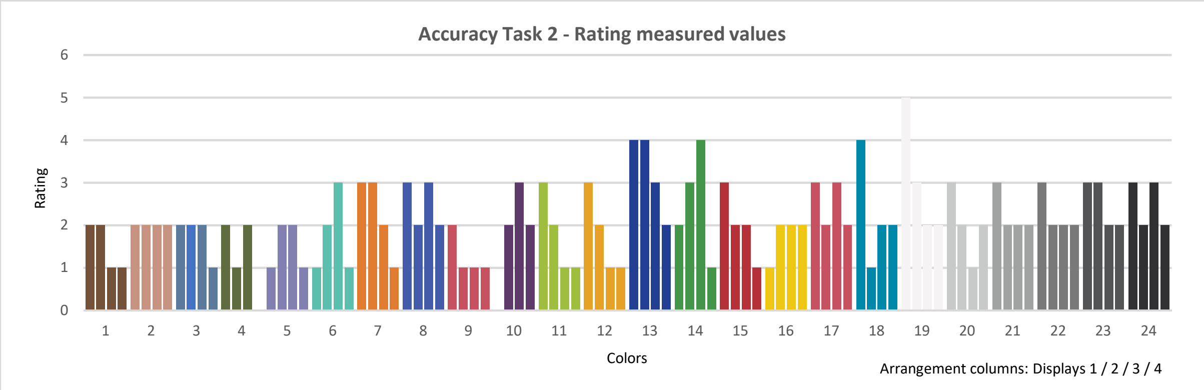
1.5 - Task 2 - Comparison of the rating for repeatability

	Display 1		Display 2		Display 3		Display 4	
	MCD → $M_{MR1+MR2}$		MCD → $M_{MR1+MR2}$		MCD → $M_{MR1+MR2}$		MCD → $M_{MR1+MR2}$	
Color	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating	ΔE_{00}	Rating
1	0.51	2	0.01	0	0.28	1	0.28	1
2	0.58	2	0.50	2	0.55	2	0.31	1
3	0.52	2	0.33	1	0.46	1	0.33	1
4	0.57	2	0.09	0	0.21	1	0.00	0
5	0.48	1	0.62	2	0.31	1	0.31	1
6	0.00	0	0.50	2	1.14	3	0.30	1
7	0.54	2	0.99	2	0.10	0	0.27	1
8	0.74	2	0.89	2	0.96	2	0.32	1
9	0.35	1	0.31	1	0.03	0	0.35	1
10	0.12	0	0.75	2	0.43	1	0.68	2
11	0.89	2	0.47	1	0.25	1	0.38	1
12	0.76	2	0.54	2	0.35	1	0.22	1
13	1.76	3	0.28	1	0.34	1	0.06	0
14	0.45	1	1.26	3	1.68	3	0.18	0
15	1.76	3	0.94	2	0.64	2	0.26	1
16	0.24	1	0.52	2	0.29	1	0.48	1
17	0.34	1	0.27	1	1.09	3	0.31	1
18	0.35	1	0.41	1	0.17	0	0.59	2
19	4.02	5	0.39	1	0.88	2	0.15	0
20	1.19	3	0.43	1	0.13	0	0.45	1
21	1.05	3	0.09	0	0.39	1	0.92	2
22	1.59	3	0.13	0	0.62	2	0.17	0
23	0.50	2	0.28	1	0.43	1	0.32	1
24	1.05	3	0.01	0	0.59	2	0.48	1
Mean	0.85	1.96	0.46	1.25	0.51	1.33	0.34	0.92

4| 5 User-related summary of the results of the color matching tests performed

1.6 - Visualization of the rating for accuracy





1.6 - Visualization of the rating for repeatability