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Discipline/ Spécialité : Sciences du Vivant - Physiologie et Biologie des Organismes, Populations, Interactions

LE DEVELOPPEMENT DES COMPETENCES ECONOMIQUES CHEZ L'ENFANT

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Thèse présentée devant l'Université de Strasbourg

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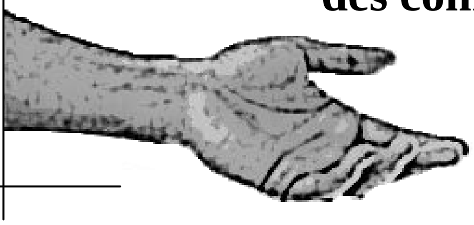

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A ma famille.

« Dans les sciences, le chemin est plus important que le but. Les sciences n'ont pas de fin.»

Erwin Chargaff

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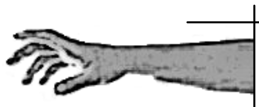
ARTICLES &



COMMUNICATIONS

Ce travail est basé sur les articles suivants :

Article 1

Steelandt, S., Thierry, B., Whiten, A., Broihanne, M.H. & Dufour, V. The early development of gifts and exchanges in children. *Social Development* [en révision]

Article 2

Steelandt, S., Thierry, B., Broihanne, M.H. & Dufour, V. (2012) The ability of children to delay gratification in an exchange task. *Cognition*, **122**, 416-425.

Article 3

Steelandt, S., Dufour, V., Broihanne, M.H. & Thierry, B. Children make investment based on calculated pay-off. [en révision]

Article 4

Steelandt, S., Broihanne, M.H., Romain, A., Thierry, B., & Dufour, V. Decision-making in children under risk. [soumis]

Articles non-inclus dans le cadre de la thèse :

Article 5

Steelandt, S., Dufour, V., Broihanne, M.H. & Thierry, B. (2011) Can monkeys make investments based on maximized pay-off? *PLoS One*, **6**(3), e17801.

Article 6

Steelandt, S., Broihanne, M.H. & Thierry, B. (2011) Are monkeys sensitive to the regularity of pay-off? *International Journal of Comparative Psychology*, **24**, 272-283.

Communications orales :

Steelandt, S., Thierry, B., Broihanne, M.H. & Dufour, V. Ability of children to delay gratification in an exchange task. Communication orale, *XVth European Conference on Developmental Psychology (ESDP)*, Bergen (Norvège), 23-27 août 2011.

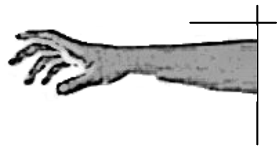
Steelandt, S., Thierry, B., Broihanne, M.H. & Dufour, V. Combien de temps des enfants peuvent-ils attendre une récompense dans un échange ? Communication orale, *Colloque de la Société Française pour l'Etude du Comportement Animal (SFECA)*, Tours, 17-19 mai 2011.

Steelandt, S., Thierry, B., Broihanne, M.H. & Dufour, V. On the foundations of economics skills: the early development of gifts and exchanges in children. Communication orale, *6th congrès international d'économie expérimentale et comportementale (IMEBE)*, Bilbao (Espagne), 7-10 avril 2010.

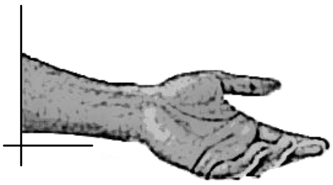
Thierry, B., **Steelandt, S.**, Dufour, V. & Broihanne, M.H. Calculating pay-offs before gamble in monkeys. Communication orale, *31ème congrès International d'Ethologie (IEC)*, Rennes, 19-24 août 2009.

Steelandt, S., Dufour, V., Broihanne, M.H. & Thierry B. Monkeys can calculate pay-offs before gambling in an exchange task. Communication orale, *3ème congrès de la Fédération Européenne de Primatologie (EFP)*, Zurich (Suisse), 12-15 août 2009.

Steelandt, S., Pelé, M., Dufour, V. & Thierry B. Des singes capucins et des macaques maximisent-ils leur profit dans une tâche d'échange? Communication orale, *21ème colloque de la Société Francophone de Primatologie (SFDP)*, Mulhouse, 15-17 octobre 2008.



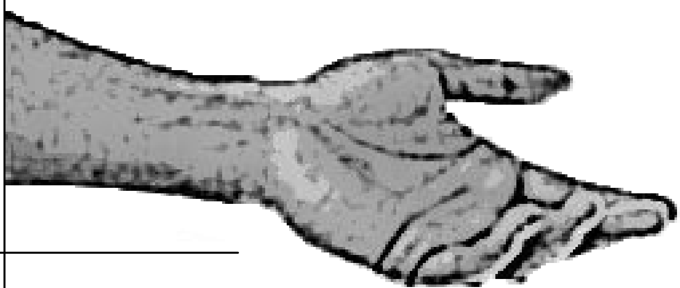
SOMMAIRE



CHAPITRE I : INTRODUCTION GENERALE 1

CHAPITRE 1

INTRODUCTION GENERALE



L'aptitude à faire du commerce, c'est-à-dire à réaliser des transactions entre individus, est caractéristique de l'espèce humaine ; elle le distingue des espèces animales et des autres hominidés que sont les grands singes. Selon Burris (1982), « la transaction économique de base dans une économie de marché est celle de l'échange, à savoir le transfert réciproque de valeurs économiques entre individus ». L'argent est l'une de ces valeurs mais les réseaux d'échange utilisent fréquemment le troc, c'est-à-dire l'échange de biens ou services de différentes natures.

Afin d'assurer et maximiser son profit, un agent économique doit développer un ensemble de connaissances et de méthodes lui permettant d'exploiter au mieux les informations à sa disposition. Réaliser une transaction mobilise des compétences telles que l'aptitude à donner à une personne inconnue, anticiper un retour, juger des risques liés à la transaction ou au partenaire d'échange, et adapter son comportement en conséquence. De telles facultés n'apparaissent pas nécessairement au même stade de l'ontogenèse. Elles sont liées au développement d'outils cognitifs permettant à l'individu de s'engager ou non dans des interactions réciproques, tels que les compétences numériques, le contrôle de l'impulsivité, ou la théorie de l'esprit.

Au cours de ces dernières années, un grand champ disciplinaire a vu le jour pour tenter d'expliquer le comportement économique des êtres humains : l'*économie expérimentale*. Il a fallu plusieurs décennies pour convaincre de la validité de la méthode expérimentale à étudier des interactions économiques dans un contexte simplifié de laboratoire. Marquée par l'attribution en 2002 du prix Nobel d'économie à Daniel Kahneman et Vernon Smith, l'économie expérimentale consiste à réaliser des expériences en environnement contrôlé afin d'isoler et modéliser les éléments de la décision individuelle. Selon Roth (1988), ses principaux objectifs consistent à tester les prédictions théoriques existantes en les confrontant à des données obtenues expérimentalement en laboratoire (*speaking to theorists*), à explorer des situations peu ou mal théorisées (*searching for facts*) et à aider à la décision en permettant d'évaluer l'impact de certaines mesures, les effets d'une stratégie, ou l'efficacité d'une option (*whispering in the ears of princes*). Bien qu'il ne permette pas toujours de modéliser et d'expliquer l'ensemble des choix économiques, cet outil d'analyse du comportement contribue de manière notable à notre compréhension des déterminants de la prise de décision.

Malgré l'importance des interactions économiques dans les sociétés occidentales, la rareté des études sur la prise de décision chez les jeunes enfants en situation d'échange avec un autre partenaire est surprenante. Si les dons et échanges sont couramment utilisés lors des transactions chez l'adulte, ils sont en effet également présents chez les enfants (Cohen, 2006) ce qui révèle chez ces derniers l'existence de compétences économiques. Les jeunes enfants représentent des acteurs de plus en plus actifs de la consommation, devenue aujourd'hui facteur d'intégration sociale. Un tel constat a conduit à s'intéresser à la relation qu'ont les enfants à l'argent, la publicité ou aux marques (Berti & Bombi, 1988 ; Furnham & Lewis, 1986 ; Stacey, 1982). Pourtant, notre savoir en termes de compétences nécessaires à la prise de décision individuelle reste pour le moins lacunaire chez l'enfant.

L'objectif de ce travail de thèse est d'étudier le développement des compétences économiques et des facteurs de décision chez les enfants en situation d'échange (1) en évaluant l'âge auquel ils comprennent l'utilisation du don et de l'échange comme un moyen de maximiser leur gain, (2) en testant s'ils intègrent le coût temporel associé à un échange, (3) en recherchant s'ils sont capables d'ajuster leur investissement au comportement des partenaires d'échange, et (4) en examinant leur aptitude à prendre en compte le risque inhérent à la situation d'échange. L'étude des performances liées à l'âge doit permettre de préciser comment se mettent en place ces compétences économiques.

Je commencerai par rappeler la place qu'occupe l'économie au sein des sociétés monétaires et non monétaires, et dans quelle mesure elle est présente dans la vie quotidienne des enfants. J'exposerai ensuite les différents modèles et théories développés pour l'étude des comportements économiques. Enfin, je détaillerai le développement des compétences cognitives et sociales nécessaires aux transactions économiques avant d'exposer les objectifs de cette thèse.

1. LA PLACE DE L'ECONOMIE CHEZ L'ETRE HUMAIN

1.1. L'échange et le don dans les sociétés non monétaires

Dans les sociétés traditionnelles où le système économique n'est pas basé sur l'argent, les transferts de biens et de services ont lieu sous forme de don et de retour de don (Mauss, 1967). En général, les transactions ne sont pas individuelles mais collectives entre personnes de même famille, clan, tribu, qui traitent en groupe ou par l'intermédiaire de leurs chefs. Ce ne sont pas exclusivement des biens et des richesses utiles économiquement qui sont échangés ; tout est matière à transmission : politesses, danses, cérémonies, fêtes, services militaires, femmes et enfants. Le temps consacré aux activités collectives est en effet supérieur à celui investi au travail : les sociétés de chasseurs-cueilleurs devant se déplacer fréquemment pour éviter de tarir leurs sources d'approvisionnement, les objets régulièrement transportés et donc les biens sont de confection simple et demandent un minimum de travail. La circulation des richesses fait partie d'un contrat moral beaucoup plus général et plus permanent que celui d'un simple échange, la réciprocité se réalisant sur le long terme.

Bien que les dons paraissent volontaires, ils se produisent fréquemment sous la contrainte d'obligations légales ou sociales, l'économie étant bien souvent indissociable des catégories familiales, religieuses ou politiques. Le don est une garantie de paix au sein de sociétés segmentées en clans. La régulation sociale se réalisant entre des groupes familiaux entiers, les relations sont souvent intenses : on s'évite ou on se fait la guerre ; on donne, on reçoit et on donne en retour. L'acte de donner crée donc un lien social et "refuser de donner, négliger d'inviter, comme refuser de prendre, équivaut à déclarer la guerre" (Mauss, 1967). Ce système de dons/contre-dons, pratiqué autant chez les chasseurs-cueilleurs des tribus amérindiennes d'Amérique du nord que de l'océan Pacifique et des Indes, est communément nommé *potlatch* et a pour but d'impressionner l'autre par sa générosité et le mettre en difficulté pour rendre la pareille. En Nouvelle Guinée, le *kula* consistant à échanger des biens symboliques sous forme de colliers et bracelets permet régulièrement de réaffirmer les alliances politiques entre groupes ethniques qui ne parlent pas la même langue (Malinowski, 1922). Le don et les transactions économiques en général ne sont donc pas libres mais réalisés entre groupes organisés de vendeurs et acheteurs, et structurés par les relations entre groupes. Lors d'échanges marchands par exemple, un individu ne peut entrer dans une transaction commerciale avec un acheteur qui serait déjà en lien avec un autre groupe (Sahlins, 1972).

Dans les sociétés non monétaires, les transactions reposent sur la notion d'honneur. Ne pas rendre peut affecter la relation avec le partenaire ou entacher la réputation de l'individu au sein de son groupe (Mauss, 1967). Au contraire, les échanges confèrent à ceux qui y participent prestige social et renommée : les dons et partages de nourriture observés chez les Ache ou les Hadza par exemple permettent aux chasseurs d'améliorer leur réputation (Hawkes, 1991 ; Wood & Hill, 2000). La générosité est marque de pouvoir et permet à l'individu de faire progresser son statut politique, son rang hiérarchique et celui de sa famille sur l'échelle sociale. Des comportements de type maximisateurs (que ce soit en terme de prestige ou de biens matériels) peuvent donc apparaître dans les sociétés non monétaires (Malinowski, 1926), mais l'échange équitable de don et contre-don reste à la base de l'économie ; l'échange dépasse ainsi la simple notion d'optimisation des gains « on ne donne pas pour recevoir ; on donne pour que l'autre donne » (Lefort, 2000). D'après Sahlins (1972), l'*Homo economicus* (« homme calculateur »), cherchant systématiquement à maximiser ses biens, serait donc une figure inventée par l'économie occidentale.

1.2. Le développement de l'économie dans les sociétés monétaires

Dans les sociétés monétaires, le don réciproque cérémoniel reste couramment utilisé : invitations, politesses, et cadeaux de cérémonie sont autant d'échanges de bons procédés qui doivent être rendus ; on retrouve l'équivalent du *potlatch* dans le cadre de contributions aux repas communautaires (apport spontané d'un plat ou d'une boisson pour tous), ou de l'obtention d'une position hiérarchique plus élevée en fonction de la qualité et de la quantité des contributions (un engagement volontaire plus important dans une association donne un accès prioritaire aux ressources collectives). Cependant, la grande majorité des échanges se réalisent sur la base du marché à travers l'achat et la vente de biens utiles économiquement (terres, outils, etc.).

Ce marché d'échange nécessite la mise en place d'une monnaie constituant un bien standard durable, échangeable contre tout. Dans les économies pré-industrielles, il prend la forme d'acier, d'or, de métal (Afrique), de sel, de coquillages, de plumes d'oiseaux (Mélanésie), ou celle d'argent dans les sociétés plus modernes (Bonvillain, 2010). Si les taux (les prix) auxquels les biens et services échangés sont plus ou moins fixés, le marché reste libre dans la mesure où chaque parti peut choisir à qui vendre ou acheter ses biens ; la monétarisation favorise donc la création d'une économie indépendante libérée des contraintes sociales, politiques, religieuses ou rituelles (cf. Aristote, 1992 ; Sahlins, 1972), permettant ainsi le développement de réseaux d'échange et l'émergence d'un commerce à grande échelle.

L'autonomie de l'économie moderne par rapport aux autres secteurs garantit une stabilité sociale du fait des relations directes existant entre individus moins intenses qu'entre groupes familiaux entiers. Dans les économies modernes, les transferts réciproques prennent la forme d'échanges bidirectionnels où deux partis décident officiellement d'échanger un bien pour un autre. Les échanges sont fondés sur la base d'un contrat individuel légal entre vendeur et acheteur, entre salarié et patron impliquant des prestations mutuelles, même si le profit tiré de cette relation est une motivation importante.

1.3. L'enfant face à l'économie

Aujourd'hui, l'enfant occupe une position importante dans les systèmes économiques fondés sur une économie de marché (Bonvillain, 2010). Dans les sociétés occidentales, l'élévation du niveau du pouvoir d'achat, le développement du temps libre et l'attention aux besoins ou désirs des enfants les placent dans le rôle d'acteurs économiques dès leur plus jeune âge (McNeal, 1992). Avant de prendre part de façon efficace au marché des adultes, les enfants doivent acquérir des capacités appropriées en matière de consommation et d'échange (Cram & Ng, 1999). Depuis une trentaine d'années, de nombreuses études ont tenté de déterminer ce que les enfants comprennent de l'économie et de leur rôle en tant que consommateurs (John, 1999 ; McNeal, 1964 ; Moschis, 1987 ; Young, 1990). Après l'étude de leur connaissance du monde économique adulte (emploi, salaire, banque ; Berti & Bombi, 1988 ; Furnham, 1996 ; Leiser et al., 1990), les recherches se sont orientées plus récemment sur la compréhension de leur propre comportement économique dans des situations quotidiennes (maison, école, loisirs) : d'abord témoins des transactions économiques qui les entourent, ils deviennent rapidement acteurs directs ou indirects de ces transactions. Ajoutons enfin que la plupart des études expérimentales du développement de l'échange ont été conduites dans les sociétés occidentales.

1.3.1. Un témoin privilégié des transactions économiques

Dès le plus jeune âge, la sphère familiale représente un lieu propice aux enfants pour l'observation des comportements économiques (Webley, 2005). Les dons ou échanges de biens et de services entre membres de la même famille sont couramment utilisés, par exemple lors des repas ou des anniversaires (Barrett & Buchanan-Barrow, 2005). La télévision et les annonces publicitaires représentent la seconde source d'information utilisée par les enfants pour réaliser une transaction (Adler et al., 1980 ; Lassare & Roland-Levy, 1989 ; McNeal 1999). Enfin, les centres commerciaux représentent pour la plupart l'une des premières expériences du marché économique (Leiser et al., 1990 ; Webley, 2005) ; durant les achats, les enfants sont exposés à une variété de situations favorisant l'apprentissage des lieux et acteurs des transactions, des biens mis en jeu et surtout du principe de l'échange d'argent contre le ou les biens désirés (McNeal & McDaniel, 1981 ; Stephens & Moore, 1975 ; Ward et al., 1977). Les enfants apprennent ainsi comment négocier et observent de nombreuses prises de décision, obtenant un savoir sur lequel ils vont baser leurs choix futurs.

1.3.2. L'enfant, agent économique

Les enfants ont de multiples occasions d'observer le fonctionnement de l'économie mais de nombreuses expériences en font également des acteurs plus ou moins directs des transactions qui les entourent. Dès 2 ans, les enfants sont couramment appelés à choisir les plats qu'ils préfèrent dans les restaurants ou les friandises et les jouets dans les magasins, bien qu'ils n'aient pas encore les moyens de finaliser la transaction (John, 1999 ; Warneryd, 1988).

La famille fournit régulièrement aux enfants l'opportunité d'être des consommateurs actifs (achat du pain par exemple) en leur permettant d'améliorer leur compréhension des transactions et du rôle de l'argent en particulier. L'argent en tant que monnaie d'échange est une notion acquise vers 4 ans lorsque les enfants comprennent la nécessité de donner de l'argent pour obtenir un objet (Marshall, 1964 ; Marshall & Mac Gruder, 1960 ; Strauss, 1952). C'est précisément à cet âge que les parents commencent à donner de l'argent de poche, un moyen utilisé dans la plupart des pays industrialisés pour inculquer aux enfants la valeur des objets et de l'argent (Furnham, 1999 ; Lassare, 1996 ; McNeal, 1992 ; Mortimer et al., 1994). En effet, à 4-5 ans les enfants calculent d'abord le prix des objets sur la base d'attributs visibles tels que leurs propriétés physiques (taille, forme), puis de leur utilité à 7-8 ans (Capon & Kuhn, 1980 ; Davidson, 1991 ; Turner & Brandt, 1978 ; Wartella et al., 1979); ce n'est que vers 10 ans qu'ils estiment leurs achats potentiels selon des caractéristiques plus fonctionnelles telles que la rareté, la qualité, la complexité ou le temps et les techniques de fabrication (Berti & Bombi, 1988 ; Fox & Kehret-Ward, 1990). C'est également l'âge auquel la notion de profit tend à émerger : un individu gagne de l'argent uniquement s'il revend ses biens plus cher que ce qu'il a payé pour les obtenir (Berti & Bombi, 1988 ; Burris, 1983 ; Danziger, 1958 ; Furth, 1980 ; Jahoda, 1979). Ce long apprentissage conduit à s'interroger sur la pertinence de donner à des jeunes enfants de l'argent à dépenser alors que leur compréhension des bénéfices et de la valeur des objets n'est pas encore acquise. On peut également se demander dans quelle mesure les bénéfices tirés d'un échange seraient mieux compris dans des tâches plus simples n'impliquant pas la notion d'argent.

De nombreuses sociétés possèdent une économie non fondée sur l'argent et, même dans nos sociétés modernes, il existe encore de nombreuses aires d'activité économique qui ne sont pas monétisées (la plus notable étant la sphère familiale). Les relations entre enfants représentent à elles seules un marché économique autonome à l'abri du contrôle des parents et des autres adultes (Cram & Ng, 1999). Au sein de ce marché, les enfants les plus jeunes commencent à réaliser des offrandes, sans contrepartie ni connaissance exacte de la valeur de ce qui est donné, mais dans l'objectif unique de plaire à quelqu'un d'apprécié. Les pratiques de troc s'instaurent un peu plus tard. L'ethnologue Delalande (2003) a observé par exemple chez les enfants de 4-5 ans des échanges de «sable» récolté dans la cour de récréation. Au sein de ce marché, les enfants sont également amenés à négocier d'autres biens sous la forme d'échanges qualitatifs sans réelle comparaison de leur valeurs respectives : négociation d'un goûter (pomme par exemple) contre un autre qui est interdit par les parents (bonbons), ou échange d'information visant à mieux duper les enseignants ou les parents (Cram & Ng, 1999 ; Nukaga, 2008). L'envie immédiate d'un enfant et son pouvoir de persuasion vis-à-vis d'un pair constituent les éléments clés de la négociation. Le troc peut se transformer en une activité plus complexe au cours de laquelle les enfants procèdent à des opérations de classification reposant sur la confrontation de plusieurs critères d'évaluation. C'est ce que soulignent les échanges quantitatifs : billes, voitures, stylos, timbres, images, cartes ou pogs (Cipriani-Crauste, 2000). La capacité des enfants à attendre la meilleure offre pour échanger des cartes à la mode, par exemple, montre que la notion d'enchère est également bien présente (Barrett & Buchanan-Barrow, 2005). A travers les trocs, l'enfant va mobiliser les connaissances acquises pour les transférer sur les transactions monétaires plus abstraites.

Différentes explications ont été proposées pour rendre compte de la diversité des transactions observées chez les enfants. Le troc aurait tout d'abord un objectif relationnel permettant de s'attirer la sympathie de ses pairs pour devenir ensuite un gage d'amitié entre deux individus ; l'approche purement ludique de l'échange a également été proposée dans la mesure où le plaisir de discuter, de montrer ses possessions et de les comparer à celles des autres est en soi une finalité de l'échange pour les enfants (Webley, 2005). Enfin, les échanges pourraient avoir une justification économique. Pour optimiser les gains obtenus, les enfants doivent connaître au préalable les normes et les règles à respecter pour conduire ces opérations sans se voir sanctionnés par des échanges déséquilibrés. Il est donc nécessaire qu'ils déterminent si la transaction qu'ils viennent de réaliser est un troc qui leur est favorable, défavorable ou à bénéfice équivalent pour les deux partenaires (Webley & Lea, 1993). Une telle compréhension est conditionnée par le développement cognitif et social que je décrirai plus tard.

2. L'ECONOMIE EXPERIMENTALE DANS L'ETUDE DES DECISIONS ECONOMIQUES

L'expérimentation en économie est un outil essentiel de l'analyse de la décision. Elle consiste en « la restitution, en laboratoire, d'une situation économique simplifiée pour laquelle l'ensemble des variables est contrôlé par l'expérimentateur » (Denant-Boèmont et al., 2008). L'économie expérimentale permet ainsi de confronter les données obtenues dans cet environnement contrôlé aux prédictions des théories et modèles économiques (Eber & Willinger, 2005), et en particulier la théorie des jeux et la théorie de la prise de décision individuelle. Pendant longtemps, les économistes ont largement ignoré l'étude des enfants dans leur approche de la compréhension des décisions économiques, les adultes et parmi eux la catégorie des étudiants étant majoritairement sollicités pour participer aux expériences. Seules quelques études expérimentales récentes s'intéressent aux compétences économiques des enfants dans le but de déterminer le caractère inné ou acquis de certains de leur comportement (Fehr et al., 2008 ; Harbaugh & Krause, 2000 ; Harbaugh et al., 2003).

2.1. Théories et modèles de prise de décision

2.1.1. La maximisation de l'utilité

D'une façon générale, on considère qu'un individu agit rationnellement lorsqu'il cherche à atteindre des objectifs cohérents en employant les moyens appropriés (Allais, 1955). En économie, la théorie des choix individuels repose sur le modèle de la rationalité économique, c'est-à-dire la maximisation de la satisfaction par l'obtention de biens ou services (Nofsinger, 2005) ; en d'autres termes, est rationnel ce qui maximise la satisfaction. En situation de certitude, cette théorie est qualifiée de *théorie de l'utilité* (*Utility Theory*) ; les acteurs connaissent parfaitement les caractéristiques des options qui s'offrent à eux et basent leur choix en fonction de leur préférence, représentée par une fonction mathématique nommée « fonction d'utilité ». La fonction d'utilité (notée $u(x)$) permet de transformer les gains monétaires des individus (notés x) en satisfaction (ou bien-être). Il s'agit par exemple, de la satisfaction que l'on peut obtenir en utilisant une somme monétaire pour acquérir tel ou tel objet. Selon la théorie de l'utilité, chaque individu effectue les choix qui lui permettent d'atteindre le niveau le plus élevé possible de satisfaction, autrement dit, ils cherchent à maximiser l'utilité de leurs décisions.

On doit remarquer, cependant, que les acteurs économiques prennent la plupart de leurs décisions en situation d'incertitude : c'est le cas par exemple de l'investissement en outils agricoles sans certitude de la demande future et de la rentabilité de l'exploitation (Brossier, 1989), ou de l'achat d'une voiture d'occasion sans connaître sa qualité et sa valeur exacte (Akerlof, 1970) ; chez l'enfant, c'est le cas de l'achat d'un lot d'images autocollantes sans certitude d'obtenir celles qui manquent pour compléter un livret « collector ». En condition d'incertitude, la théorie des choix a été qualifiée par von Neumann et Morgenstern (1944) de *théorie de l'espérance d'utilité* (*Expected Utility Theory*). Dans ce cadre, les valeurs d'utilités des options sont pesées par leurs probabilités respectives et comparées par les individus pour déterminer leur choix. Si x est une loterie à n issues possibles et p_i la probabilité du gain x_i (i = 1, …, n), alors l'espérance d'utilité de l'individu est égale à:

$$[u(x)] = \sum_{i=1}^{n} p_i u(x_i)$$

Les fondements de cette théorie reposent sur une série d'axiomes[1] que des agents rationnels sont supposés respecter pour maximiser leur espérance d'utilité. Deux axiomes méritent d'être évoqués en particulier car leur violation a conduit au développement des théories alternatives que j'aborderai dans cette thèse : l'axiome d'indépendance et l'axiome de transitivité. L'axiome d'indépendance implique que si deux loteries sont mélangées avec une troisième, alors les préférences des individus ne seront pas perturbées par la troisième loterie. L'axiome de transitivité implique que si une personne préfère l'option A à l'option B, et

[1] Pour une description précise de ces axiomes, se référer à l'ouvrage de A. Mas-Collel, M.D. Whinston et J.R. Green, *Microeconomic Theory* (1995), chapitres 1 et 6.

l'option B à l'option C, alors elle devrait préférer l'option A à l'option C. En cherchant à déterminer si des enfants âgés de 7 à 11 ans étaient capables de maîtriser l'axiome de transitivité, Harbaugh et ses collaborateurs (2001) ont montré que la violation de cet axiome diminuait avec l'âge. Les enfants de 7 ans agissaient en effet de façon beaucoup moins rationnelle que les 11 ans dont les capacités étaient équivalentes à celles des adultes (Andreoni & Miller, 2002 ; Harbaugh et al., 2001).

2.1.2. La théorie des jeux

La théorie des jeux (von Neuman & Morgenstern, 1944) est une théorie de la décision en environnement incertain qui prédit les choix individuels au cours d'interactions stratégiques entre deux ou plusieurs personnes. L'économie expérimentale a permis de confronter les prévisions de la théorie des jeux à des expérimentations en environnement contrôlé. Les sujets sont placés dans des situations interactives dans lesquelles leurs bénéfices potentiels dépendent des décisions des autres individus (von Neuman & Morgenstern, 1944). Cette théorie postule qu'un groupe d'agents rationnels va faire des choix personnels dépendant des choix effectués par les autres acteurs concernés ; elle a pour objectif de déterminer quel doit être le comportement rationnel de ces acteurs. Les situations expérimentales suivantes permettent d'introduire la théorie des jeux.

2.1.2.1. Coopération

Le dilemme du prisonnier (Sally, 1995) est la situation expérimentale la plus fréquemment utilisée pour étudier le conflit entre l'incitation sociale à coopérer et la motivation personnelle à ne pas le faire. Ce dilemme entre intérêt individuel et collectif se retrouve dans de nombreuses situations politiques, économiques ou sociales, par exemple la concurrence entre des entreprises alors qu'une entente permettrait de limiter les coûts, ou la coopération entre deux coureurs cyclistes d'une échappée permettant à l'un d'eux de remporter la victoire. Chez les enfants, on retrouve ce comportement lorsque deux enfants s'accusent mutuellement d'être la cause d'une dispute alors que tous deux éviteraient une punition si chacun présentait des excuses.

Dans ce jeu, deux personnes qui n'ont pas la possibilité de communiquer choisissent simultanément entre deux stratégies C ou D. A la fin du jeu, chacune confronte son choix avec celui de l'autre voisin pour déterminer son gain. Pour la matrice des gains proposée dans le tableau 1, si le joueur 2 choisit C, jouer C rapporte 3 euros pour le joueur 1 alors que jouer D lui en rapporte 4. Si le joueur 2 choisit D, jouer C ne rapporte rien au joueur 1 alors que jouer D lui rapporte 1 euro.

Tableau 1. Matrice des gains pour le jeu du dilemme du prisonnier. Le premier chiffre (gras italique) correspond aux gains du joueur 1, le second chiffre aux gains du joueur 2.

		Joueur 2	
		C	D
Joueur 1	C	***3 euros***, 3 euros	***0 euro***, 4 euros
	D	***4 euros***, 0 euro	***1 euro***, 1 euro

Pour chaque joueur, D est une stratégie dominante ; si chacun suit une rationalité individuelle cherchant à optimiser les gains personnels, ils devraient donc opter pour la stratégie D. Cette situation a la propriété d'être sous optimale puisque si chaque joueur suit la stratégie D, chacun obtient 1euro au lieu des 3 euros qu'ils auraient pu obtenir en jouant tous les deux la stratégie C. La rationalité individuelle peut donc engendrer des situations collectives inefficaces. Avec les gains proposés ici, on observe qu'environ 60% des adultes se détournent des prédictions théoriques : ils suivent une rationalité collective les obligeant à coopérer en sélectionnant la stratégie C (en espérant que l'autre joueur suive la même stratégie) (Axelrod & Hamilton, 1981). Chez des enfants âgés de 6 à 11 ans testés dans un jeu du dilemme du prisonnier similaire, on observe un taux de coopération qui augmente avec l'âge ce qui suggère un apprentissage progressif des normes sociales de coopération (Fan, 2000). Cela suggère également que, dans certaines situations, les enfants pourraient être sur le plan individuel des maximisateurs plus efficaces lorsqu'ils n'ont pas encore été soumis à certaines règles sociales.

La version répétée du jeu permettant d'envisager la question de l'évolution des normes de coopération a montré que, bien que les adultes tendent à trahir l'autre joueur à l'approche de la fin de jeu (risque de ne pas être le premier à cesser de coopérer), le comportement de coopération reste prédominant (Andreoni & Miller, 1993 ; Axelrod & Hamilton, 1981 ; Cooper et al., 1996 ; Selten & Stoecker, 1986). Il est optimal d'être coopératif avec les autres (jouer C lors du premier dilemme auquel on se trouve confronté), de punir son partenaire lorsqu'il n'a pas coopéré (jouer D à chaque fois qu'il a joué D le coup précédent), de pardonner et de revenir à la coopération dès que le partenaire se remet à coopérer (jouer C à chaque fois qu'il a joué C le coup précédent). Bien étudiée chez les adultes et adolescents (Jones et al., 1968 ; Tedeschi et al., 1969), l'aptitude à adapter son comportement à celui du partenaire mérite d'être également approfondie chez les jeunes enfants.

D'autres études expérimentales comme le jeu de bien public (Isaac et al., 1994 ; Janssen & Ahn, 2003) ou le jeu d'exploitation d'une ressource commune (Hardin, 1968) ont permis de généraliser le dilemme du prisonnier avec un nombre de joueurs et de stratégies plus importants. Dans les modèles de bien public, par exemple, les individus ont le choix entre contribuer à un bien collectif (cagnotte qui sera partagée équitablement entre tous) ou agir de manière égoïste en gardant l'argent pour soi. L'analyse théorique du jeu prédit qu'un individu rationnel cherchant à maximiser son gain individuel ne contribuera pas au bien collectif tout en espérant que les autres n'auront pas le même comportement égoïste que lui ; c'est ce qu'on appelle communément le comportement du « passager clandestin » (Olson, 1965). Les observations montrent que les adultes ne se conforment pas à la théorie économique et se montrent plus altruistes en contribuant à la cagnotte commune à hauteur de 40 à 60% de leur somme initiale (Anderson et al., 1998 ; Douglas & Holt, 1993 ; Ledyard, 1995). Harbaugh et Krause (2000) ont montré ce même comportement altruiste chez les enfants âgés de 6 à 12 ans. Lorsque le jeu est répété, le niveau de contribution moyen des adultes et des enfants plus âgés est d'environ 50% de leur richesse initiale, et tend à diminuer au cours des répétitions de demande de contribution au bien public. En revanche, celui des jeunes enfants augmente avec le temps, suggérant qu'ils sont moins guidés par le besoin de maximiser leur bénéfice que les adultes et plus désireux de maintenir une coopération sociale. Il est probable qu'ils n'aient pas encore eu l'expérience des avantages et désavantages de la coopération dans différentes situations, contrairement aux enfants plus âgés, et ne possèdent donc pas toutes les connaissances nécessaires à l'optimisation des décisions économiques.

2.1.2.2. Confiance et réciprocité

Dans le jeu de la confiance, également connu comme jeu de l'investissement (Berg et al., 1995), le premier joueur reçoit une somme donnée d'argent. Il peut soit la prendre et le jeu s'arrête, soit placer la totalité ou une partie de cette somme chez un second joueur. Cette somme est ensuite triplée et le second joueur détermine le montant du total qu'il souhaite remettre au premier joueur. La rationalité voudrait que le second joueur en position de « dictateur » adopte un comportement purement égoïste en gardant toute la somme reçue. Le joueur 1 doit être capable d'anticiper ce comportement opportuniste et ne rien lui donner initialement.

Les comportements observés expérimentalement ne vérifient pas cette solution théorique ; la très grande majorité des premiers joueurs préfèrent, en effet, d'abord confier cette somme au second joueur, et ce dernier lui en restitue en général une proportion non négligeable (Berg et al., 1995 ; Charness et al., 2010 ; Cox, 2004). Toutefois, le montant est tel que le second joueur gagne un niveau significatif du montant reçu suite à la décision d'investir du premier joueur ; après réception, le premier joueur retrouve à peine le montant initial. La confiance n'est donc pas forcément payante. En effet, pour faire le choix de coopérer (dilemme du prisonnier), d'investir dans une cagnotte (jeu du bien public) ou ici de donner la réciproque, les investisseurs doivent accorder leur confiance. Lorsque le jeu est répété (Cochard et al., 2004), on observe des niveaux de confiance et de réciprocité plus élevés que dans le cas d'un jeu joué une seule fois. Cependant, lors des derniers tours (connus à l'avance des joueurs), les montants renvoyés sont plus faibles. Les résultats expérimentaux de Sutter et Kocher (2007) ont montré que la confiance évolue avec l'âge, augmentant entre l'âge de 8 ans et l'âge adulte. Il reste à déterminer si cela est dû à une meilleure estimation de la fiabilité du partenaire. En effet, si ce jeu permet d'une part de tester la confiance du premier joueur, il estime également le degré de réciprocité du second, le montant renvoyé pouvant être vu comme une mesure de la loyauté envers le partenaire. De plus, on apprend en grandissant que ne pas honorer la confiance d'un partenaire peut amener à des punitions (Fehr & Gächter, 2000). L'introduction de mécanismes de sanction peut ainsi renforcer la coopération (Fehr, 2004), même si elle a parfois des effets inverses en introduisant une suspicion entre joueurs et en inhibant certains comportements coopératifs (Fehr & Rockenbach, 2003). De nouveau, on peut se demander si l'acquisition de normes sociales durant l'enfance ne représente pas un frein à l'optimisation des comportements, empêchant les enfants plus âgés, à l'inverse des plus jeunes, d'adopter une attitude plus égoïste et ainsi maximiser leurs gains personnels.

2.1.2.3. Négociation

Le jeu de l'ultimatum (Güth et al., 1982) est une négociation entre deux individus dans laquelle le joueur 1 fait une unique offre au joueur 2 qui peut soit accepter (auquel cas les gains des joueurs sont conformes à la proposition de l'offreur), soit émettre un veto en refusant les conditions proposées (auquel cas les deux joueurs ne gagnent rien). Par exemple, lorsqu'une somme d'argent de 10 euros doit être répartie entre deux joueurs, la solution théorique est que le joueur 1 fasse la plus petite offre au joueur 2 (0.01 euro) et que celui-ci l'accepte étant donné que n'importe quelle somme positive reçue représente un gain. Chez les adultes, les résultats montrent une tendance des individus à s'éloigner de la solution théorique, les joueurs 1 faisant des offres entre 40 et 50% de la somme à partager, et les joueurs 2 refusant généralement des offres inférieures à 20% (Blount, 1995 ; Güth & Tietz, 1990 ; Güth et al., 1982 ; Neelin et al., 1988 ; Roth et al., 1991).

Les enfants et adolescents étant régulièrement soumis à des situations du genre « à prendre ou à laisser » par leur camarades, parents, et frères et sœurs, les jeux d'ultimatum apparaissent comme des tâches parfaitement adaptées pour étudier les comportements liés à l'âge dans le partage d'une somme d'argent ou de friandises (Murnighan, 1991). Les enfants âgés de moins de 5 ans tendent à être égoïstes dans leur offre (Damon, 1980 ; Handlon & Gross, 1959 ; Harbaugh et al., 2003) bien que des résultats contraires aient parfois été obtenus (Murnighan & Saxon, 1998). En revanche, ils acceptent souvent les offres les plus faibles. Après 5 ans et jusqu'à l'âge adulte, les enfants deviennent de plus en plus équitables, autant dans leur réponse que dans leur offre de partage (Fehr et al., 2008 ; Güth & Tietz, 1990 ; Harbaugh et al., 2003 ; van Avermaet & McClintock, 1988). Bien qu'un tel comportement ne maximise pas leur bénéfice, il devient rationnel si on le place d'un point de vue collectif. En effet, comme je l'ai précisé précédemment, les normes sociales prédisent des mécanismes de punitions pour des comportements égoïstes ou ne respectant pas la justice (Fehr & Gächter, 2002) ; il est donc rationnel pour un individu de renoncer à une partie de ses gains et de faire preuve d'équité.

Ainsi, l'issue de nombreuses décisions individuelles repose sur des choix permanents entre bénéfices personnels et intérêts collectifs. Les résultats expérimentaux ont montré de l'altruisme dans les comportements stratégiques des individus basés sur la confiance et le désir d'équité (Eber & Willinger, 2005). Un des objectifs de l'économie expérimentale a donc été d'étudier les choix individuels lorsque seule la maximisation des gains personnels entre en jeu.

2.1.3. La théorie des perspectives

Certains comportements non rationnels mis en évidence dans les interactions sociales, ainsi que la description de nombreux biais dans des articles empiriques ou d'économie expérimentale ont montré l'incapacité de la théorie de l'espérance d'utilité à refléter de façon acceptable la prise de décision dans un contexte d'incertitude[2]. Ce constat a donné lieu au développement d'alternatives comportementales comme les modèles d'utilité dépendant du rang (Quiggin, 1982), la théorie des perspectives (Kahneman & Tversky, 1979 ; Tversky & Kahneman, 1992) ou, plus récemment, celle des croyances optimales (Brunnermeier & Parker, 2005). La théorie des perspectives est l'alternative qui a eu le plus d'influence en économie et repose sur trois hypothèses fondamentales.

Alors que la théorie économique classique postule que les individus évaluent différentes offres de manière absolue et objective, Kahneman et Tversky (1979) proposent que les individus sont sensibles à la variation relative de leur richesse c'est-à-dire qu'ils évaluent leurs perspectives de gains et de pertes par rapport à un *point de référence* qui est la plupart du temps la richesse initiale. Le second élément intègre la *déformation des probabilités* objectives opérée par les individus. La forme la plus courante des fonctions de pondération des probabilités est un S inversé qui correspond à la surestimation des petites probabilités et à la sous-estimation des fortes probabilités. Les agents sont également plus sensibles aux différences de probabilités lorsque leur niveau est plus élevé. Le recours à ce type de distorsion des probabilités suffit par exemple à expliquer la souscription d'assurances couvrant des risques très peu probables mais aussi la participation aux jeux de loto, alors que la théorie de l'espérance d'utilité échoue dans cette tentative puisque l'espérance mathématique de ces jeux est généralement négative. Enfin, l'intensité de l'utilité (la satisfaction) que l'on tire d'un gain est différente de celle que l'on tire d'une perte (regret). Une *perte a ainsi davantage d'impact psychologique qu'un gain*.

Sous la théorie des perspectives, considérons une loterie x à n issues possible et p_i la probabilité de l'issue x_i (i = 1, …, n). On suppose par convention que $x_1 < ... < x_m = 0 < x_{m+1} < … < x_n$, avec m issues qui sont des pertes alors que les n-m issues restantes sont des gains. La fonction d'évaluation d'un individu (notée $V(x)$) est donc l'analogue de la fonction d'utilité dans le modèle de la théorie de l'espérance d'utilité, mais la fonction d'évaluation mesure la satisfaction par rapport à un point de référence, généralement le niveau de richesse initiale. En conséquence, elle mesure de manière différente la satisfaction de montants positifs (gains) et de montants négatifs (pertes), et est décomposée en deux parties, dans les gains et dans les pertes :

[2] Pour une description des expériences mettant en évidence la violation de ces axiomes, se référer à l'ouvrage de M.H. Broihanne, M. Merli et P. Roger, *Finance Comportementale* (2004), chapitre 3.

$$V(x) = V(x^+) + V(x^-)$$

où x^+ = max (0, x) et x^- = -max (-x, 0). $V(x^+)$ et $V(x^-)$ sont définis par les formules suivantes :

$$V(x^+) = \sum_{i=m}^{n} \pi^+_i v(x_i) \quad \text{et} \quad V(x^-) = \sum_{i=1}^{m} \pi^-_i v(x_i)$$

où π_i^+ et π_i^- sont les poids affectés par l'individu aux différents résultats possibles et $v(x)$ est la fonction d'évaluation.

Le premier élément, la fonction d'évaluation $v(x)$, est l'équivalent de la fonction d'utilité $u(x)$ mais est définie du côté des gains (fonction concave) et du côté des pertes (fonction convexe) de la façon suivante :

$$v(x) = (x - x^*)^{\alpha} \text{ si } x \geq x^* \text{ et}$$

$$v(x) = -\lambda(x^* - x)^{\beta} \text{ si } x < x^*,$$

où x^* est le point de référence à partir duquel les gains et les pertes sont calculées, et α, β sont deux paramètres estimés à 0.88 (Tversky & Kahneman, 1992). Puisque la fonction devient linéaire par morceau avec cette valeur, les études récentes utilisent pour simplifier $\alpha = \beta = 1$ (Barberis et al., 2001). Le coefficient λ représente l'indice d'aversion aux pertes ; quand $\lambda > 1$, les individus sont averses aux pertes c'est-à-dire que dans une loterie où une perte k est en jeu, le gain net potentiel devra être supérieur à lambda fois k pour que les individus acceptent de participer à cette loterie. Tversky et Kahneman (1992) ont estimé ce paramètre à $\lambda = 2.25$ chez l'être humain traduisant une forte aversion à la perte.

Le second élément expliquant le choix des individus qui suivent la théorie des perspectives dans leur prise de décision sont les coefficients π_i^+ et π_i^- . Les individus utilisent le poids des issues (et non leur probabilités) définis à l'aide de fonctions de pondération notées w^+ dans le domaine des gains et w^- dans celui des pertes :

$$\pi_n^+ = w^+(p_n)$$

$$\pi_i^+ = w^+(1 - F_x(x_{i-1})) - w^+(1 - F_x(x_i)) = w^+\left(\sum_{j=1}^{n} p_j\right) - w^+\left(\sum_{j=i+1}^{n} p_j\right) \text{ pour } m \leq i < n$$

$$\pi_1^- = w^-(p_1)$$

$$\pi_i^- = w^-(F_x(x_i)) - w^-(F_x(x_{i-1})) = w^-\left(\sum_{j=1}^{i} p_j\right) - w^-\left(\sum_{j=1}^{i-1} p_j\right) \quad \text{pour } 2 \leq i \leq m$$

où F*x* est la fonction de répartition de la loterie *x*, et *p* les probabilités affectées à cette loterie. Les deux fonctions de pondérations ont une forme similaire de S inversé. Pour simplifier, je considérerai donc par la suite $w^+ = w^- = w$, définie de la façon suivante :

$$w(p) = \frac{p^\gamma}{(p^\gamma + (1-p)^\gamma)^{1/\gamma}}$$

avec w (0) = 0 et w (1) = 1, et où γ est le paramètre de distorsion des probabilités. La valeur de ce paramètre a été estimée entre 0.56 et 0.71 selon les chercheurs (Camerer & Ho, 1994 ; Tversky & Kahneman, 1992 ; Wu & Gonzalez, 1996). Une valeur moyenne de $\gamma = 0.6$ (Tversky & Kahneman, 1992) correspond à la surpondération des faibles probabilités et à la sous-pondération des fortes probabilités avec un point d'inflexion en 0.35 (Figure 1).

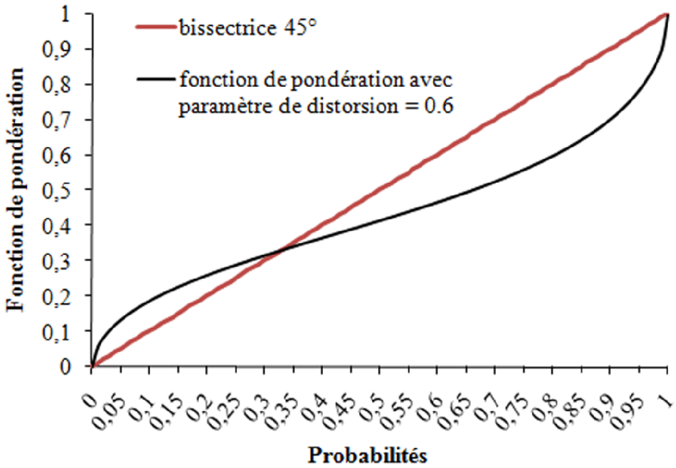


Figure 1. Fonction de pondération de Tversky et Kahneman (paramètre de distorsion γ = 0.6).

Le modèle de Kahneman et Tversky a pu rendre compte de la plupart des anomalies observées expérimentalement en situation de certitude ou d'incertitude. Le chapitre suivant présente les principaux biais rencontrés par les individus confrontés à une décision.

2.2. Les biais cognitifs

Comme évoqué précédemment, un individu peut être considéré comme rationnel s'il maximise son utilité et répond à plusieurs axiomes lors de sa prise de décision. Plusieurs travaux montrent que les décisions économiques sont en réalité souvent faussées par des biais qui résulteraient d'un manque de maturation de certains mécanismes cognitifs ou d'une mauvaise application de ces mécanismes (Tversky & Kahneman, 1981). Certains biais ou heuristiques peuvent être bénéfiques dans une situation donnée car ils simplifient la tâche d´évaluation des probabilités et conduisent à des décisions plus rapides et plus efficaces permettant une optimisation des gains. En revanche, dans d'autres situations, ces biais affectent l'évaluation que les individus ont de la situation économique pouvant conduire à des décisions moins rationnelles que celles prédites par les modèles.

Jusqu’ici, la recherche de biais décisionnels a été principalement menée chez l’adulte et l’adolescent car ils représentent les acteurs principaux des problèmes de société tels que les dépendances et les comportements à risque (drogue, jeu, etc.). Pourtant, les études réalisées récemment, dans le cadre de la théorie des jeux par exemple, indiquent que les enfants seraient, au même titre que les adultes, soumis à de nombreux biais cognitifs.

2.2.1. L'illusion du joueur

L’illusion du joueur ou erreur du parieur (*gambler’s fallacy*) est un faux raisonnement consistant à croire que la probabilité de gagner augmente ou diminue en fonction des événements précédents, alors que la probabilité est fixe (Croson & Sundali, 2005). « Après l´observation d´une longue suite de rouge sur une roulette, par exemple, la plupart des gens croit erronément que les cases noires vont maintenant arriver, probablement parce que l´occurrence des noires aboutira à une séquence plus représentative que l´occurrence d´une rouge supplémentaire » (Tversky & Kahneman, 1974). Parmi les sujets qui ont indiqué au cours d’une telle expérience sur quelle couleur ils miseraient à la roulette après que le rouge soit sorti plusieurs fois de suite, deux tiers ont préféré le noir, dont 89% ont précisé que le noir avait une plus forte probabilité que le rouge d'être gagnant au coup suivant (Lambert & Zaleska, 1966). Ainsi, de nombreux joueurs de casino continuent à perdre de l’argent avec l’illusion qu’une prochaine bonne main va changer leur chance, leur permettant de récupérer la somme qu’ils ont perdue. De la même façon, on peut observer une diminution dans la prise de risque après une suite de gains chez certains adultes et adolescents qui croient que la chance va tourner et que la probabilité qu’ils perdent au prochain coup augmente à mesure qu’ils gagnent (Ayton & Fischer, 2004 ; Clotfelter & Cook, 1993; Terrell, 1994 ; Tversky & Kahneman, 1971). Pour Tversky et Kahneman (1971), l’illusion du joueur est un biais cognitif dû à un principe heuristique réduisant les tâches complexes d´évaluation des probabilités et de prédiction de valeurs à de plus simples opérations de jugement. Encore peu étudiée chez les plus jeunes, on retrouve couramment cette erreur dans des jeux comme « tirer à pile ou face » au cours desquels les enfants qui obtiennent un grand nombre de fois pile croient avoir plus de chance d'obtenir face lors des tirages suivants.

2.2.2. L’erreur de la série gagnante

L’erreur de la série gagnante ou effet main chaude (*hot hand fallacy*) est un faux raisonnement observé lorsqu’une personne croit de façon irrationnelle qu’une série d’événements va continuer à se produire avec une haute probabilité (Tversky & Kahneman, 1971). Gilovich et ses collaborateurs (1985) ont observé ce biais pour la première fois chez des supporters de joueurs de basketball qui avaient tendance à croire qu’après une série de paniers, le joueur avait la main heureuse et allait continuer à gagner. Quand il y avait une suite d’échecs, les supporters supposaient que le joueur avait perdu la main. Ce biais, contraire à l’illusion du joueur, serait dû à la même difficulté à assimiler la notion d'indépendance des événements d'une série aléatoire.

2.2.3. L’effet argent du ménage

L’effet argent du ménage (*house money effect*) consiste à croire qu’on peut prendre plus de risque avec l’argent que l’on vient de gagner (Thaler & Johnson, 1990). Plus précisément, un joueur considère un gain important ou un gain inattendu comme n’appartenant pas à son propre argent, et consent plus volontiers à jouer avec cet argent. Toute perte inférieure au gain qui vient d’être obtenu est intégrée à ce gain, diminuant ainsi l’effet de l’aversion à la perte et facilitant la prise de risque. L’effet argent du ménage est en accord avec la théorie des perspectives pour laquelle les issues précédentes influenceraient le comportement des individus. Dans une étude réalisée sur des étudiants, Thaler et Johnson (1990) leur ont proposé de parier 4,5 dollars sur un lancer de pièce « pile ou face », après leur avoir initialement offert 15 dollars. Les résultats montrent que 70% des étudiants ont accepté de parier cette somme ; en revanche, seul 41% ont accepté le pari quand aucune somme d’argent ne leur avait été donnée au départ. Ainsi des étudiants sont plus enclins à prendre un risque financier avec de l’argent gagné et après un profit inattendu même s’ils ne prennent habituellement pas un tel risque avec leur propre argent. Des études plus récentes sur des adultes et des adolescents ont confirmé cette observation (Ackert et al., 2006). En revanche, ce faux raisonnement n’a pas encore été étudié chez les enfants.

2.2.4. L'effet de dotation

L’une des anomalies les plus importantes pour les choix en certitude est l’effet de dotation (*endowment effect*) qui traduit le fait que les gens exigent souvent plus pour céder un objet qu’ils ne sont prêts à payer pour l’acquérir (Knetsch, 1989). Knetsch (1989) a observé pour la première fois ce phénomène dans une expérience de choix entre deux biens au cours de laquelle les participants étaient répartis aléatoirement au sein de trois groupes. Les sujets du premier groupe recevaient une tasse et avaient l’opportunité de l’échanger contre une barre de chocolat ; les sujets du second groupe recevaient, au contraire, une barre de chocolat qu’ils pouvaient échanger contre une tasse. Enfin, les sujets du dernier groupe n’avaient pas de dotation initiale et devaient choisir entre une tasse et une barre de chocolat. Les résultats ont montré que 89% des sujets du premier groupe préféraient conserver leur tasse, 90% des sujets du second groupe préféraient conserver leur barre de chocolat, et 56% des sujets du dernier groupe choisissaient la tasse. Les préférences révélées par les échanges sont donc sensibles à la dotation initiale puisque les sujets préfèrent le bien qu’il leur a été attribué initialement : les sujets détenant la tasse l’ont valorisée davantage par rapport à la barre de chocolat alors que les sujets détenant la barre de chocolat l’ont valorisée par rapport à la tasse.

Ces résultats ont été confirmés plus tard dans des situations de marché présentant un choix entre un bien et une somme d’argent (Kahneman et al., 1990 ; Knetsch, 1992). Dans l'une d'elles (Kahneman et al., 1990), un premier groupe d’étudiants s’est vu offrir une tasse puis on leur a demandé s'ils acceptaient de la revendre pour une série de prix allant de 0,25 à 9 dollars. Ceux du second groupe devaient décider si pour chacun de ces prix ils seraient prêts ou non à acheter une telle tasse. Enfin, les étudiants du troisième groupe ne recevaient rien en début d'expérience mais devaient indiquer pour chacun de ces prix s'ils préféraient empocher l'argent ou recevoir la tasse. La théorie de l'utilité prédit que ces trois situations devraient aboutir au même prix d'équilibre en moyenne. Or, les observations ont montré que les sujets du premier groupe exigeaient un prix de vente d'environ 7,12 dollars en échange de leur tasse, alors que les sujets du second et troisième groupe proposaient un prix d'achat de 2,87 et 3,12 dollars respectivement. Appliqué sur le marché immobilier, l'effet de dotation explique par exemple les divergences possibles entre le prix de vente et le prix d'achat d'un même bien, ou la rigidité des vendeurs qui ne vendent pas leur bien plutôt que de baisser le prix (Kahneman et al., 1990).

Quelques études ont étudié la manière dont l'expérience du marché et les répétitions de transactions pouvaient agir sur l'effet de dotation (Brookshire & Coursey, 1987 ; Coursey et al., 1987 ; Knez et al., 1985). Une étude récente conduite chez des enfants de 5 à 10 ans et des étudiants a ainsi montré que l'effet de dotation est déjà présent durant l'enfance mais ne diminue pas avec l'expérience (Harbaugh et al., 2001). Aucune expérience n'a encore été menée chez les très jeunes enfants. Pourtant, l'effet de dotation existant du seul fait de posséder un bien, cela justifierait la recherche d'un tel biais dès lors que la notion de possession est acquise vers l'âge de 2 ans (Berti & Bombi, 1988 ; Dittmar, 1992 ; Miller & Johnson-Laird, 1976).

2.2.5. L'aversion aux pertes

Dans la théorie économique classique, un gain d'une certaine somme est censé compenser exactement la perte de cette même somme. Pourtant, s'enrichir puis perdre tout ce qu'on a gagné ne donne pas la sensation d'un retour à l'état psychologique initial : retirer un os à un chien après le lui avoir donné ne le fait pas revenir à son bien-être initial comme le prédit la théorie. Le regret et la frustration font que les êtres humains possèdent également une certaine aversion pour la perte (*loss aversion*) traduisant le fait qu'on attache plus d'importance à ce qu'on perd qu'à ce qu'on gagne (Tversky & Kahneman, 1986), entre deux et trois fois plus selon les cas. Il faut ainsi généralement un gain de 2,25 euros pour compenser une perte de 1 euro (Kahneman & Tversky, 1979 ; Tversky & Kahneman, 1991).

Tversky et Kahneman (1986) ont montré l'existence de l'aversion à la perte en proposant à des personnes interrogées les deux choix ci-dessous où chaque option est définie par les gains qu'elle peut procurer associée à sa probabilité respective :

	On vous donne 300 dollars Que préférez-vous ?		On vous donne 500 dollars Que préférez-vous ?
A	50 % de chance de gagner 200 dollars 50 % de chance de ne rien gagner	C	50 % de chance de perdre 200 dollars 50 % de chance de ne rien perdre
B	Un gain certain de 100 dollars	D	Une perte certaine de 100 dollars

Dans les deux cas, les positions finales étaient les mêmes c'est-à-dire obtenir 400 dollars avec certitude, et 50% de chance de gagner 500 ou 300 dollars. Pourtant, on a observé que pour le premier choix 72% des personnes ont préféré B contre 28% pour A. Pour le second choix, 36% des personnes ont préféré D contre 64% pour C. Il semble donc que les pertes soient perçues plus intensément que les gains. Les individus évaluent différemment les perspectives de gains et de pertes, les valorisant non pas en termes de richesse finale mais en termes de variation par rapport à un point de référence (cf. théorie des perspectives). Une telle asymétrie des valeurs permettrait d’expliquer l’effet de dotation (Kahneman & Tversky, 1984 ; Kahneman et al., 1991).

En situation d’incertitude ou de risque, l’hypothèse théorique standard est que les individus se basent sur une évaluation subjective des probabilités. Ainsi, les adultes et les adolescents refusent généralement de prendre des risques dans le domaine des gains alors qu’ils préfèrent en prendre dans le domaine des pertes (Camerer et al., 2003 ; Chien et al., 1996 ; Eber & Willinger, 2005 ; Tversky & Kahneman, 1981). L’étude de Reyna et Ellis (1994) a montré que les enfants de 8 ans présentent une réponse opposée à celle des adultes tandis que les enfants de 5 ans préfèrent prendre des risques à la fois dans le domaine des pertes et des gains. Au vu du faible nombre d’études réalisées chez les enfants, conclure à la présence d’une aversion à la perte et d’un pattern spécifique de réponse en fonction de l’âge demande des travaux supplémentaires.

Alors que plusieurs études semblent tomber d’accord sur une compréhension des situations économiques comparable à celle des adultes vers l’âge de 11-12 ans (Harbaugh & Krause, 2000 ; Harbaugh et al., 2001 ; Murnighan & Saxon, 1998), les expériences montrent une grande variation dans l’âge de développement d’acquisition et de mise en œuvre des principes relatifs à l’axiomatique des choix. Les modèles économiques standards développés sur la base des comportements des adultes pourraient donc demander un certain ajustement pour expliquer d’une manière plus fine et rigoureuse le choix des enfants.

3. LE DEVELOPPEMENT DES FACULTES DE DECISION

Maximiser les bénéfices au cours d’une transaction économique requiert un certain nombre de compétences aussi bien sociales, telles que tolérer la présence d’autrui ou comprendre le but de la transaction, que cognitives, telles qu’estimer la valeur des biens, attendre avant de recevoir l’autre bien, se souvenir de ce qui a été offert, calculer le risque qu’un bien reçu soit inférieur aux attentes, détecter les tromperies et adapter son comportement en retour.

3.1. Développement chez l’enfant

Le développement des capacités cognitives et sociales conditionne l’aptitude des enfants à comprendre puis à participer au marché économique (Breslow, 1981 ; Harbaugh et al., 2001). Chez l’enfant, le développement cognitif a fait l’objet de nombreuses théories, la plus connue étant sans nul doute la théorie du développement cognitif de Piaget qui précise les étapes de l'acquisition des compétences cognitives (Piaget, 1972 ; Piaget & Inhelder, 1966). Piaget a proposé quatre changements majeurs liés à l'âge : le *stade sensori-moteur* (depuis la naissance jusqu'à 2 ans) limité à la coordination sensorielle et motrice des actions ; le *stade préopératoire* (2 à 7 ans) où l'enfant apprend à utiliser des instruments symboliques, acquiert des capacités de représentation imagées et conceptuelles comme le langage et utilise ses représentations pour voir le monde de sa propre perspective ; le *stade opératoire concret* (7 à 11-12 ans) où il est capable de prendre en compte un autre point de vue et plus d'une perspective à la fois ; le *stade opératoire formel* (après 12 ans) où il peut penser de façon logique, raisonner et confronter différents points de vue au cours d'une conversation.

Malgré l'apport considérable de la conception piagétienne dans la compréhension de la mise en place des instruments cognitifs durant l'enfance, l'accumulation des connaissances au cours des dernières décennies a remis en question plusieurs aspects de sa théorie : problème de méthodologie (avec un aspect trop ouvert des questions proposées aux enfants), échantillon de base trop faible ne prenant pas en compte les différences individuelles (Case, 1992), même classe sociale et origine culturelle des individus (Murray, 1983). Des recherches plus récentes ont en outre montré que les jeunes enfants font preuve de capacités cognitives plus étendues que celles rapportées par Piaget dont les tests tentaient davantage de piéger les enfants plutôt que de rechercher les limites de leur raisonnement. Enfin, Piaget a sous-estimé la valeur de l'apprentissage social issu des parents et des professeurs.

Les changements de méthodes expérimentales (Clifton, 2001) expliquent les différences observées par les chercheurs pour un développement de compétences plus précoces (Bullock et al., 1982 ; Levin, 1977 ; Spelke, 1991 ; Wynn, 1992) ou plus tardifs (Bideaud & Houdé, 1987 ; Levin, 1986) que ne l'avait proposé Piaget. La liste suivante, non exhaustive, décrit les connaissances actuelles concernant les compétences cognitives et sociales nécessaires à un enfant pour s'engager dans un échange de type économique. Etablir un lien entre les stades connus de développement de ces capacités et le développement des compétences économiques constituerait un premier pas dans la compréhension de la prise de décision chez les enfants.

3.1.1. Le développement cognitif

Le développement cognitif de l'enfant influence sa manière de traiter l'information (John, 1999). Il va progressivement acquérir les outils cognitifs qui lui serviront à effectuer les meilleurs choix et optimiser ses gains.

3.1.1.1. L'estimation de la valeur des biens

La détermination de la valeur relative du ou des biens mis en jeu est nécessaire à l'échange, que celui-ci soit monétaire ou non. En effet, qu'un enfant désire troquer des cartes à collectionner ou les acquérir chez un commerçant, il doit au préalable juger le « prix » demandé qui peut prendre la forme d'un autre objet ou être monétaire. Dès 10-12 mois, les enfants peuvent identifier qu'une table contient plusieurs objets (plus de un) sans en connaître le nombre exact (Feigenson & Carey, 2005), mais ce n'est qu'entre 20 et 24 mois qu'ils apprennent à distinguer les marques linguistiques du singulier et du pluriel (Barner et al., 2007 ; Kouider et al., 2006 ; Wood et al., 2009).

Durant la première année de vie, les enfants peuvent discriminer et juger la valeur de petites quantités discrètes allant jusqu'à 3 (Butterworth, 2005 ; Cooper, 1984). Des enfants habitués à reconnaître une certaine quantité regardent plus longtemps la nouvelle quantité lors de la présentation des paires 1 vs. 2, 2 vs. 3 et 1 vs. 3, qu'ils s'agissent de points (Clearfield & Mix, 1999, 2001), d'objets (Feigenson & Carey, 2003 ; Starkey & Cooper, 1980 ; Starkey et al., 1990), de formes en mouvement (van Loosbroeck & Smitsman, 1990), d'images (Starkey & Cooper, 1980 ; Strauss & Curtis, 1981), d'items alimentaires (Feigenson et al., 2002), de sauts successifs d'une poupée (Wynn, 1995), ou de syllabes (Bijeljac-Babic et al., 1993). On a également pu montrer que, face à deux quantités discrètes de 1 et 2 ou 2 et 3 items alimentaires, des enfants âgés de 10 à 28 mois sont capables de comparer et choisir la plus grande quantité (Feigenson & Carey, 2000 ; Feigenson et al., 2002 ; Sophian & Adams, 1987). Les jeunes enfants de moins d'un an échouent dans des discriminations numériques plus importantes où il s'agit de sélectionner la plus grande quantité entre 1 et 4 (Feigenson & Carey, 2003), 4 et 5 (Strauss & Curtis, 1981), 4 et 6 (Starkey & Cooper, 1980), ou entre 2 et 4, 3 et 4, ou 3 et 6 (Feigenson et al., 2002). D'autres recherches montrent toutefois que des enfants âgés de 5 à 10 mois sont capables de différencier 3 et 4, ou 4 et 5 objets (van Loosbroeck & Smitsman, 1990), et des quantités plus importantes pourvu que le ratio qui les séparent soit élevé (ratio 2:1 ; 4 vs. 8, 8 vs. 16, 16 vs. 32 ; Brannon et al., 2004 ; Lipton & Spelke, 2004 ; Xu, 2003 ; Xu & Spelke, 2000). Lorsque le ratio est moins grand (ratio 2:3 ; 8 vs. 12, 16 vs. 24), ils ne réussissent pas à percevoir la différence (Lipton & Spelke, 2004 ; Xu & Spelke, 2000) tandis que des enfants âgés de plus de 9-10 mois y parviennent (Lipton & Spelke, 2004 ; Xu & Arriaga, 2007). On peut déplorer l'absence d'études sur de très faibles ratios qui pourraient également devenir un facteur limitant chez les enfants plus âgés pour estimer correctement leurs biens. Une telle limite pourrait affecter la compréhension d'un échange équilibré entre l'enfant et son partenaire d'échange. La validité de ces résultats a été remise en question par de nombreux auteurs attribuant la réussite des enfants non pas à leurs capacités numériques mais à des indices alternatifs comme la surface totale de l'objet, sa densité ou son périmètre (Clearfield & Mix, 1999 ; Feigenson et al., 2002). Il se pourrait que la discrimination de certaines quantités n'émerge que beaucoup plus tard durant l'enfance (Sophian & Adams, 1987).

Vers l'âge de 2 ans, les enfants apprennent à compter jusqu'à environ 6 (Gelman & Meck, 1983 ; Potter & Levy, 1968 ; Wynn, 1990, 1992). Pourtant, ce n'est pas avant 6 ans que l'ensemble des principes de comptage utilisés par les adultes est acquise, c'est-à-dire le principe d'ordre stable (la séquence ordonnée des mots nombres), le principe de correspondance un à un (la correspondance entre des objets et leurs mots nombres), et le principe de cardinalité (Butterworth, 2005 ; Starkey & Gelman, 1982).

Les enfants sont également capables de reconnaître et prédire le résultat de simples additions et soustractions de 1 à 3 objets (Wynn, 1992, 1995). Sur le principe qu'ils devraient réagir plus fortement à des événements qui semblent en violation avec leur connaissance du monde physique, on a présenté à des enfants de 3 à 13 mois des situations d'addition et de soustraction justes (par exemple, 1 + 1 = 2) ou erronées (par exemple, 1 + 1 = 1) de petits nombres d'objets. L'expérimentateur place l'un après l'autre deux objets dans une boîte à la vue des enfants puis le contenu de la boîte leur est présenté : deux objets dans le cas d'une addition juste, un seul dans le cas d'une addition erronée. Lorsque le nombre d'éléments révélés est impossible ou ne correspond pas au résultat attendu, les enfants passent plus de temps à regarder le contenu de la boîte, montrant leur surprise devant la violation des règles additives ou soustractives (Baillargeon, 1994 ; Feigenson et al., 2002 ; Uller et al., 1999 ; van Loosbroek & Smitsman, 1990). Des résultats similaires ont été trouvés avec un nombre plus important d'objets (McCrink & Wynn, 2003). Une autre expérience consistant à présenter deux ensembles d'items, recouvrir ceux-ci et ajouter ou retirer des items, a montré que les enfants de plus de 10 mois sont capables de choisir l'ensemble le plus important, indiquant qu'ils prennent en compte l'ajout et le retrait d'items (Feigenson et al., 2002 ; Sophian & Adams, 1987 ; Starkey, 1992 ; Starkey & Gelman, 1982). Cependant plusieurs études soutiennent que la sélection ne serait pas faite sur l'ensemble le plus grand mais celui qui a été modifié (Sophian & Adams, 1987). Ces performances précoces pourraient donc s'expliquer de façon plus parcimonieuse par d'autres processus cognitifs tels que la mémoire, la permanence de l'objet ou les facultés spatio-temporelles (Simon, 1997). Les enfants pourraient également avoir été influencés par des caractéristiques non numériques comme l'aire et le périmètre des objets de la collection (Barth et al., 2005 ; Clearfield & Mix, 1999 ; Huttenlocher et al., 1994 ; Mix et al., 2002).

Vers 5-6 ans, les enfants peuvent résoudre des problèmes de calcul mental demandant des capacités arithmétiques avancées (Barth et al., 2006 ; Jordan et al., 1992 ; Levine et al., 1992). La résolution d'addition et de soustraction peut cependant être accomplie plus précocement avec des objets manipulables sans la maîtrise complète des outils de calcul. Lorsque des objets sont ajoutés ou retirés d'un ensemble d'objets cachés, les 2 et 3 ans peuvent réaliser l'ensemble final correspondant au nombre exact d'objets (Canobi & Bethune, 2008 ; Carpenter & Moser, 1984 ; Fuson, 1982 ; Huttenlocher et al., 1994). L'échec d'enfants plus jeunes dans cette même tâche suggère qu'ils utilisent des mécanismes plus approximatifs.

Les enfants deviennent capables de faire des discriminations numériques plus précises au fur et à mesure qu'ils vieillissent. L'acquisition précoce de connaissances numériques avant même l'âge de 2 ans suggère que la détermination de la valeur des biens peut difficilement limiter leur capacité à maximiser une transaction excepté si le ratio entre les deux valeurs d'objets à évaluer est trop faible ou si la suite d'échange met en jeu des problèmes arithmétiques trop abstraits.

3.1.1.2. <u>Le contrôle de soi</u>

L'aptitude à attendre pour obtenir un bien est nécessaire à toute transaction économique. Par exemple, il faut être capable de contrôler son comportement et gérer ses émotions pour prendre en compte la perspective des autres (Hughes & Lecce, 2010). Alors que cette attente peut être limitée à quelques secondes lors de l'achat d'un objet par exemple, elle peut également atteindre plusieurs années lorsqu'il s'agit d'obtenir une satisfaction monétaire importante (fructification d'argent sur un compte bancaire par exemple) (Putnam et al., 2002 ; Rachlin et al., 1991 ; Tobin & Logue, 1994). Un moyen de déterminer la capacité d'un individu à attendre est de mesurer son aptitude à retarder l'accès à une récompense. Contrairement aux 18 mois, des enfants âgés de 22 mois sont capables d'attendre qu'on les autorise à toucher un jouet interdit (Kochanska et al., 2001 ; Vaughn et al., 1984) et des enfants de 30 mois peuvent attendre plusieurs minutes avant d'ouvrir un cadeau (Vaughn et al., 1984).

Un premier type d'expérience développé pour mesurer le contrôle de soi consiste à proposer un choix entre une récompense immédiatement disponible ou deux récompenses disponibles après un temps d'attente (Mischel, 1974). L'enfant décide donc d'attendre ou non en fonction de variables telles que la durée de l'attente ou la dimension de la récompense (Toner & Smith, 1977 ; Toner et al., 1979). Lorsque les récompenses prennent la forme d'autocollants, Thompson et ses collègues (1997) ont montré que les enfants de 3 ans choisissaient l'image immédiate alors que les enfants de 5 ans préféraient attendre pour en obtenir deux à la fin de l'expérience. L'expérience équivalente standard mettant en jeu de la nourriture, le test du chamallow (Mischel, 1974), a permis de révéler l'effet de facteurs contextuels sur les capacités d'attente des enfants (Hayden & Platt, 2007 ; Rosati et al., 2007). Par exemple, les enfants acceptent d'attendre plus longtemps lorsque la récompense offerte n'est pas visible durant la période d'attente (Mischel et al., 1989). La plupart des enfants âgés de 2 à 5 ans testés dans cette tâche ont attendu entre 2 et 15 mn lorsque la récompense alimentaire était visible (Eigsti et al., 2006 ; Kochanska et al., 2001 ; Peake et al., 2002 ; Vaughn et al., 1984) mais ont été capables de résister jusque 18 mn lorsque la récompense était occultée (Mischel et al., 1989 ; Patterson & Mischel, 1976). D'autres études expérimentales ont montré que les enfants attendent plus longtemps lorsqu'on leur demande de considérer la récompense comme un item non alimentaire ou de la comparer à un item non appétant (Metcalfe & Mischel, 1999 ; Mischel et al., 1989,1996 ; Patterson & Mischel, 1976), lorsqu'ils verbalisent les conséquences positives ou négatives qu'auraient leur prise de décision (Toner & Smith, 1977), et lorsqu'ils se distraient ou que l'expérimentateur leur fournit une distraction durant l'attente (Cournoyer & Trudel, 1991 ; Miller & Karniol, 1976 ; Mischel, 1974 ; Mischel & Ebbesen, 1970 ; Toner & Smith, 1977).

Un second modèle d'expérience consiste à présenter une accumulation d'items au fur et à mesure du temps d'attente. Les enfants doivent inhiber la prise immédiate de l'objet ou de la nourriture afin de maximiser leur bénéfice. Dans ce test d'accumulation, des enfants âgés de 3 à 6 ans peuvent attendre entre 2 et 6 mn avant de saisir la récompense selon qu'ils utilisent ou non des stratégies de distraction (Toner, 1981 ; Toner et al., 1979).

Les études expérimentales visant à mesurer l'aptitude des enfants à retarder leur accès à une récompense ont permis de montrer que le temps entre la récompense immédiate et retardée était le facteur principal pris en compte dans la décision d'attente (Forzano & Logue, 1994, 1995 ; Strayhorn, 2002). Elles ont mis en avant une amélioration des capacités d'attente avec l'âge et une influence de la procédure expérimentale employée sur la performance des enfants. Cependant, ces résultats ne nous permettent pas de conclure quant à la capacité des enfants à attendre au cours d'un échange économique : alors que les expériences menées chez les enfants proposent un choix entre deux récompenses, la plupart des transactions prennent en effet la forme d'échanges. Les jeunes enfants pourraient donc rencontrer dans ce type de tâche des difficultés à attendre équivalentes, si ce n'est supérieures dans la mesure où une composante sociale est également à l'œuvre.

3.1.1.3. Le calcul du risque

Le risque de subir un échange déséquilibré - « se faire avoir » - et être sujet aux moqueries des pairs, constitue pour l'enfant une forte injonction à s'approprier rapidement la valeur des produits soumis à l'échange mais aussi l'estimation des gains et des pertes associés (Cipriani-Crauste, 2000). En effet, en s'engageant dans un échange différé, l'enfant prend le risque qu'au cours de l'attente le bien à retourner soit détérioré ou ne soit jamais rendu.

En économie, la notion de risque se distingue de la notion d'incertitude (Knight, 1921). Le risque se définit comme une situation dans laquelle les issues possibles sont affectées de probabilités estimables ou connues. L'incertitude correspond en revanche à une situation liée à des probabilités inconnues. Ainsi, estimer les probabilités de gains et de pertes peut aider les enfants à prendre une décision optimale en situation risquée. Jusqu'à présent, on pensait que les compétences des enfants en matière d'estimation des probabilités étaient très limitées (Hoemann & Ross, 1971 ; Kreitler & Kreitler, 1986 ; Piaget & Inhelder, 1975) ; pourtant, de récents travaux ont montré qu'à l'âge de 4-5 ans, ils présentent déjà une compréhension intuitive du concept de probabilité (Acredolo et al., 1989 ; Anderson, 1991 ; Denison et al., 2006 ; Reyna & Brainerd, 1994 ; Schlottmann, 2001). A contrario, des enfants plus jeunes n'ayant pas encore développé cette compréhension mathématique leur permettant d'estimer les différentes issues possibles, pourraient ne pas être capables de prendre la meilleure décision au cours d'une situation risquée.

De nombreuses tâches expérimentales ont été développées pour tester les enfants en situation risquée (Baron et al., 1993 ; Marks, 1951). Parmi celles-ci, Slovic (1966) a utilisé la roue fléchée que les participants pouvaient choisir de tourner pour accumuler des gains autant de fois qu'ils le souhaitent mais avec la possibilité de tout perdre à chaque lancer de roue. Ce jeu a permis de rendre compte de la grande variabilité individuelle dans l'attitude face au risque des enfants âgés de 5 et 6 ans. Pourtant, lorsqu'on leur demande de choisir à chaque essai entre une issue certaine et un pari dont les issues étaient pondérées de probabilités différentes (Levin & Hart, 2003 ; Levin et al., 2007 ; Reyna, 1996 ; Reyna & Ellis, 1994), les enfants de 5 ans montrent une propension significative à prendre des risques. Un inconvénient des travaux réalisés jusqu'ici est que les enfants n'avaient aucun moyen visuel d'évaluer leur chance de gain et de perte qui étaient symbolisées par deux plages de couleurs et non par les récompenses elles-mêmes. De plus, même si de telles procédures nous donnent des indications sur les facteurs influençant la prise de décision des individus, elles ne nous permettent pas d'étudier la réponse des enfants face à un risque de perte, étant donné qu'ils ne possèdent pas de cagnotte initiale. A ce jour, seule l'étude de Harbaugh et ses collaborateurs (2002) a testé des enfants en leur offrant une somme initiale qu'ils pouvaient réellement perdre. Elle a montré que les enfants de 5 à 13 ans avaient tendance à surestimer les événements avec une haute probabilité. Les capacités d'enfants plus jeunes à juger les risques liés à la situation d'échange doivent encore être mesurées.

3.1.1.4. La mémoire et l'anticipation

D'un point de vue économique, anticiper ce qui va être échangé et mémoriser les termes de cet échange sont deux facultés indispensables à une transaction. Se projeter dans le passé afin de revivre dans leur contexte d'origine spatial et temporel des événements personnellement vécus, ou encore imaginer des événements futurs dans le but de les anticiper, peut s'assimiler à « un voyage mental dans le temps » (Conway, 2005 ; Suddendorf & Corballis, 1997 ; Tulving, 1995). La capacité à voyager mentalement dans le temps permet d'optimiser la prise de décision des individus en leur offrant l'opportunité de modifier leur comportement et de simuler une solution future sur la base des expériences passées (Boyer, 2008 ; Gilbert & Wilson, 2007 ; Schacter et al., 2007 ; Tulving, 2002).

La reconstruction mentale d'événements personnels du passé repose principalement sur la mémoire épisodique ou autobiographique (Tulving et al., 2004). Les études expérimentales ont montré que des jeunes enfants sont capables de se souvenir d'événements auxquels ils ont participé plusieurs semaines ou mois auparavant (Hitchcock & Rovee-Collier, 1996 ; Myers et al., 1994 ; Perris et al., 1990 ; Rovee-Collier, 1990). La durée de conservation du souvenir augmente avec l'âge de l'enfant (Rovee-Collier, 1997). Des enfants de 3 et 6 mois peuvent se rappeler avoir joué à un jeu après 1 à 3 semaines alors que la mémoire de ce souvenir atteint près de trois mois chez les enfants de 18 mois. Des enfants âgés de 3 ans se rappellent de leur venue dans un laboratoire de psychologie et de la procédure générale de la tâche motrice qui leur avait été apprise (Myers et al., 1987 ; Perris et al., 1990).

L'évolution du langage durant l'enfance est liée à l'aptitude à se déplacer mentalement dans le temps (Suddendorf & Corballis, 1997). L'exploration de la mémoire épisodique devient en effet plus facile avec l'amélioration des aptitudes linguistiques qui permettent de décrire avec précision les événements passés (Pinker, 2003). On a montré qu'environ 60% des enfants de 3 ans relatent confusément leurs souvenirs passés (Suddendorf & Corballis, 1997) et sont incapables de visualiser la distance temporelle entre deux événements passés auxquels ils n'ont pas pris part (Droit, 1995 ; Droit-Volet, 1999 ; Friedman & Kemp, 1998 ; Macar, 1988). Des enfants de plus de 4 ans décrivent avec plus de détails un voyage réalisé dans un parc d'attraction (Hamond & Fivush, 1991), un musée (Hudson & Fivush, 1991), un parc zoologique, un cirque ou une fête d'anniversaire (Fivush et al., 1987 ; Todd & Perlmutter, 1980). En revanche, un événement ponctuel peu marquant est plus difficile à raconter en détail (Davidson & Hoe, 1993 ; Fivush, 1984 ; Hudson & Nelson, 1983 ; Hudson et al., 1992).

La récupération d'événements dans le passé et la projection dans le futur seraient étroitement liées (Schacter & Addis, 2007). La pensée épisodique future dépendrait en effet de la mémoire des expériences passées (Addis et al., 2008 ; Buckner & Carroll, 2007 ; Spreng & Levine, 2006 ; Szpunar, 2010). Récemment, Suddendorf (2010) a démontré que les enfants de 3 et 4 ans capables de reporter précisément ce qu'ils avaient fait la veille étaient meilleurs pour émettre des idées sur ce qu'ils feraient le lendemain. A partir de 4 ans, les enfants comprennent que le futur est connecté au présent et que toute décision présente peut par conséquent avoir un impact sur leur bien-être ou leur bénéfice à venir (Lemmon & Moore, 2007). Une étude a récemment montré qu'ils sont capables d'anticiper un besoin futur (Suddendorf & Busby, 2005 ; Suddendorf et al., 2011) : après s'être assuré qu'ils savent ouvrir une boîte avec une clé spécifique, des enfants ont été laissés 15 mn dans une pièce contenant différentes clés. Ils ont ensuite été reconduits dans la pièce contenant la boîte. Alors que les enfants de 4 ans ont su planifier le transport et l'utilisation de la bonne clé, les plus jeunes se sont montrés incapables de résoudre cette tâche. Hudson et ses collaborateurs (1995) ont également montré que les 3-4 ans pouvaient planifier leur besoin (prévention des éventuels imprévus qui pourraient se produire) lors d'une future sortie familiale bien que les enfants de 5 ans étaient plus prévoyants sur leur prochaine sortie. En ce qui concerne l'estimation du temps, c'est également vers l'âge de 4-5 ans que les enfants parviennent à reconnaître la distance temporelle entre deux événements futurs (Atance & O'Neill, 2001 ; Droit-Volet, 2000 ; Friedman, 2000, 2005).

La capacité à se projeter dans le passé et le futur et à établir les distances entre deux événements passés ou à venir se développerait donc de façon simultanée entre 3 et 5 ans (Busby & Suddendorf, 2005 ; Nelson & Fivush, 2004 ; Perner & Ruffman, 1995 ; Suddendorf & Corballis, 1997), bien qu'une certaine confusion entre passé et futur semble persister jusqu'aux alentours de 6 ans (Friedman, 2005). De meilleures performances chez les 4-5 ans dans la réminiscence d'événements passés et la projection dans le futur pourraient leur permettre d'orienter leur prise de décision de manière plus efficace que des enfants plus jeunes au cours d'une transaction économique (Bechara & Damasio, 2005).

La faculté des enfants à se déplacer mentalement dans le temps n'est pas une capacité isolée mais influence le développement d'autres capacités cognitives ; par exemple, les enfants de 4-5 ans sélectionnent plus souvent des récompenses futures retardées dans le temps, probablement sur la base de leur aptitude à conceptualiser cet événement futur et le temps qui les sépare de sa réalisation (Moore et al., 1998 ; Thompson et al., 1997). A l'inverse, se projeter dans le passé et le futur repose sur la maturation de différentes structures cérébrales durant l'enfance et jusqu'à l'adolescence (Bauer et al., 1994 ; Ghetti & Lee, 2011 ; Hudson, 1990 ; Tulving et al., 2004) mais également sur le développement d'autres compétences comme attribuer des états mentaux et dissocier les états présents de ceux imaginés dans le futur (Suddendorf & Corballis, 1997).

3.1.2. Le développement social : l'émergence d'une théorie de l'esprit

Bien que Piaget ait négligé l'apport des relations sociales telles que l'apprentissage des parents puis des professeurs dans l'élaboration de sa théorie du développement de l'enfant, il a su tenir compte de ce qui sera appelé plus tard « la théorie de l'esprit » (Piaget, 1926). Faire preuve d'une théorie de l'esprit, c'est être capable d'attribuer des états mentaux à soi-même et aux autres (Baron-Cohen et al., 1985 ; Premack & Woodruff, 1978). Directement en lien avec le développement cognitif (conflit socio-cognitif), cette faculté permet d'interpréter, prédire et tirer des conclusions sur les intentions d'autrui, et d'imaginer leurs préoccupations et leurs croyances. Elle représente un outil majeur dans la compréhension des transactions pour comprendre d'une part les attentes du partenaire d'échange, et d'autre part estimer sa fiabilité afin de détecter d'éventuelles tricheries.

On peut distinguer deux grandes étapes dans le développement de la compréhension des autres : dès un an, les enfants considèrent leurs partenaires comme des *agents intentionnels* poursuivant un but au cours de leurs actions ; vers 3-4 ans, ils commencent à voir les autres comme des *agents mentaux* possédant des croyances et représentations mentales différentes des leurs (Tomasello & Rakockzy, 2003).

3.1.2.1. <u>But et intention</u>

Comprendre les buts et les intentions de l'autre, c'est-à-dire considérer l'autre comme un agent intentionnel, est une des premières étapes de l'élaboration d'une théorie de l'esprit (Tomasello, 1995). Elle va permettre à l'enfant de s'engager socialement dans des activités avec une autre personne.

La perception visuelle représente la première étape de compréhension des autres. L'utilisation correcte de mots liés à la vision se développe peu avant 2 ans (Bretherton & Beeghly, 1982). A cet âge, les enfants comprennent qu'une personne voit un objet s'il regarde dans sa direction et s'il n'y a pas d'obstruction interposée entre elle et l'objet (Flavell, 1992 ; Lempers et al., 1977). Ils peuvent ainsi déduire qu'une personne perçoit un objet qu'ils ne peuvent pas voir eux-mêmes et inversement, ce qui représente un premier niveau de compréhension sur les informations que peut posséder un partenaire sur un élément auquel ils n'ont pas accès (Phillips et al., 2002 ; Wellman et al., 2000). Vers 3-4 ans, les enfants peuvent reconnaître que les perspectives visuelles d'un même objet peuvent être multiples, c'est-à-dire qu'une personne peut avoir une représentation visuelle qui est différente de la leur (Flavell, 1992 ; Hughes & Donaldson, 1979 ; Masangkay et al., 1974).

Dès un an, les jeunes enfants apprennent également la valeur que peut avoir un objet en lisant les émotions positives ou négatives associées à la fois au regard mais aussi au langage utilisé (Moses et al., 2001 ; Mumme & Fernald, 2003 ; Repacholi, 1998). Ainsi, ils passent moins de temps à observer l'objet sur lequel leur mère a exprimé du dégout que sur celui auquel elle a montré du contentement (Moses et al., 2001 ; Repacholi, 1998). Cette lecture des émotions s'améliore avec l'âge, les enfants d'environ 2 ans comprenant qu'un objet placé hors de leur vue est probablement désirable si un partenaire porte un regard positif sur celui-ci (Wellman et al., 2000). En plus de lire au travers du comportement et du regard les informations qu'un partenaire peut fournir, les jeunes enfants savent manipuler la réponse émotionnelle des autres ; ils peuvent réconforter un ami en détresse en le caressant et en l'embrassant, ou apporter leur peluche à un adulte souffrant (Zahn-Waxler et al., 1992). Vers 4-5 ans, les enfants comprennent des émotions plus complexes comme le fait que des personnes ne ressentent pas toujours ce qu'elles laissent paraître, que leur réaction émotionnelle à un événement peut être influencée par leur expérience passée ou leur humeur actuelle, et qu'elles peuvent ressentir deux émotions conflictuelles simultanément (Flavell & Miller, 1998).

La capacité à analyser la signification du regard d'un partenaire fournit donc à l'enfant des éléments essentiels sur la compréhension de son état émotionnel et sur les informations potentiellement cachées ou erronées qu'il pourrait lui donner, autant d'indices qui peuvent l'aider à mieux prédire le résultat d'un échange et à mener à bien une transaction économique en maximisant ses gains.

Lorsqu'on s'attache aux activités plus concrètes des personnes, on observe que c'est vers 9-12 mois que les enfants commencent à distinguer des actions réalisées mécaniquement de celles d'agents ayant des buts précis (Carpenter et al., 1998 ; Gergely et al., 1995 ; Woodward & Sommerville, 2000). Ils s'engagent spontanément dans des interactions dites triadiques (*passive joint engagment*) dans le sens où elles impliquent l'enfant, la personne engagée dans l'activité et l'objet vers lequel l'attention est dirigé (Bakeman & Adamson, 1984 ; Tomasello, 1995, 2007). Au cours de ces activités, les deux intervenants agissent simultanément sur l'objet vers un but commun, bien que leurs actions - mouvement de va et vient d'une balle, par exemple - restent indépendantes (Eckerman et al., 1989 ; Mueller & Brenner, 1977). Entre 12 et 18 mois, les enfants développent la compréhension des intentions du partenaire c'est-à-dire le plan d'action nécessaire pour atteindre leur but (Bratman, 1989). Plus actifs dans leur interaction, ils sont capables d'aider un adulte en pointant le moyen à utiliser pour atteindre son but, ou en réalisant eux-mêmes l'action nécessaire pour le réaliser, comme ouvrir une porte si les mains du partenaire sont chargées (Liszkowski et al., 2006 ; Rheingold et al., 1976 ; Tomasello 1995 ; Warneken & Tomasello, 2007, 2008). C'est également à cette période qu'ils commencent à s'engager dans des activités coopératives, partageant activement avec le partenaire à la fois les buts et les intentions (*shared intentionnality*) (Bratman, 1992 ; Tomasello, 2007). Ces activités peuvent être simples - s'engager dans une conversation, échanger des objets - ou plus complexes - réaliser une construction, jouer un morceau de musique - (Tomasello et al., 2005) et impliquent la compréhension des différents rôles impliqués dans la coopération et leur complémentarité (Searle, 1995 ; Tuomela, 1995). Par exemple, si un partenaire a cessé d'interagir avec lui, l'enfant essaie de le réengager dans le rôle qu'il est supposé jouer pour atteindre leur but commun (Carpenter et al., 2005 ; Ross & Lollis, 1987 ; Tomasello et al., 2005 ; Warneken & Tomasello, 2007). Certains auteurs suggèrent cependant que la coordination complexe des rôles avec des buts multiples ne serait effective qu'après 2 ans (Ashley & Tomasello, 1998 ; Smiley, 2001).

3.1.2.2. Croyances et représentations mentales associées

La seconde étape de l'émergence d'une théorie de l'esprit, spécifique à l'être humain (Tomasello & Rakockzy, 2003), se développe avec la compréhension que les autres personnes peuvent avoir des croyances et des pensées qui diffèrent des siennes et de la réalité. Les travaux réalisés pour déterminer la période de développement à laquelle les enfants considèrent autrui comme un *agent mental* s'accordent sur un âge de 4-5 ans. Ces études consistent à demander à l'enfant soit de considérer différentes perspectives dans des tâches de fausse croyance (*false belief task*) soit de distinguer l'apparence de la réalité (*appearance-reality task*).

Introduits par Wimmer et Perner (1983), les tests de fausse croyance sont basés sur la faculté de l'enfant à expliquer son point de vue d'un événement et la perspective d'autrui. La tâche la plus fréquemment utilisée, le test des smarties, concerne sa propre croyance (Gopnik & Astington, 1988 ; Perner et al., 1987 ; Wimmer & Hartl, 1991). Elle consiste à présenter à l'enfant une boîte de smarties et à lui demander ce qu'il croit qu'il y a à l'intérieur. L'enfant répond bien entendu que la boîte contient des bonbons. L'expérimentateur montre alors qu'à l'intérieur de la boîte se trouve un crayon, puis il lui demande ce qu'il croit qu'un camarade va répondre à propos du contenu de la boîte. A partir de 4 ans, les enfants comprennent que leur camarade n'est pas informé de la situation et pense que la boîte contient des bonbons. Une seconde tâche consiste à déplacer, sous les yeux de l'enfant mais à l'insu d'une autre personne, un objet d'un endroit A à un endroit B. On demande alors à l'enfant de prédire où l'autre personne, qui a vu l'objet être placé initialement en A, ira le chercher. Cette tâche, adaptée sous plusieurs versions avec « Sally et Anne » (Baron-Cohen et al., 1985 ; Frith, 1989) ou « Max et sa barre de chocolat » (Doherty & Perner, 1998 ; Perner & Lang, 1999) a de nouveau montré que ce n'est qu'à 4 ans que les enfants sont capables d'attribuer à l'autre personne, qui n'a pas vu le déplacement de l'objet, une fausse croyance et de répondre qu'elle ira chercher en A l'objet qui est en réalité placé en B.

Dans les tests d'apparence-réalité, l'enfant doit nommer l'apparence d'un objet puis ce que l'objet est en réalité. Le test du caillou-éponge (Flavell, 1986) consiste à présenter à l'enfant une éponge en forme de roche et à lui demander ce qu'il s'agit. Comme l'expérimentateur a feint que l'objet est lourd, l'enfant répond que c'est une roche. Après lui avoir montré que l'objet a été peint et qu'il s'agit d'une éponge, on redemande à l'enfant s'il pense que l'objet est un caillou ou une éponge. Seuls les enfants de plus de 4 ans sont capables de répondre que l'objet ressemble à un caillou mais qu'il s'agit réellement d'une éponge.

Les connaissances des enfants sur les représentations mentales continuent à s'améliorer après l'âge de 4 ans. En particulier, la capacité à prêter à une personne une pensée en fonction de la pensée d'une autre personne (raisonnement du type « Sylvie pense que Patrice pense que… ») n'apparaît que vers 6-7 ans (Fabricius & Schwanenflugel, 1994 ; Flavell et al., 1999 ; Wellman & Hickling, 1994). En règle générale, les études tendent donc à montrer que la capacité à distinguer sa propre perspective de celle d'autrui est une compétence qui semble se consolider entre 4 et 7 ans (Perner et al., 2011 ; Wellman & Gelman, 1998). Elle représente un outil efficace dans la maximisation des gains, permettant par exemple à des enfants de passer de simples requêtes à l'élaboration de négociations ou de méthodes de persuasion (Palan & Wilkes, 1997 ; Popper, 1979 ; Rust, 1993). La grande majorité des enfants de 3 ans n'ont pas encore acquis une véritable compréhension de la fausse croyance et attribuent à autrui une croyance basée sur la réalité objective plutôt que sur la subjectivité individuelle. Leur incapacité à séparer ce qu'ils savent eux-mêmes de ce que quelqu'un d'autre sait et donc à juger de la fiabilité de l'information provenant de leur partenaire d'échange peut d'une part les rendre vulnérables à toute sorte de tricherie, et d'autre part limiter leur aptitude à leurrer leur adversaire au cours de la transaction économique pour maximiser leur bénéfice.

3.1.2.3. Confiance et détection de la tricherie

De nombreux modèles d'interactions économiques tels que le jeu de l'investissement décrit précédemment (Berg et al., 1995) ont montré que la prise de décision est influencée par des préférences sociales telles que la confiance ou la réciprocité (Bolton & Ockenfels, 2000 ; Charness & Rabin, 2002 ; Falk & Fischbacher, 2006 ; Fehr & Schmidt, 1999). La confiance représente en effet un « lubrifiant » important du système social (Arrow, 1974) qui guide les choix des agents économiques dans des situations d'investissement (Berg et al., 1995 ; Braynov & Sandholm, 2002). Avant d'accorder leur confiance à un partenaire d'échange, les individus doivent être en mesure d'estimer sa fiabilité en détectant d'éventuelles dissimulations ou tricheries (Evans & Krueger, 2011).

Les enfants sont souvent placés dans des situations de jeux compétitifs qui laissent intervenir des possibilités de tricheries ou de tromperies de la part de l'adversaire. Trivers (1971) a distingué deux formes de tricherie : flagrante (*gross cheating*) où le tricheur ne donne rien ou fournit une information ou un objet différent de ceux initialement prévus, ou plus subtile (*subtle cheating*) où le tricheur maintient un comportement apparemment coopératif mais rend moins que ce qui a été donné. Le paradigme de non-révélation de la localisation d'un objet caché a montré que les enfants de 4 ans ont beaucoup de difficultés à inhiber leur comportement d'orientation vers l'objet caché quand on les interroge sur la localisation (La Frenière & Ménard, 1990). En revanche les enfants de plus de 5 ans sont capables de prétendre ne pas savoir où se trouve l'objet. Ils peuvent également fournir une fausse localisation pour induire l'autre en erreur. D'autres études ont montré des compétences plus poussées à l'âge de 10 ans, consistant à fournir de fausses informations ou de faux résultats (Christie & Geis, 1979 ; Desmezières & Lehodey, 1994).

L'étude de la tromperie en tant que stratégie sociale est étroitement liée à l'émergence d'une théorie de l'esprit et en particulier au développement de la distinction entre apparence et réalité (Astington et al., 1988 ; Flavell, 1986). L'ensemble de ces recherches offre donc des résultats convergents pour un âge de détection et de pratique de la tromperie stratégique après 4 ans, ce qui correspond à la période de développement de la compréhension des pensées et croyances des partenaires sociaux (Harris et al., 1986). Etant mieux prémunis pour estimer si leur partenaire est digne de confiance, les enfants plus âgés pourraient s'engager plus facilement dans une transaction économique.

3.2. Ce que nous apprend l'étude des primates non humains

L'être humain apparaît comme la seule espèce ayant développé les compétences économiques nécessaires à l'émergence d'un système de coopération complexe tel que le commerce. Afin de comprendre les bases évolutives de l'économie, il est primordial de connaître les capacités d'échange chez les animaux. Comparer les capacités cognitives nécessaires à l'émergence et au développement des compétences économiques chez les primates non humains avec ceux des enfants doit permettre de préciser les mécanismes à l'origine des décisions économiques.

Les travaux des dernières années ont révélé l'aptitude des primates non humains à s'engager dans des transactions économiques avec un expérimentateur humain sur la base de dons et d'échanges d'objets et de nourriture (Drapier et al., 2005 ; Lefebvre, 1982 ; Ramseyer et al., 2006 ; Westergaard et al., 2004). Ces tâches d'échange ont permis de mettre en lumière des facultés cognitives avancées en termes d'estimation des valeurs, de contrôle de l'impulsivité ou d'estimation du risque. On a pu montrer la capacité des singes et des grands singes à comparer des biens selon leur qualité et leur quantité (Addessi et al., 2007 ; Beran, 2008 ; Boysen & Berntson, 1995 ; Hanus & Call, 2007 ; Silberberg & Fujita, 1996) et à combiner des quantités discrètes d'items (Beran et al., 2008 ; Call, 2000 ; Hauser et al., 2000 ; Rumbaugh et al., 1988). Des macaques rhésus (*Macaca mulatta*), testés dans une expérience similaire à celle de Wynn (1992) chez les enfants, peuvent reconnaître des additions et des soustractions (Hauser et al., 1996) alors que des capucins bruns (*Cebus apella*) sont également capables de sommer la valeur de jetons représentant de petites quantités (Addessi et al., 2007). Des études récentes ont montré que des singes sont capables d'adapter leur investissement en fonction du risque de la transaction (Pelé et al., soumis) ou du risque lié au comportement du partenaire d'échange lui-même (ARTICLES 5 et 6 de l'annexe). En terme de contrôle de l'impulsivité, il apparaît que la valeur de la récompense et la durée d'attente sont les facteurs principaux limitant les capacités d'attente des individus : les chimpanzés (*Pan troglodytes*), les macaques et les capucins bruns attendent d'autant plus souvent que le temps imposé est court et la récompense élevée (Dufour et al., 2007 ; Pelé et al., 2010, 2011 ; Ramseyer et al., 2006). Etant donné que le contrôle de soi et l'estimation du temps ne sont pas entièrement maîtrisés par les jeunes enfants, on peut supposer qu'ils rencontreraient des difficultés semblables pour différer une récompense dans des tâches de gratification retardée. Enfin, les grands singes réussissent généralement mieux que les autres singes dans des tests où on leur demande d'attribuer des intentions à l'autre (Tomasello & Call, 1997).

Les travaux actuels cherchent à déterminer si des biais cognitifs typiques des êtres humains peuvent également limiter la rationalité de la décision chez les primates non humains. On a ainsi montré l'existence d'un effet de dotation chez les chimpanzés et les capucins bruns (Brosnan et al., 2007 ; Lakshminaryanan et al., 2008), ainsi qu'une aversion à la perte chez les capucins bruns (Chen et al., 2006).

4. OBJECTIFS DE LA THESE

Nous avons vu qu'une importante littérature s'est intéressée à la compréhension que les enfants ont du monde économique adulte et de ces concepts tels que la notion d'argent, de banque ou de salaire (Berti & Bombi, 1988 ; Furnham, 1996 ; Leiser et al., 1990). Quelques travaux ont également cherché à étudier, principalement sur la base d'observations de situations quotidiennes, ce qu'ils comprenaient de leur propre marché économique (Barrett & Buchanan-Barrow, 2005 ; Cipriani-Crauste, 2000 ; Webley, 2005). Cependant, comment les enfants apprennent à optimiser leur comportement économique reste un domaine encore mal connu.

Ce travail de thèse a eu pour objectif de comprendre comment les compétences économiques se mettent en place au cours du développement. Il s'est agi de déterminer l'âge auquel les enfants sont capables de maximiser leur gain et de préciser les facteurs susceptibles d'entraîner ou de modifier leur décision. Pour chacune des compétences étudiées, j'ai cherché à identifier les parallèles entre la justesse des décisions économiques et les stades connus du développement socio-cognitif chez l'enfant.

L'aptitude précoce des enfants à s'engager dans des interactions avec un adulte, avant même qu'ils puissent communiquer de manière efficace au travers du langage, a permis d'envisager l'étude de situations d'échange chez des enfants encore très jeunes. J'ai testé des enfants âgés de 14 mois à 10 ans au centre de recherche Living Links du zoo d'Edimbourg et dans différentes écoles de Strasbourg.

Dans une première partie (Chapitre III), j'ai étudié le développement du don et de l'échange chez les enfants pour déterminer l'âge auquel ils apprennent à utiliser ces compétences pour maximiser leur gain (ARTICLE 1). J'ai testé des enfants âgés de 14 mois à 4 ans dans une tâche d'échange dans laquelle ils devaient donner un objet à l'expérimentateur puis l'échanger pour obtenir une récompense alimentaire. Je leur ai ensuite proposé des échanges d'items alimentaires pour tester leur capacité à prendre en compte la valeur relative des biens au cours d'une transaction. Pour évaluer l'influence du partenaire d'échange, les enfants qui refusaient de donner ou d'échanger avec l'expérimentateur étaient testés en présence de leur parent.

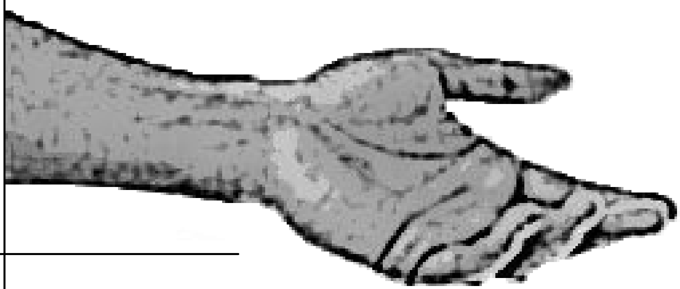
Dans une seconde partie (Chapitre IV), j'ai étudié la capacité des enfants à différer le retour d'une récompense au cours d'une transaction avec un expérimentateur présent tout au long de l'interaction (ARTICLE 2). Pour cela, j'ai soumis des enfants âgés de 2 à 4 ans à une tâche d'échange avec des délais croissants d'attente avant l'obtention de la récompense finale. J'ai employé différentes qualités et quantités de récompense pour savoir si la performance des enfants est influencée par la valeur de la récompense.

Dans une troisième partie (Chapitre V), j'ai cherché à déterminer dans quelle mesure les enfants sont capables de calculer leur investissement sur la base de différentes offres (ARTICLE 3). Les enfants âgés de 3 à 10 ans recevaient initialement 4 items alimentaires qu'ils pouvaient garder ou échanger. Le premier expérimentateur offrait le double de la quantité de bonbons initialement rendue par l'enfant tandis que le second offrait systématiquement une quantité maximale de bonbons peu importe l'investissement initial de l'enfant. Pour maximiser leurs gains, les enfants devaient ajuster leur investissement de manière différente en fonction des expérimentateurs, en donnant le maximum de bonbons au premier et le minimum au second.

La dernière partie (Chapitre VI) a eu pour objectif d'évaluer l'aptitude des enfants à maximiser leur bénéfice dans une situation risquée (ARTICLE 4). J'ai cherché à identifier les facteurs de décision susceptibles de déterminer les choix économiques des enfants en fonction de l'âge. J'ai testé des enfants âgés de 3 à 8 ans dans une tâche d'échange où je leur ai présenté une combinaison de récompenses de dimensions différentes : inférieure, équivalente ou supérieure à l'item de nourriture qu'il devait rendre. Si l'enfant acceptait l'échange, il recevait de manière aléatoire l'une des récompenses de la combinaison proposée. J'ai confronté les choix des enfants à différents modèles économiques de prise de décision de manière à préciser l'évolution avec l'âge des stratégies des enfants face au risque.

CHAPITRE 2

METHODES GENERALES



1. PERIODES ET SITES D'ETUDE

Les expériences se sont déroulées sur quatre périodes, d'avril 2009 à mars 2011, qui correspondent aux quatre grandes problématiques de cette thèse. Les périodes d'étude sont précisées dans le Tableau 2.

Tableau 2. Périodes d'étude

N°	Nom de l'étude	Période
1	DON ET ECHANGE	avril à décembre 2009
2	DELAI	juillet à septembre 2010
3	INVESTISSEMENT	novembre 2010 à mars 2011
4	RISQUE	janvier à mai 2010

Les études 1, 2 et 4 ont été réalisées au Living Links, centre de recherche sur l'Evolution Humaine du zoo d'Edimbourg en Ecosse. L'étude 3 a été réalisée au sein des écoles maternelle et élémentaire de la Robertsau de Strasbourg en France. Sept enfants ont également été testés séparément chez eux à Strasbourg.

Les expériences ont eu lieu au sein de pièces calmes (salle de recherche ou pièce annexe aux salles de classe) comportant une petite table rectangulaire, des chaises et une décoration minimaliste.

2. AUTORISATIONS

J'ai obtenu l'autorisation de travailler avec les enfants en Ecosse par le comité d'éthique, l'UTREC, de l'Université de Saint-Andrews (référence n°PS5528).

J'ai également reçu l'autorisation de l'inspection d'académie du Bas-Rhin (référence DIVEL1/09-670/IJ) pour travailler dans les écoles en France. Les directrices Mme Michelle Helmstetter et Mme Annick Leclerc ainsi que l'inspecteur de circonscription, M. Reiss, ont donné leurs accords pour la réalisation d'expériences au sein des écoles maternelles et élémentaires de la Robertsau.

Pour tous les enfants participant aux études, j'avais préalablement reçu l'accord écrit des parents. L'enregistrement vidéo des sessions de tests était réalisé uniquement si une autorisation spécifique des parents avait été obtenue.

3. GROUPES D'ETUDE

3.1. Présentation générale

J'ai mené ce projet sur 802 enfants : 210 enfants pour l'étude 1, 252 pour l'étude 2, 32 pour l'étude 3 (testés 10 fois chacun), 288 pour l'étude 4. Le ratio filles-garçons était le même dans chacune des expériences. Vingt enfants supplémentaires ont également été testés (sept pour l'étude 1, un pour l'étude 3, douze pour l'étude 4) mais ont ensuite été exclus des données analysées car ils n'avaient pas atteint le critère de succès permettant de passer à la phase de test, ils n'avaient pas été attentifs aux différents tests, ou ils n'appartenaient pas aux classes d'âge désirées pour l'expérience. Les participants étaient européens et appartenaient à la classe moyenne de la population. Ils parlaient tous couramment anglais (étude 1, 2, 4) ou français (étude 3).

3.2. Détermination des classes d'âge

Le choix des groupes d'âge a été réalisé sur la base de nos connaissances des différentes étapes du développement cognitif et social de l'enfant. En intégrant ce que l'on sait du développement de certaines facultés, j'ai pu cibler les périodes au cours desquelles les différentes compétences économiques pouvaient émerger et se développer. Selon les études, les enfants ont été répartis en plusieurs classes d'âge de 14 mois à 10 ans. On trouvera dans le Tableau 3 un récapitulatif par classe d'âge de l'âge moyen et du nombre d'enfants ayant participé à chaque étude.

Pour la première étude, j'ai testé des enfants âgés de 14 mois à 4 ans révolus. On sait que les enfants peuvent donner spontanément des objets à une tierce personne dès leur première année de vie (observation réalisée à 9,5 mois par Rheingold et ses collègues en 1976). Cependant, notre étude impliquant une situation d'échange non familière avec la présence d'un partenaire inconnu, on pouvait supposer qu'ils ne seraient capables de s'engager dans le don et l'échange que plus tardivement ; j'ai donc opté pour une première catégorie d'âge de 14 à 17 mois. Les études préliminaires ont également montré qu'avant cet âge les enfants étaient moins disposés à maintenir leur attention tout au long de la séance de test et à rester calmement assis sur les genoux de leurs parents. Dans l'objectif de définir le plus précisément possible l'âge d'émergence du don et de l'échange, la période sélectionnée a été divisée en catégories d'âge de 4 mois pour les enfants âgés de moins de 2 ans et demi ; les facultés recherchées étant supposées acquises après cet âge, les enfants plus âgés ont été regroupés dans deux catégories de 17 mois chacune.

Pour la seconde étude, j'ai porté mon attention sur des enfants âgés de 2 à 4 ans révolus. Les précédents travaux portant sur les capacités d'attente (Lemmon & Moore, 2007 ; Mischel et al., 1989) ont impliqué des enfants de cette catégorie d'âge, il m'a donc paru intéressant de sélectionner les mêmes périodes de développement dans un but comparatif de situations impliquant ou non un échange de type économique.

Dans la troisième étude, j'ai testé des enfants âgés de 3 à 10 ans révolus. Peu de données permettaient de cerner l'âge auquel des enfants seraient en mesure d'ajuster leur investissement en fonction du profit de deux partenaires d'échange. J'ai donc sélectionné une longue période de développement. Cette étude pouvant nécessiter une certaine maîtrise des compétences numériques, j'ai sélectionné des enfants âgés d'au moins 3 ans. Les contraintes de recrutement des enfants ont conduit à ne réaliser l'étude que sur quatre catégories d'âge de 3 ans, 5 ans, 7 ans et 10 ans.

Pour la dernière étude, j'ai recruté des enfants âgés de 3 à 8 ans révolus. Seule une étude s'est intéressée à la prise de décision des enfants âgés de 5 à 8 ans face à un choix risqué (Harbaugh et al., 2002), mais les données chez les enfants plus jeunes sont absentes. On sait que les enfants de 4-5 ans possèdent une compréhension intuitive des probabilités dans des situations de prise de décision risquée (Anderson, 1991 ; Denison et al., 2006 ; Schlottmann, 2001). Cependant, on ne peut affirmer que cette maîtrise soit suffisante ou nécessaire pour maximiser ses bénéfices, ni même que des enfants plus jeunes possèdent des raisonnements différents qui leur permettraient néanmoins de mener à bien une transaction. Sur la base de ces données, j'ai donc opté pour un âge minimum plus précoce de 3 ans.

Tableau 3. Caractéristiques des groupes d'enfants (nombre d'enfants, âge moyen)

<table>
<tr><th></th><th colspan="3">Etude 1 : don et échange</th><th colspan="3">Etude 2 : délai</th><th colspan="3">Etude 3 : investissement</th><th colspan="3">Etude 4 : risque</th></tr>
<tr><th>Age (mois/ ans)</th><th>Fille</th><th>Garçon</th><th>Age moyen (mois)</th><th>Fille (exp1/2)</th><th>Garçon (exp1/2)</th><th>Age moyen (mois)</th><th>Fille</th><th>Garçon</th><th>Age moyen (mois)</th><th>Fille</th><th>Garçon</th><th>Age moyen (mois)</th></tr>
<tr><td>14-17</td><td>15</td><td>15</td><td>15.5</td><td>non testé</td><td>non testé</td><td>-</td><td>non testé</td><td>non testé</td><td>-</td><td>non testé</td><td>non testé</td><td>-</td></tr>
<tr><td>18-21</td><td>15</td><td>15</td><td>19.6</td><td>non testé</td><td>non testé</td><td>-</td><td>non testé</td><td>non testé</td><td>-</td><td>non testé</td><td>non testé</td><td>-</td></tr>
<tr><td>22-25</td><td>15</td><td>15</td><td>23.4</td><td>non testé</td><td>non testé</td><td>-</td><td>non testé</td><td>non testé</td><td>-</td><td>non testé</td><td>non testé</td><td>-</td></tr>
<tr><td>26-31</td><td rowspan="3">45</td><td rowspan="3">46</td><td rowspan="3">33.9</td><td rowspan="2">30 / 12</td><td rowspan="2">30 / 12</td><td rowspan="2">28.9/28.7</td><td>non testé</td><td>non testé</td><td>-</td><td>non testé</td><td>non testé</td><td>-</td></tr>
<tr><td>32-35</td><td>non testé</td><td>non testé</td><td>-</td><td>non testé</td><td>non testé</td><td>-</td></tr>
<tr><td>36-41</td><td>30 / 12</td><td>30 / 12</td><td>41.1/40.9</td><td rowspan="2">4</td><td rowspan="2">4</td><td rowspan="2">41.4</td><td rowspan="2">24</td><td rowspan="2">24</td><td rowspan="2">42.3</td></tr>
<tr><td>42-47</td><td rowspan="2">15</td><td rowspan="2">14</td><td rowspan="2">54.8</td><td rowspan="2">30 / 12</td><td rowspan="2">30 / 12</td><td rowspan="2">53.5/52.7</td></tr>
<tr><td>4 ans</td><td>non testé</td><td>non testé</td><td>-</td><td>24</td><td>24</td><td>54.3</td></tr>
<tr><td>5 ans</td><td>non testé</td><td>non testé</td><td>-</td><td>non testé</td><td>non testé</td><td>-</td><td>4</td><td>4</td><td>66.4</td><td>24</td><td>24</td><td>65.5</td></tr>
<tr><td>6 ans</td><td>non testé</td><td>non testé</td><td>-</td><td>non testé</td><td>non testé</td><td>-</td><td>non testé</td><td>non testé</td><td>-</td><td>24</td><td>24</td><td>78.0</td></tr>
<tr><td>7 ans</td><td>non testé</td><td>non testé</td><td>-</td><td>non testé</td><td>non testé</td><td>-</td><td>4</td><td>4</td><td>88.0</td><td>24</td><td>24</td><td>89.3</td></tr>
<tr><td>8 ans</td><td>non testé</td><td>non testé</td><td>-</td><td>non testé</td><td>non testé</td><td>-</td><td>non testé</td><td>non testé</td><td>-</td><td>24</td><td>24</td><td>100.0</td></tr>
<tr><td>10 ans</td><td>non testé</td><td>non testé</td><td>-</td><td>non testé</td><td>non testé</td><td>-</td><td>4</td><td>4</td><td>125.6</td><td>non testé</td><td>non testé</td><td>-</td></tr>
<tr><td>Sous - total</td><td>105</td><td>105</td><td>-</td><td>90 / 36</td><td>90 / 36</td><td>-</td><td>16</td><td>16</td><td>-</td><td>144</td><td>144</td><td>-</td></tr>
<tr><td>Total</td><td colspan="2">210</td><td>-</td><td colspan="2">180 / 72</td><td>-</td><td colspan="2">32</td><td>-</td><td colspan="2">288</td><td>-</td></tr>
</table>

4. DEROULEMENT D'UNE SEANCE

Les enfants ont été recrutés au cours de leur visite du centre de recherche du Living Links situé dans le zoo d'Edimbourg. Une lettre d'invitation et une feuille d'information décrivant le but général et les modalités de l'étude étaient données aux parents afin d'obtenir leur autorisation (ANNEXE 1). Les enfants étaient testés durant une seule séance de plusieurs tests. La troisième étude, réalisée au sein même des écoles a nécessité de tester les enfants pendant 10 séances de plusieurs tests. Les invitations étaient données aux parents tôt le matin lors du premier jour de test (ANNEXE 2).

Tous les enfants étaient testés individuellement. Une séance de tests durait entre 15 et 20 minutes. Avant le début des tests, l'expérimentateur se présentait à l'enfant pour le mettre le plus possible en confiance. Puis l'expérimentateur l'invitait à s'asseoir à une table sur une chaise située en face d'elle.

Lorsqu'il le désirait, un seul parent était autorisé à rester avec son enfant au cours des tests. Dans ce cas, il lui était demandé de ne pas communiquer ou d'interagir avec lui. Si l'enfant recherchait une interaction avec le parent, celui-ci devait rediriger son attention sur l'expérimentateur sans orienter sa réponse ou lui donner des indices sur ce qu'il devait faire. Si l'enfant cherchait à entrer en contact avec l'expérimentateur, celle-ci répétait les instructions et encourageait l'enfant à rediriger son attention sur la tâche.

Aucune rémunération financière n'était offerte en fin de séance mais les enfants pouvaient emporter les récompenses alimentaires obtenues.

5. DONNEES RELEVEES

5.1. Paramètres identifiés

Un questionnaire détaillé a été donné à remplir à chaque parent afin de prendre en compte les différents paramètres susceptibles d'affecter les facultés de l'enfant. Les paramètres relevés étaient les suivants :

- ✓ La *date de naissance*, afin de connaître l'âge exact de l'enfant le jour du test.
- ✓ Le *sexe* de l'enfant.
- ✓ L'*existence de frères et sœurs* et la *position de l'enfant au sein de la fratrie*.
- ✓ L'*état de satiété*. L'heure de la dernière prise alimentaire a été notée afin de s'assurer que la faim ou le manque d'appétit n'influencerait pas les résultats de l'étude. Je me suis régulièrement assurée au cours des séances de la motivation de l'enfant à obtenir les récompenses proposées.

5.2. Observations comportementales

A chaque séance de tests, les comportements des enfants ont été notés pour les cinq variables suivantes :

- ✓ L'*attitude générale* de l'enfant face à l'expérimentateur : neutre, timide, assuré.
- ✓ Les *coups d'œil ou regard persistants* portés sur l'expérimentateur ou la récompense. Ces comportements permettent d'une part d'estimer l'état de confiance de l'enfant envers le partenaire d'échange et d'autre part de mesurer sa motivation à obtenir la récompense.
- ✓ Les *tentatives de communication* avec l'expérimentateur ou le parent.
- ✓ Les *commentaires autocentrés* : les paroles dirigées vers soi. Elles sont révélatrices de la manière dont l'enfant procède pour réussir la transaction : par exemple, estimation du temps restant lors de la seconde étude, ou dénombrement des items alimentaires à rendre et du bénéfice total de la transaction lors de la troisième étude.
- ✓ La *séquence comportementale*. L'enchaînement des comportements et leurs durées ont été relevés au cours de la période d'attente, uniquement dans l'Etude 2 :
  - attente passive : tenir le biscuit, regarder le biscuit, regarder l'expérimentateur, regarder l'environnement.
  - distraction : toucher, jouer avec le biscuit, jouer seul(e), simuler ou goûter le biscuit, parler avec le parent.

Le relevé des stratégies d'attente pouvait être facilité par les vidéos réalisées sur les enfants dont les parents avaient donné préalablement leur accord. Quand différentes stratégies ont été utilisées par un enfant, la stratégie dominante retenue était celle qui avait duré le plus longtemps en fonction de la durée totale d'attente.

CHAPITRE 3

LE DEVELOPPEMENT

DU DON ET DE L'ECHANGE

SYNTHESE DE L'ARTICLE 1

Le développement précoce du don et de l'échange chez les enfants

Article en révision pour *Social Development*

◆◆◆

Pour comprendre comment se développent les compétences économiques chez les enfants, la première étape consiste à s'interroger sur les bases sur lesquelles repose toute transaction, à savoir le don et l'échange. Réaliser une transaction économique nécessite un transfert de biens, d'objets ou de services. De tels transferts ne sont pas le monopole des êtres humains puisque différentes espèces animales, en particulier les singes, en sont capables. Bien que l'approche évolutive ne soit pas le but premier de mes recherches, il reste pertinent de confronter les différentes compétences nécessaires aux transactions économiques chez les enfants et les primates non humains, afin de considérer à la lumière de l'évolution les fondements de l'économie. Chez la plupart des sociétés humaines, les transactions prennent la forme de dons volontaires bien qu'ils soient en réalité régis par de nombreuses obligations sociales ou morales. Le don est également présent dans les sociétés occidentales mais c'est sur un système d'échanges mutuels entre personnes qu'est principalement basée notre économie. Etre en mesure de mobiliser rapidement ces deux compétences reste aujourd'hui indispensable à la fois pour s'intégrer socialement et dans une certaine mesure pour évoluer en société.

Si les dons et échanges sont couramment utilisés lors des transactions chez l'adulte, ils apparaissent déjà chez les enfants, soulignant chez ces derniers l'existence de compétences de type économique. Les enfants sont exposés très tôt aux échanges que ce soit au sein de leur famille ou à l'école. Les jeunes enfants sont en outre des acteurs de plus en plus actifs de la consommation ce qui a provoqué des recherches sur les connaissances qu'ils peuvent avoir de notions économiques telles que l'argent ou la publicité. Pourtant, bien que nous sachions que les aptitudes au don et à l'échange soient déjà présentes au cours de l'enfance, nous ne disposons pas de données quantitatives sur leur âge d'émergence et leur développement. En particulier, quand et comment les enfants comprennent que donner ou échanger peut leur permettre de tirer des avantages dans leurs relations sociales ou d'obtenir des biens désirés nécessite une investigation spécifique. La capacité précoce des enfants à s'engager dans des interactions avec un adulte, avant même qu'ils communiquent efficacement au travers du langage, permet d'envisager l'étude de situations d'échange chez des enfants encore très jeunes. La présente étude a pour but d'étudier le développement du don et de l'échange chez les enfants. Il s'agit dans cette première série d'expériences de déterminer quelle proportion d'enfants s'engagent dans le don ou l'échange, et cela en fonction de l'âge et de la familiarité du partenaire.

J'ai testé des enfants âgés de 14 mois à 5 ans dans une tâche d'échange où il leur était d'abord demandé de donner un objet à l'expérimentateur puis de l'échanger pour obtenir une récompense alimentaire. La plupart des enfants ont donné un ou plusieurs objets bien qu'aucune récompense n'ait été offerte en retour. Le nombre moyen d'objets échangés a augmenté après 18 mois. L'analyse des résultats montre que les enfants privilégient leur propre intérêt dans une tâche d'échange car ceux qui ont refusé de donner tous les objets ont accepté de les échanger contre une récompense. Afin de déterminer leur capacité à prendre en compte la valeur relative des biens au cours d'une transaction, je leur ai ensuite proposé des échanges qualitatifs et quantitatifs d'items alimentaires. Dès 15 mois, les enfants étaient capables de s'engager dans des échanges qualitatifs mais réussir des échanges quantitatifs n'a été observé qu'après 16 mois. Les performances des enfants ont augmenté vers 22 mois. Enfin, pour évaluer l'impact du partenaire d'échange, les enfants qui refusaient de donner ou d'échanger avec l'expérimentateur ont été testés avec leur parent. Environ un tiers des enfants ont refusé de s'engager dans une transaction avec un partenaire non familier mais ont alors accepté de le faire avec un parent. Par ailleurs, une interaction entre le sexe des enfants et la présence de frères et sœurs a été mise en évidence chez les plus jeunes.

Les performances des enfants dans le don et l'échange augmentent entre 14 et 22 mois. Cela correspond au développement de plusieurs facultés socio-cognitives telles que le contrôle de soi ou l'expérience avec la fratrie pendant la seconde année de vie. Il apparaît que les très jeunes enfants peuvent déjà accepter de partager des objets avec une tierce personne, même quand rien n'est offert en retour. En parralèle, ils reconnaissent très tôt leur propre intérêt et peuvent utiliser les autres personnes pour maximiser leurs gains. L'effet de la familiarité du partenaire et de la fratrie souligne l'influence additionnelle de l'environnement social.

The Early Development of Gifts and Exchanges in Children

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Abstract

Gifts and exchanges represent the foundations on which economic skills are built. Despite the importance of these phenomena, we have limited knowledge about how gifts and exchanges arise in children, and whether the stages of cognitive development match the development of economic skills. So we studied age-related changes in the performances of 210 children aged 14 to 60 months when giving an object to an adult, and when exchanging an object with an adult to obtain a food reward. Children were also offered qualitative and quantitative exchanges of food items to assess their ability to take into account the relative value of the goods when exchanging. We found that most children, even the youngest, could freely give objects to an adult when nothing was offered in exchange. They could also, from an early age, recognize their interest in an exchange and use others to acquire more. Performances in giving and exchanging increased after 18 and 22 months of age, respectively. This supports the idea that changes in cognitive abilities that occur just before children turn 2 years old are related to the optimality of decision-making. Lastly, having siblings positively influenced the performances of subjects, which points at the role of the social environment in the acquisition of economic skills.

Keywords: economics; psychology; trading; age; children

Introduction

In Western economies, where most developmental experimental studies of reciprocation have been conducted, reciprocal transfers typically take the form of one-for-one exchange, where two parties formally agree to exchange one good for another. In contrast, reciprocal transfers of goods and services in many societies can take place under the guise of gifts, extending to the returning of gifts without initial agreement or contract (Mauss, 1967). Such gifts appear to be voluntary but in many cultures they are often given and repaid through legal or social obligation: examples include dances, ceremonies, food sharing, or mutualisation of goods in a business enterprise. In these cases the act of giving creates a social bond with an obligation to reciprocate. Not giving in return affects the relationship with the giver and has a negative effect on one's reputation (Mauss, 1967). Gifts and exchanges occur amongst children (Cohen, 2006); they likely represent the corner stone on which economic skills are built. In many societies children are either exposed to or involved in gifts and exchanges from an early age within their families. Yet, we lack information about how gifts and exchanges arise in children. In particular, we need to know at what stage of their cognitive development they understand that they can give freely or that they can use gifts as a way to gain more, for example to improve social support or gain appealing goods.

When trading, adults rely on complex cognitive abilities including evaluation, patience, anticipation, and understanding the role of others (Kahneman & Tversky, 2000; Nofsinger, 2005). In children these abilities are subjected to a developmental process and are not mature at the same time; thus one can expect that younger children should be less skilled at optimizing their gains than adults (Mischel, 1966; Tulving, 2005). A primary skill is the ability to give. Free giving (i.e. offering on its own initiative) to a partner, peers or siblings, has been described in play contexts at around 9 to 12 months of age (Eckerman, Whatley, & Kutz, 1975; Hay, 1979; Hay & Murray, 1982; Rheingold, Hay, & West, 1976; Ross & Goldman, 1977). Rheingold and colleagues (1976) reported that 12- to 15-month-old children could also respond to an unfamiliar person's gestural request by bringing an object. This behavior appears to increase as children approach their second birthday (Hay, 1979).

Sharing behavior includes actions as well as emotions (Eisenberg & Fabes, 1998). During the first years of life children can respond to others' psychological and emotional states (Baron-Cohen, Tager-Flusberg, & Cohen, 1993; Tomasello & Rakoczy, 2003; Wellman & Bartsch, 1994). Children who have younger siblings often comfort them if they show signs of distress (Howe & Ross, 1990). Two-year-olds can identify emotional distress and offer assistance to older persons. However, they often respond in ways that they themselves find comforting, based on their own needs rather than the needs of the person in distress; for example, they offer a teddy bear as comfort to an older child or adult. Children may lack skills or insights into appropriate helping behavior (Barnett, Darcie, Holland, & Kobasigawa, 1982; Hoffman, 1982) and their motives are probably also changing throughout development. Some studies showed that sharing behavior decreases as language improves (Cook, 1977; Eckerman, Davis, & Didow, 1989) with verbal interactions becoming the prominent tool to demonstrate goodwill (Eckerman et al., 1989; Howes, 1987). According to their age children may engage in giving due to an intrinsic "altruistic" motivation (Dunn, 1988), to a motivation to share behavior and emotion (Tomasello, Carpenter, Call, Behne, & Moll, 2005), or due to self-centered objectives when they realize that giving may allow them obtaining more.

Maximizing gains requires evaluating the value of goods or services, and exhibiting a certain level of self-control. In Western societies, studies have shown that children make "more" and "less" value judgments about discrete quantities from the age of 10 months (Cooper, 1984). They can, for example, recognize high numerosities of 4 items or more, albeit in an imprecise way (Brannon, 2002; Feigenson, Dehaene, & Spelke, 2004; Lipton & Spelke, 2004; Xu, 2003; Xu & Spelke, 2000). Concerning self-control abilities, they follow a developmental process improving from 12 to 30 months of age (Kopp, 1982; Piaget, 1952, 1954; Vaughn, Kopp, & Krakow, 1984). For example, 18-month-old children cannot resist the temptation to touch a toy (Kochanska, Coy, & Murray, 2001; Vaughn et al., 1984). In comparison, 3-year-old children can wait several minutes for the experimenter to return before opening a gift box (Vaughn et al., 1984). When given a choice between an immediate sweet or a bigger but delayed one, children aged between 2 and 5 years can wait for 2 to 15 min (Eigsti et al., 2006; Kochanska et al., 2001; Mischel, Shoda, & Rodriguez, 1989; Peake, Hebl, & Mischel, 2002; Vaughn et al., 1984). Thus, when giving or sharing, self-control should only be problematic for children aged below 2 years.

Understanding that another person can help them to obtain more and maximize benefits has not been thoroughly investigated in children. From the second year of life, children start understanding and sharing other's goals and action plan in cooperative games, and become able to reverse roles with an adult partner in games involving two complementary roles (Bratman, 1992; Carpenter, Nagell, & Tomasello, 1998; Tomasello, 2007; Tomasello et al., 2005; Warneken, Chen, & Tomasello, 2006). From 2 years, children appear able to share toys with a peer as a mean to resolve conflict over the toys' possession (Caplan, Vespo, Pedersen, & Hay, 1991; Hay, Caplan, Castle, & Stimson, 1991), thus they initiate a gift with a positive social outcome in mind. From 3 to 4 years, they can also anticipate potential defection from partners (Clément, Koenig, & Harris, 2004; Pasquini, Corriveau, Koenig, & Harris, 2007). When confronted to informants who differ by their level of reliability, children this age select the partner having given the more accurate information in the past (Birch, Vauthier, & Bloom, 2008; Corriveau & Harris, 2009; Jaswal & Neely, 2006; Scofield & Behrend, 2008). This is consistent with the fact that, by the age of 4, children typically see others as mental agents possessing beliefs and thoughts different from their own (Gopnik & Astington, 1988; Perner, 1991; Sullivan & Winner, 1993; Tomasello & Rakoczy, 2003; Wellman, 1990).

Seeing others as potential partners and controlling one's own impulsivity according to the value of a potential return is bound to improve significantly over the development of children (Tomasello et al., 2005; Warneken & Tomasello, 2007). It is likely that these skills support the way children learn to give and exchange. We investigated how early children could recognize the possibility to gain more in a transaction resembling an economic context. We involved children aged between 14 and 60 months in a bartering task to test their capacity to give an object to an adult (Step 1), then to exchange one object for a food reward (Step 2), a low-value food reward for a food of better quality (Step 3), and a high-value food reward for more of the same (Step 4). By increasing the difficulty from one step to another, we aimed at detecting possible age-related variations in the performances of children.

Methods

Participants and Experimental design

The experiment took place at the Living Links to Human Evolution' Research Centre in Edinburgh Zoo. Ethical authorization to work with children was given by the University of St Andrews ethics committee, UTREC (reference n°PS5528). Children were recruited upon their visit to the 'Living Links' Centre. A letter and an information sheet describing the general purpose of the study were given to the parents who gave signed consent for their children's participation. Participants were 210 children (105 boys, 105 girls) between the ages of 14 and 60 months. Table 1 summarizes the characteristics of children. This sample was divided on the basis of age into three age groups aged 14-25, 26-42 and 43-60 months. Given that the second year life is crucial in the development of cognitive skills, we performed further analyses on the youngest age group, dividing it into three smaller sub-groups (14-17, 18-21, and 22-25 months). Note that seven additional children whose parents had given consent were tested but excluded from the dataset analyzed: six for being outside of the appropriate age ranges, and one for not paying attention to the tests. Participants were Europeans from middle-class backgrounds with English as their first language. No financial remuneration was offered, but children kept the sweets they won during the testing session.

Tests were conducted in a small, quiet and decorated room (3.5 x 2 m). Children were tested individually while seated on a chair, or on their parent's lap in front of rectangular table (1.2 x 0.6 m). A video camera recorded the session after parental written consent. The apparatus consisted of six bottle caps and three boxes split into compartments containing sweets.

Table 1. Characteristics of children. Children were divided into three age groups aged 14-25, 26-42 and 43-60 months. For some analyses, the youngest age group was divided into three sub-groups (14-17, 18-21, and 22-25 months).

N	Age (months)		Sex		Sibling status		Birth order			
	Range	Mean	Male	Female	Sibling(s)	No sibling	First born	Middle born	Later born	Twin
90	14-25	19.5	45	45	35	55	5	0	30	0
91	26-42	33.9	46	45	56	35	11	5	32	8
29	43-60	54.8	14	15	21	8	16	2	3	0

30	14-17	15.5	15	15	9	21	0	0	9	0
30	18-21	19.6	15	15	12	18	1	0	11	0
30	22-25	23.4	15	15	14	16	4	0	10	0

Procedure

A session lasted approximately 20 minutes. The experimenter was unfamiliar to the children. Before testing the experimenter introduced herself to the child to put them at their ease. We recorded whether s/he had siblings and their order of birth (firstborn, middle born, later born, twin). Only mother or father was allowed to stay with the child during testing. Parents were instructed not to interfere by initiating communication or interactions during testing. If a child sought interaction with parents, parents were asked to draw the child’s attention back to the experimenter without directing her/his response, or give any hints of what s/he was supposed to do. If the child wanted to interact with the experimenter, she repeated the instructions and encouraged her/him to redirect her/his attention to the task. During testing children were seated on a chair across from the experimenter. Each test session was subdivided into four increasingly difficult steps testing the children’s development of gift (Step 1), and exchange (Steps 2, 3 and 4) as follows.

Step 1. Six consecutive trials were conducted in this step. The first trial began when six plastic bottle caps were given by the experimenter to the child: the caps were placed on the surface of the table in front of the child. At the first trial the experimenter pointed to the bottle caps, held out a hand, palm open, in front of the child, and said “Oh look I just put this here! Now can you give one back to me?” Then, if the child did not give an object after 5 s she repeated the verbal and gestural request “Oh come on! Try to give one to me”. The experimenter could attempt gaining the child's attention by calling her/his name. If nothing happened after 5 s, the experimenter asked the parent to replace her. The parent repeated the same gesture and instruction as the experimenter. If the child did not give an object, the trial ended. Then the experimenter asked “Do you want to try again?” before starting another trial. If the parent’s assistance was required at the first trial, the next trials were run with the parent only. The experimenter maintained a friendly demeanor throughout demonstrations. Every time the child gave an object to the experimenter, she accepted it, thanking the child, and placing it on the table directly in front of her saying “Good, well done!” At the end of the series of six trials, the experimenter said “OK for this game! That was very nice. Let's play another game now!”

Step 2. Whatever the success at Step 1, all children were tested at Step 2 where they were invited to exchange an object to receive a valuable edible reward, one sweet. Before testing children were given a choice between different small sweets (Smarties®, Skittle®, Dragibus®, Cheerios®). Each child was asked to indicate a preference for either the object or the preferred sweet; every child selected the sweet. The child was told that for this game, the experimenter needed a small box placed on the table directly in front of her. A demonstration was carried out prior to the trials to inform the child of the exchange potential in this new context. One bottle cap was placed in front of the child who was asked to give it back. If the child returned it, the experimenter uncovered a sweet from the box placed on the table and handed it to the child saying "Oh thank you! Here is a sweet. Do you want to try again?" If the child refused to give the object after 10 s, the experimenter asked the parent to demonstrate what was required. The experimenter then proceeded to carry out three consecutive trials. She uncovered the next potential sweet in the box and put one bottle cap on the table, inviting the child to exchange it for the sweet. If the child did not exchange the object after approximately 10 s she repeated the request. If nothing happened after 10 s, the parent was asked to play the experimenter's role. If the child did not exchange the object with the parent, the trial ended, and a new trial started. If the parent's assistance had been required at the first trial, the next trials were run with the parent only. Every time the child exchanged the bottle cap, the experimenter rewarded him/her with the sweet. The child could consume or kept the sweet s/he had obtained; s/he was given a plastic bag to save sweets after the first trial. If the child was successful in at least two trials out of three, the experimenter proceeded to the next step. If not, testing ended without running the following steps.

Step 3. Each participant was first asked to indicate a preference for either a digestive biscuit of dimension 1 x 1 x 0.5 cm, or a sweet; every child selected the sweet. Then, the child was given the low-value food item (the piece of biscuit) and was invited to return it to obtain the higher-value food (the sweet). Three consecutive trials were conducted. If the child consumed the piece of biscuit the trial ended. Then the experimenter asked "All right, if you want to keep it, that's OK. Do you want to try again?", before starting another trial. If the child exchanged successfully in at least two trials out of three, s/he was tested in Step 4. If not, testing ended without running the following step.

Step 4. Step 4 involved quantitative exchanges inviting the child to exchange one highly valuable sweet for four of the same value, thus quadrupling the attained value. The procedure was identical to the one used in Step 3.

Statistical analysis

The results were analyzed separately for Step 1 (gift), and for Steps 2, 3 and 4 (exchange). Data were analyzed in R 2.9.0 (The R Foundation for Statistical Computing, Vienna, Austria).

For analyses, we considered separately the results of children tested with the unfamiliar partner, i.e. the experimenter, from those of children tested with their parents. In each case, we used a generalized linear model, specifically a logistic regression model, with a binomial or Poisson distribution and a logit or log link function to assess whether the variables of age, sex (1 for boys and 0 for girls), siblings (1 for children with siblings and 0 for only children) and order of birth (1 for firstborn, 2 for middle born, 3 for later born and 4 for twins) influenced the mean number of gifts and the maximal exchange step reached by children. Since not all children reached the last steps, we categorized levels of performance to compare their ability to exchange; children obtained scores according to their success: they received a score of 1 when succeeding at Step 2, a score of 2 when succeeding in exchanging on a qualitative basis at Step 3, and a score of 3 when succeeding in exchanging on a quantitative basis at Step 4. Tukey's HSD tests were used for testing the significance of the pair-wise comparisons. Whenever the youngest age group (14-25 months) significantly differed from the others, we splitted it into three sub-groups (14-17, 18-21, and 22-25 months) and conducted additional analysis to detect potential developmental effects. Average values are given as means and standard error of the mean. The significance level was set as 0.05.

Results

By experimental design, children who refused to engage in giving and exchanging with the unfamiliar partner were tested with their parents. Overall, 72.0% of the children accepted to interact directly with the unfamiliar experimenter, 28.0% chose to interact with the parent. The younger the children, the less frequently they were able to give at Step 1 and exchange at Steps 2, 3 or 4 with the experimenter (GLM, gift: $z = 71.9$, $p < .001$; exchange: $z = 28.0$, $p < .001$).

Performances of children tested with the experimenter

At Step 1 the mean number of objects given differed between the three age groups (GLM, $z = 51.2$, $p < .001$), with children aged 14 to 25 months giving significantly less objects than the older two age groups (mean number of gifts ± SD = 5.7 ± 0.2 vs. m = 6.0 ± 0; Tukey's test: $p < .001$ for all comparisons). To look in more details at the younger age group response, we divided it into sub-groups (14-17, 18-21, 22-25 months). Comparing the three sub-groups yielded statistically significant differences (GLM, $z = 32.7$, $p < .001$) with children aged 14 to 17 months giving significantly less objects (m ± SD = 5.5 ± 0.2) than 18-21 and 22-25 months (m ± SD = 5.8 ± 0.1 and 6.0 ± 0, respectively, Tukey's test: $p < .001$ for all comparisons; Figure 1). Despite lower performances in 14-25 months, success in giving was observed from as early as 14 months of age and 91% of these children were able to give at least one object. Four children never gave any object; they all belonged to the 14-25 months age group. At Step 2, however, 100% of the children accepted to return at least one object, and 98.9% exchanged all three objects to get the high-value sweet in return.

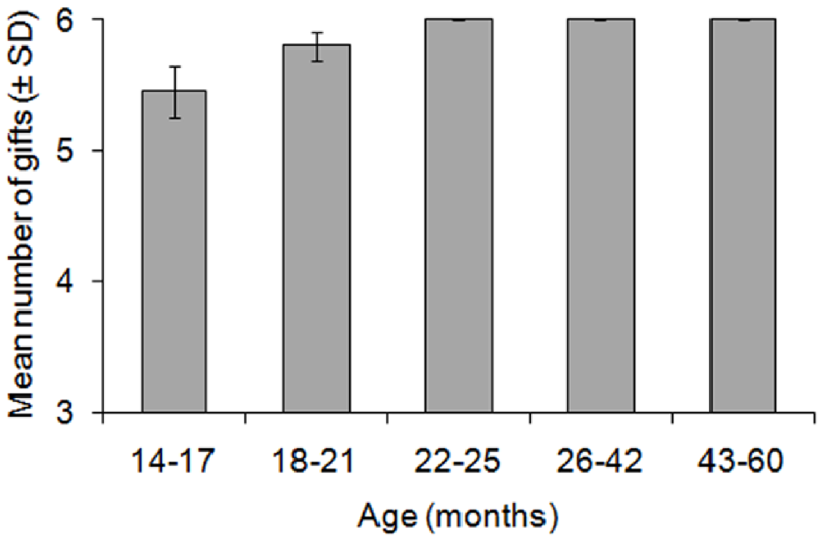

Figure 1. Mean number of gifts for children tested with the experimenter.

Success in qualitative (Step 3) and quantitative food exchanges (Step 4) was observed from 15 and 16 months of age, respectively. Only 14.7% of the children (thirteen 14-25 months old) did not reach the exchange criterion to be tested at Step 4. Comparing the exchange performance index at Steps 2 to 4 between the different age groups yielded significant differences (GLM, z = 3.1, p < .001) with children aged 14 to 25 months reaching lower performances (exchange performance index ± SD = 2.49 ± 0.06) than those from the two older age groups (index = 2.99 ± 0.01; Tukey's test, p < .001 for both comparisons). To look in more details at this younger age group, we divided it into sub-groups. Comparing the three sub-groups yielded statistically significant differences (GLM, z = 3.7, p < .001), with children aged 14-17 months (index = 1.83 ± 0.09; Tukey's test: p < .001) and 18-21 months (index = 2.71 ± 0.05, Tukey's test: p < .01) reaching lower performances than children aged 22 to 25 months (index = 2.95 ± 0.04). It may be noted that at Steps 3 and 4, twelve children aged between 17 and 25 months were seen to put the initial item into their mouth before exchanging it. Nine children aged from 20 to 31 months hesitated before either eating or giving back a food item.

Children with one or more siblings reached higher performances than only children (index = 2.97 ± 0.03 vs. 2.42 ± 0.13; GLM, z = 3.2, p < .001) at the exchanging Steps 2 to 4. We did not find, however, an effect of the order of birth (GLM, z = 3.2, p = 0.82). Also, girls aged between 14 and 25 months with siblings were more likely to reach more difficult steps than only children of the same age regardless of gender (sex*age*sibling interaction: GLM, z = 2.2, p < .01; Figure 2). Note that all tested twins (4 pairs) belonged to the 26-42 months age group and were tested with the experimenter. Although we could not test it, no differences appeared in their performances compared to others children of the same age group (mean number of gifts ± SD = 6.0 ± 0 vs. 5.82 ± 0.14; exchange index = 2.75 ± 0.23 vs. 2.98 ± 0.01).

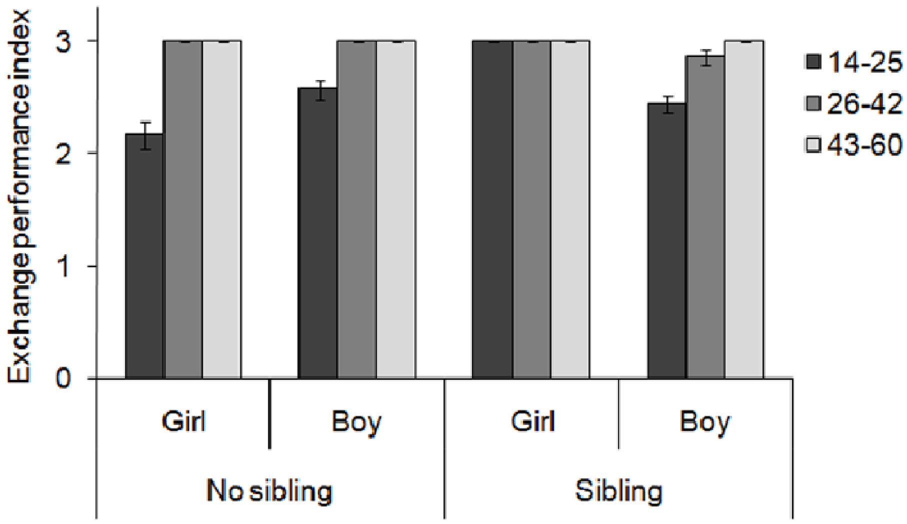

Figure 2. Influence of age, sex and siblings on the exchange performance index of children tested with the experimenter. Ages are given in months.

Performances of children tested with the parent

At Step 1, the mean number of objects given did not differ between the three age groups (GLM, z = 50.1, p = .07). Comparing the exchange performance index at Steps 2 to 4 between the different age groups yielded significant differences (GLM, z = 4.2, $p < .01$). Children aged 14 to 25 months reached lower performances (exchange performance index ± SD = 1.80 ± 0.07) than those from the two older age groups (index = 2.70 ± 0.04; Tukey's test, $p < .01$ for both comparisons). To look in more details at this younger age group, we divided it into sub-groups. Comparing the three sub-groups yielded statistically significant differences (GLM, z = 4.7, p < .01), with children aged 14 to 17 months reaching lower performances than 22-25 months (index = 1.50 ± 0.08 vs. 2.00 ± 0.05; Tukey's test: $p < .01$).

Children with one or more siblings gave more objects than only children at the giving Step 1 (m = 5.1 ± 0.5 vs. 4.4 ± 0.2; GLM, z = 49.6, $p < .01$). They also reached higher exchange performances than only children at the exchange Steps 2 to 4 (index = 2.05 ± 0.08 vs. 1.78 ± 0.11; GLM, z = 3.4, $p < .05$). We did not find any significant effect of the order of birth (GLM, gift: z = 4.6, p = 0.67; exchange: z = 3.4, p = 0.71), nor gender (GLM, gift: z = 43.4, p = 0.31; exchange: z = 2.9, p = 0.22).

Discussion

Most children, even the youngest, could give objects in response to gestural requests. Refusal to give for no reward was mainly seen in younger children. All children succeeded in exchanging an object for a sweet at Step 2. As the difficulty increased from Steps 3 to 4, children performances decreased. From 15 months, children could succeed in qualitative exchanges, but success in quantitative exchanges was not observed before 16 months of age.

Children’s performances significantly increased with age, especially after 18 months for the giving step, and after 22 months for the exchanges steps. When focusing on children tested with the experimenter, we found that children with siblings gave more and reached higher levels of performances in exchanges. In addition, 14-25 years old girls with siblings succeeded in more difficult steps when exchanging than any other children of the same age. For children tested with their parents, we found a global effect of sibling on giving and exchanging performances.

The observation that almost all children accepted to give at least one object following the adult pleading gesture is consistent with previous literature on giving and sharing in children aged 14 months or less (Hay et al., 1991; Rheingold et al., 1976). Younger children were, however, less prone to give than older children. It may be due to strong differences in children social experience (Hay & Murray, 1982), including education from parents about sharing (West & Rheingold, 1978). Parents often encourage children to help others, and thank or praise them when they perform their first communicative motions (Warneken et al., 2006; West & Rheingold, 1978). This encouragement to learn prosocial norms probably play a considerable part in the children's degree of precocity by boosting the accomplishment of giving gestures. A second possibility is that children exhibited shyness (i.e. behavioral inhibition in unfamiliar social situations; Leary, 1986) that is known to be stronger in young children (Crozier, 2000). The novelty of the experimental set-up and the unfamiliarity of the partner may have caused a feeling of awkwardness or discomfort in younger children, who either refused to be tested with the experimenter (being more at ease with their parents) or were less prone to give when tested with the experimenter compared to older children. Indeed, we found no age effect in giving in the children tested with their parents, when all children where at ease. Still, in the first giving step, this later group did show a sibling effect that suggests that having siblings improves the capacity to cope with a novel situation in shy children. Several studies have already demonstrated that the presence of siblings in the family encourages cooperation rather than competition, and enhances skills in persistence (Jiao, Ji, & Jing, 1986; Miller & Maruyama, 1976). Early experiencing in sharing with siblings may help children counterbalance the shyness exhibited in unfamiliar social contexts.

All children successfully exchanged at least one object for a sweet at Step 2. Interestingly, children who refused to give any object at Step 1 accepted to exchange one object or more when offered one sweet in return. This result suggests that refusing to give was the outcome of a choice rather than a failure to understand the request. From 2 years of age, children can use sharing to resolve conflict over toys (Caplan et al., 1991; Hay et al., 1991). In the first ten years of life, most children learn to identify positive or negative short-term interests such as « If you want a dessert, eat your vegetables », or « If you behave well, you will have a toy » (Smetana, 1999). Here, children who initially refused to give an object for nothing were all capable to reevaluate their decision when they could obtain a treat in return. Thus, they could take their own interest into account and maximize their gains from as early as 14 months of age. Despite the main observation that most children gave freely, this anecdotal result points at the potential for selfish motives early in life.

When looking at transactions that involved exchanging one valued food for another, thus requiring some impulsivity control, performances increased with age. Fourteen-month-old children failed to maximize their benefit in both qualitative and quantitative exchanges. Former studies have shown that children this age discriminate small quantities from 10 months (Cooper, 1984; Feigenson & Carey, 2000; Sophian & Adams, 1987; Strauss & Curtis, 1984), making it unlikely that failure to exchange one sweet for four in quantitative exchanges was due to a lack of quantity discrimination. An improved self-control, that is known to emerge between 12 and 18 months and to rapidly improve between 24 and 30 months of age (Kopp, 1982; Logue, Forzano, & Ackerman, 1996; Mischel & Mischel, 1983; Piaget, 1952, 1954; Vaughn et al., 1984), may provide a better explanation. The difficulty of some children aged 17 to 31 months to return an intact edible item (putting it in their mouth first or showing hesitation before either eating or giving back the food) perfectly fit with the stages of this development. We cannot exclude that children's performances in quantitative exchanges may have benefited from their experience of qualitative exchanges. Nevertheless, exchanging one small quantity for another proved a difficult step for the children. The use of an exchange task here reveals how the development of self-control abilities in children may impact their skills in a functionally important social context such as bartering.

Previous studies showed that, with age, children interact more often with adults over a shared goal (Hay, 1979; Hay & Murray, 1982; Tomasello, 2007; Verba, 1994). In addition to self-control, increasing performances in exchanging can also be related to a better understanding of the role of the experimenter as a partner to obtain more. Several studies have shown that having sibling promotes the development of theory-of-mind abilities (Bartsch & Estes, 1996; Jenkins & Astington, 1996; Perner, Ruffman, & Leekam, 1994; Ruffman, Perner, Naito, Parkin, & Clements, 1998). It is likely that repeated interactions with sibling gives children more practice in understanding this role. This could explain why children having one or more siblings performed better in exchanging than children without siblings. Interestingly, younger girls having siblings performed better at more difficult steps than other children of the same age. Observational research from preschool to adolescence indicates that girls can perform better in tasks involving resistance to temptation and delay of gratification (Bjorklund & Kipp, 1996; Silverman, 2003). Together, having siblings and resisting temptation better may have given the youngest children a head start in our study.

The early forms of sharing were found in children as young as 14 months but were increasingly displayed as children grow up, with a major shift between 18 and 22 months. The current findings draw attention to the fact that the motivations to share as a function of age relate to several socio-cognitive factors such as self-control, experience with sibling and maybe shyness. Our results fit with the findings of other authors who concluded that major changes in socio-cognitive abilities occur at around the age of two (Eckerman & Peterman, 2001; Tomasello, 2007). Children could freely give without expectation of return, which was the main response seen. Whether it was an altruistic response (Dunn, 1988) or this was due to a desire to share emotion (Tomasello et al., 2005) with the adult is not known. Previous work reported a decrease in sharing as children proficiency in language improved (Cook, 1977; Eckerman et al., 1989). Such a decrease was not observed in our study. Alongside to prosocial behaviors, children could from an early age recognize their interest and use others to acquire more. The social environment seems to play a key role in how early children acquire their economic skills. Further studies should investigate the role of social experience in the development of trading.

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CHAPITRE 4

L'APTITUDE A DIFFERER UNE RECOMPENSE

SYNTHESE DE L'ARTICLE 2

L'aptitude des enfants à attendre une récompense

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Les enfants sont capables d'échanger très tôt au cours de leur développement. Dès la seconde année de vie, ils comprennent que s'engager dans une transaction peut leur être bénéfique. Il est probable que leurs performances s'affinent en grandissant et qu'ils développent des compétences additionnelles leur permettant de maximiser leur bénéfice lors de situations économiques plus complexes. De nombreuses transactions sont en effet plus exigeantes qu'un échange immédiat dans le sens où elles supposent un délai. Cela est vrai par exemple pour des investissements à long terme ou des échanges de services qui peuvent être différés sur de longues périodes. Le contrôle de soi est nécessaire pour vivre en société, il procure aussi le temps nécessaire à la prise de décision et à l'attente d'un bénéfice. La présente étude a eu pour objectif d'évaluer la capacité des enfants à s'engager dans une transaction offrant un profit différé dans le temps. J'ai cherché à déterminer à quel âge les enfants peuvent intégrer le temps d'attente et contrôler leur impulsivité en fonction de la valeur de la récompense espérée : leurs performances sont-elles proportionnelles à la dimension de la récompense, et le partenaire d'échange a-t-il une influence sur leur décision?

J'ai testé des enfants âgés de 2 à 4 ans dans deux tâches d'échange de nourriture. Les enfants recevaient un petit morceau de biscuit, puis ils avaient l'opportunité d'attendre durant une période de temps déterminée avant de l'échanger pour une plus grande quantité de biscuit qui pouvait être égale à deux, quatre, ou huit fois la quantité du premier item. Le délai imposé entre le don du petit morceau de biscuit et le retour de la récompense variait de 5 s à 4 mn. Les enfants âgés de 3-4 ans ont soutenu des délais d'attente plus longs pour les récompenses les plus importantes (8 fois la quantité de l'item initial), comparé aux plus petites récompenses (2 et 4 fois la quantité). Un tel effet de la quantité n'a pas été mis en évidence chez les 2 ans. Dans le but de déterminer le délai maximal pouvant être toléré par les enfants, je leur ai ensuite proposé d'attendre entre 4 et 16 min afin d'obtenir une récompense égale à quarante fois la quantité du premier item. Tous les enfants ont augmenté leur temps d'attente lorsque la récompense proposée était 40 fois plus importante que l'item initial. Certains 2 ans (deux enfants sur 24) ont été capables de tolérer des délais allant jusque 16 min mais ce sont surtout les enfants plus âgés qui se sont avérés plus performants. L'analyse du temps de renoncement a permis de montrer que les enfants plus âgés prenaient leurs décisions plus rapidement, indiquant une anticipation de la durée d'attente et la prise en compte de la valeur des récompenses dans leur prise de décision. Par ailleurs, des stratégies de distraction ont été observées durant l'attente chez les enfants plus âgés. Il semblerait enfin que la présence du partenaire ait un impact positif en augmentant la tolérance à l'attente.

De jeunes enfants se montrent capables de différer le retour d'une récompense alimentaire pendant plusieurs minutes. L'augmentation des performances en fonction de l'âge est en accord avec le développement de l'aptitude à contrôler leur impulsivité et à évaluer le temps d'attente en fonction de la valeur de la récompense. Des stratégies d'attente plus efficaces pourraient également expliquer cette amélioration. De très jeunes enfants ont su contrôler leur impulsivité malgré leur difficulté à faire face à une perspective temporelle imprécise ; il semble donc que le contrôle de soi soit maîtrisé par les enfants avant même qu'ils intègrent la dimension temporelle de la tâche. Malgré l'effet de l'âge, je n'ai pas pu établir ici la limite maximale de la durée d'attente, ce qui révèle chez l'enfant des capacités meilleures que celles de primates non humains testés dans la même tâche.

The Ability of Children to Delay Gratification in an Exchange Task

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Abstract

The ability to wait for a reward is a necessary capacity for economic transactions. This study is an age-related investigation of children's ability to delay gratification in an exchange task requiring them to wait for a significant reward. We gave 252 children aged 2 to 4 a small piece of cookie, then offered them an opportunity to wait for a predetermined delay period before exchanging it for a larger one. In a first experiment, the children had to exchange the initial food item for rewards two, four or eight times larger. Results showed that children aged 3 to 4 years old sustained longer time lags for larger rewards than for smaller rewards. This effect was not found in 2-year-old subjects. In a second experiment, a reward 40 times larger than the initial piece was offered to determine the maximum waiting time that children could sustain. All age groups increased their performances. Older children were more successful at waiting, but some children as young as 2 years old were able to tolerate delays of up to 16 min. Older children who chose to give up waiting earlier than their known capacity demonstrated anticipation skills which had not been seen in younger children, showing that they had anticipated an increase in the time lag, and that they had considered both time and reward value when making their decision. Despite the age effect, we did not establish any limits for delaying gratification in children. This study may have educational implications for dealing with behavioral misconduct, which is known to be related to impulsivity control in young children.

Keywords: Decision-making; Delay of gratification; Exchange; Economics; Children

1. Introduction

The ability to control impulsive behaviors is an important feature of culturally suitable conduct, and is necessary for societies to function successfully. How individuals exert self-regulation clearly depends on their ability to control their behavior in order to obtain a given reward at some time in the future. In everyday life, the ability to delay benefits can help individuals make optimal decisions when facing a choice. The decision to wait or persevere when facing a delay is often oriented by future interests that guide decisions (Kacelnik, 2003; Mischel, 1974). This is particularly true for economic transactions in which individuals can wait months to obtain larger monetary rewards (Putnam, Spritz, & Stifter, 2002; Rachlin, Raineri, & Cross, 1991; Tobin & Logue, 1994). Such control over impulsivity makes human adults stand out compared to non-human animals (Logue, Peiia-Correal, Rodriguez, & Kabela, 1986; Tobin, Logue, Chelonis, Ackermann, & May, 1996) in which self-control is often shown to be limited (Mazur, 1987; Richards, Mitchell, de Wit, & Seiden, 1997; Stevens, Hallinan, & Hauser, 2005; Szalda-Petree, Craft, Martin, & Deditius-Island, 2004; Tobin et al., 1996). In humans, failure to control impulsivity has been related to numerous behavioral problems, including substance abuse (Madden, Petry, Badger, & Bickel, 1997), risky sexual behavior (Wulfert, Safren, Brown, & Wan, 1999), aggression and violence (Baumeister, Heatherton, & Tice, 1994; Cherek, Moeller, Dougherty, & Rhoades, 1997; Mischel, Shoda, & Rodriguez, 1989). This suggests that limited self-control may be at the core of problems affecting social relationships. The ability to understand how far patience can be rewarded probably involves slow maturing cognitive skills that may be critical for our acquisition of economic behaviors. However, information about the developmental stages involved in this maturation process is scant. More specifically, we do not know to what extent children take into account time and control over impulsivity when evaluating whether a reward is worth waiting for or not.

In economics, the ability of adult humans to wait is usually tested under conditions in which participants can either consume immediately or delay consumption in order to have larger amounts (discounting). Economics usually consider that time preference is related to how large a reward is, and whether it is close enough in time to bring more well-being than a more distant gratification. The size of this reward is an important question with regard to the time value of money (Ramsey, 1928). For example, when waiting time increases over several days or weeks for a mildly interesting reward, adults and adolescents chose more immediate rewards (Hyten, Madden, & Field, 1994; Mischel & Metzner, 1962; Strayhorn, 2002; Wulfert, Block, Santa-Ana, Rodriguez, & Colsman, 2002). In another version of this delayed choice task, 5-year-old children can wait for several minutes when the options are to either receive one sticker immediately or two stickers at the end of the game. Three-year-old children chose the immediate reward whatever the delay (Thompson, Barresi, & Moore, 1997) although at this age they can wait several minutes for the experimenter to return before opening a gift box (Vaughn, Kopp, & Krakow, 1984). In comparison, 18-month-old children cannot resist the temptation to touch a toy (Kochanska, Coy, & Murray, 2001; Vaughn et al., 1984). Several studies have identified a limited self-control ability in younger children that hinders their capacities to succeed in delaying gratifications. Contextual factors affect the willingness or capacity to wait in children (Forzano & Logue, 1995; Mischel, 1974). Children accept longer delays if the reward is not visible (Eigsti et al., 2006; Kochanska et al., 2001; Mischel et al., 1989; Peake, Hebl, & Mischel, 2002; Vaughn et al., 1984), when they are instructed to think about the properties of the delayed reward as a non-edible item or in a negative way (Metcalfe & Mischel, 1999; Mischel, Cantor, & Feldman, 1996; Mischel et al., 1989; Patterson & Mischel, 1976; Toner, Lewis, & Gribble, 1979), when they verbalize about rightness or wrongness of actions (Toner & Smith, 1977; Toner et al., 1979), and when they distract themselves or are provided with distraction during the delay (Cournoyer & Trudel, 1991; Miller & Karniol, 1976; Mischel, 1974; Mischel & Ebbesen, 1970; Mischel, Ebbesen, & Zeiss, 1972; O'leary, 1968; Toner & Smith, 1977). Thus, when children are given adequate means to refrain from impulsivity, their performances in such tasks increase. Similar findings on the ability to direct attention away from the delay are obtained in non-human primates (i.e. self-distracting strategies in chimpanzees; Evans & Beran, 2007). Moreover, although they tend to have poor control over impulsivity in classic tasks involving delay of gratification, they are able to accept longer waits in food exchange paradigms (Dufour, Pelé, Sterck, & Thierry, 2007; Pelé, Dufour, Micheletta, & Thierry, 2010; Pelé, Micheletta, Uhlrich, Thierry, & Dufour, 2011; Ramseyer, Pelé, Dufour, Chauvin, & Thierry, 2006). Such means could be necessary to improve the quality of their decision in a trading situation, especially for the youngest children, whose self-control and anticipation abilities are not yet fully matured (Logue & Chavarro, 1992; Logue, Forzano, & Ackerman, 1996; Vaughn et al., 1984).

In addition to self-control, children probably also need cognitive maturation to accurately calculate the relative value of the food to be obtained according to the time needed to obtain it. Children are known to differentiate between several foods of different values from their first year of life; they can make 'more' and 'less' value judgments about discrete quantities (Brannon, 2002; Butterworth, 2005; Feigenson, Dehaene, & Spelke, 2004; Feigenson, Spelke, & Carey, 2002; Lipton & Spelke, 2004; Xu, 2003). With regard to time understanding, children's skills develop slowly with age (Atance & Meltzoff, 2005). At the age of 3, children understand the duration of their personal experiences (Droit-Volet, 1999; Droit-Volet & Gautier, 2000), but they are still unable to visualize a temporal distance between two events in which they are not involved (Droit, 1995a,b; Droit-Volet, 1999; Macar, 1988). It is only from around the age of 4 or 5 that they can temporally differentiate between future events, and accurately discriminate temporal distance of past events (Atance & O'Neill, 2001; Friedman, 2000, 2005; Friedman & Kemp, 1998). Judging whether or not a reward is worth waiting for could therefore be a difficult task for children.

As seen in human adults, common economic situations often involve an active partner and mutual agreements. On the one hand, implicit or explicit agreements may lead each partner to assume that the other side will be trustworthy. On the other hand, one might be wary of the behavior displayed by a non-familiar partner. In previous delay-of-gratification tasks run with children, the potential influence of the experimenter on children's decision to wait is often removed, and children are left alone in the testing room (Mischel, 1974; Mischel et al., 1989). Yet the presence of a partner could mimic the social component usually involved in an economic transaction. The involvement of the partner in the task, however neutral, could make the conclusion of the transaction less certain and lead children to avoid the risk of losing what they have already obtained. Decision-making in face-to-face transactions requires children to detect the partner's reliability by anticipating potential cheating. Whilst children are able to understand both the goals and intentions of others develops during the two first years of life (Eckerman, Whatley, & Kutz, 1975; Tomasello, 2007; Tomasello, Carpenter, Call, Behne, & Moll, 2005; Warneken & Tomasello, 2007; Warneken, Chen, & Tomasello, 2006), they may not recognize untrustworthy or dishonest partners before the age of 4, where they start to see others as mental agents possessing beliefs and thoughts different from their own (Gopnik & Astington, 1988; Perner, 1991; Sullivan & Winner, 1993; Tomasello & Rakoczy, 2003; Wellman, 1990).

In this paper we tested children in a delayed food exchange task in order to detect the full extent of children's ability to wait for a reward, and the influence of the partner in this process. We expected age-related performances depending on how children perceive the presence of partner and calculate whether a reward is worth waiting for. Data acquired through the use of this experiment with non-human primates (Dufour et al., 2007; Pelé et al., 2010, 2011) may allow us to highlight the constraints experienced by children, and their relative scores compared to animals. The task consists of giving children aged between 2 and 5 years a small initial food item, then offering them the opportunity to wait for a predetermined time lag to receive larger rewards. In the first experiment, children can return a small piece of cookie to an adult to receive another reward differing in quantity. In a second experiment, a reward 40 times the quantity of the initial piece is offered to determine the maximum sustainable time lag for children.

2. Methods

2.1. Participants and conditions

Participants were 252 children (126 males and 126 females) aged between 2 and 5 years. Table 1 summarizes the children's characteristics. Equal numbers of girls and boys were separated into three age groups for tests: 2, 3 and 4 years old. Five additional children whose parents had given consent were excluded from the dataset analyzed: three were outside the appropriate age ranges, and two failed the training procedure (see Exchange procedure for details). Participants were European, from middle-class backgrounds, and spoke English as their first language. Eleven children had already participated in previous experiments and were familiar with the exchange procedure (Steelandt, Thierry, Whiten, Broihanne, & Dufour, submitted).

Table 1. Characteristics of children in Experiments 1 and 2

		Age		Sex		Sibling status	
	N	Age (years)	Mean (months)	Male	Female	Sibling(s)	No sibling
Experiment 1	60	2	28.9	30	30	32	28
N = 180	60	3	41.1	30	30	40	20
	60	4	53.5	30	30	39	21
Experiment 2	24	2	28.7	12	12	10	14
N = 72	24	3	40.9	12	12	16	8
	24	4	52.7	12	12	17	7

The experiment took place at the 'Living Links to Human Evolution' Research Centre in Edinburgh Zoo. Ethical authorization to work with children was given by the University of St Andrews ethics committee, UTREC (reference n°PS5528). Children were recruited upon their visit to the zoo. A letter and an information sheet describing the general purpose of the study were given to the parents, who all gave signed consent for their child's participation. No remuneration was offered, but children received the sweets they gained during the testing session. Additional information on whether children had siblings or twins was also recorded.

The test was conducted in a small area (2.5 m x 2 m) limited by four screens allowing complete visual seclusion from the public. The child was individually tested while seated on a chair or on his/her parent's lap in front of a square table (1 m x 1 m). Sitting on parent's laps occurred in three 2-year-olds. A video camera recorded the session with prior written consent to video the child.

2.2. Exchange Procedure

The children did not know the experimenter. Before testing, the experimenter introduced herself to the child to put them at ease. Parents were instructed not to interfere by initiating communication or interactions during testing. Parents were instructed to draw the child's attention back to the experimenter if their child sought to interact with them, without directing her/his response or give any hints of what s/he was supposed to do. Parents were careful to apply these directives by staying motionless throughout the session, making experimental conditions similar between children tested alone and those sat on parent's laps. If the child wanted to interact with the experimenter, the latter repeated the instructions but remained as neutral as possible. Children sat on a chair opposite the experimenter during testing.

The experiment lasted approximately 20 minutes. Before testing, each participant was asked to select a preferred food item among different types of cereals ("cookies" in the following). The child was then given the choice between a small piece of the preferred cookie and a larger piece of it (the reward). Each child selected the larger reward. During testing, an empty plastic box, turned upside down, was placed close to the child and was left untouched throughout the waiting period. For each trial, the experimenter presented the initial piece of cookie in one hand and the larger reward in the other. The experimenter then gave the small piece of cookie to the child and offered him/her a possibility to acquire more: "You can eat the small cookie now, or you can wait a while to have the larger reward. If you put the piece of cookie into the box when I turn it over, I will give you the larger reward". The larger reward remained visible in the experimenter's hand throughout the time lag. At the end of the waiting period, the experimenter turned the empty box over, still presenting the reward in the other hand. If the child gave back the small piece of cookie by putting it into the box, s/he received the larger reward. If the child did not give back the initial piece at the end of the time lag, the experimenter did not reward the child and moved away the hand containing the reward, thereby ending the trial. Whenever children nibbled or ate before the end of the time lag or refused to give the cookie back at the end of the time lag, the experimenter moved the hand holding the larger reward away, saying "OK, you can eat/keep the piece of cookie. If you had given me the piece of cookie, you would have had the larger reward, do you remember?" Children who had not eaten the cookie by the end of the trial were given a plastic bag to store the cookies they had obtained before starting a new trial. Trials were separated by 10 sec intervals. The experimenter maintained a friendly demeanor throughout the trial intervals but remained as neutral as possible during the waiting period of the tests.

Prior to testing, the experimenter completed a demonstration of the procedure with a 5-sec time lag (for a reward twice the quantity of the initial item) as she gave the instructions. The child was then tested over the 5-sec time lag. If the child did not return the piece of cookie after the elapsed time, s/he was tested once more. Children who failed again were not tested further. Only two children of 2 years of age were unsuccessful with the 5-sec time lag, and were henceforth removed from the dataset. The other children who met this criterion were then involved in a succession of trials, with time lag ranging from 15 sec to 16 min depending on the experiment. Throughout the experiments the partner did not ask direct questions after each trial about the children's understanding of the task or their perception of the waiting duration, as this could have biased the children' responses in subsequent trials. The involvement of 2-year-old children also meant that instructions had to be kept to a minimum.

2.3. Procedure for Experiment 1

In Experiment 1 we tested whether the duration of the waiting period sustained by children would vary according to the value of the food items being offered. For each trial, the experimenter presented the initial piece of cookie in one hand and two, four or eight pieces of cookies in the other (the reward). After the 5-sec time lag demonstration, children took part in a succession of five trials with a time lag that increased gradually from one trial to the next:

15 sec, 30 sec, 1 min, 2 min, and 4 min. We recorded the failure to return the initial piece of cookie, the type of error, the timing of error (time elapsed after the beginning of the trial in seconds). The children's behavior during the waiting period was also noted.

2.4. Procedure for Experiment 2

Experiment 2 aimed to assess whether the time lags reached in Experiment 1 were maximal delays for each age group, or whether children could sustain longer waiting periods when increasing the final pay-off had been increased. Children tested in Experiment 2 were not the same as children tested in Experiment 1. After the 5-sec time-lag demonstration, children took part in a succession of three trials which differed in both the time lag tested and the quantity of the final reward: 30 sec for four pieces of cookie, 2 min for eight pieces of cookie, and 4, 8 or 16 min for 40 pieces of cookie. Children were divided into three groups that were randomly assigned to one of the three longer time lags. The increased duration of the time lag was set up in order to give children a chance to anticipate the longer waiting periods. The procedure was the same as in Experiment 1, except that the 40 pieces of cookie were placed on a round plastic lid (diameter 10 cm) held in the experimenter's hand. As in Experiment 1, we recorded the success, timing, type of error made by children and their behavior.

2.5. Statistical analysis

We used generalized linear models with a binomial distribution and a logit (respectively Poisson and log) link function to assess whether age, sex (1 for boys and 0 for girls), sibling status (a value 1 was attributed to children with siblings, 0 to only children), quantity of cookie and time lag could influence children's propensity to wait (value 1 for successfully waiting during the entire duration of the time lag at a given trial and then returning the initial item, 0 for failure to wait until the end of the time lag and eating or keeping the initial item) in Experiments 1 and 2.

An additional analysis using a generalized linear model (binomial distribution and a logit link function) was run on the error time, i.e. the time at which children gave up waiting in the failed trials. The reasoning behind the analysis was to detect whether children failed because they reached a limit in their waiting capacity, or because they judged that waiting for a given time lag was simply not worth it. We therefore checked whether the children who were able to succeed in the 2-min test stopped earlier than their known capacity when giving up during the next, longer trial (at the 4-min time lag in Experiment 1, and at 4-, 8- or 16-min time lag in Experiment 2). We hypothesized that if they could anticipate an increase in the time lag at each trial, i.e. that the next trial should be longer than the immediately preceding one (2 min), they could thus stop significantly earlier than their known capacity of 2 min. The analysis was only conducted for children who had successfully passed the previous trial involving a 2-min time lag, but who had failed at the next longer time lag. The error time was expressed as the percentage of time elapsed according to the total time lag in the trial.

We used another generalized linear model to determine whether different strategies adopted by the children helped them succeed at longer time lags. In a first analysis, the value 1 was attributed when children used distraction to divert attention from waiting and from the reward (including touching, playing with, tasting or pretending to taste the piece of cookie, talking with the parent, playing alone), and the value 0 when they adopted passive waiting (including holding the piece of cookie during the waiting period, looking elsewhere, or looking at the piece of cookie, the reward or the experimenter). In a second analysis, we distinguished each strategy more specifically according to whether they were treat-focused (looking at or manipulating the piece of cookie including touching, playing with it, holding, tasting or pretending to taste it) or not (looking at the experimenter or elsewhere, playing alone, talking with the parent). When different strategies were used during the waiting period we considered the one that lasted the longest according to the total percentage of waiting time. These analyses were only conducted for trials where children waited for a minimum of 3 sec during the trial.

Average values are given as means and standard error of the mean. The significance level was set as 0.05.

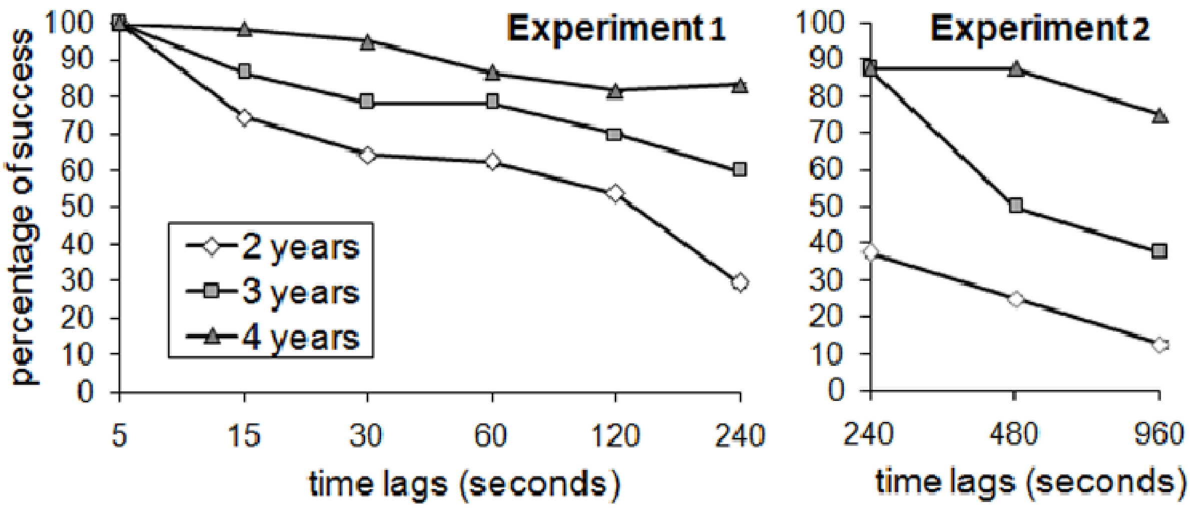

Fig.1. Percentage of successful children for each age in Experiment 1 (all sizes of cookies combined) at each time lag (from 5 sec to 4 min; left panel) and Experiment 2 (when the reward was 40 times the quantity of the initial item) at each time lag (from 4 to 16 min; right panel).

3. Results

3.1. Percentage of successful return

In Experiment 1, most children were able to delay rewards at the 15 sec, 30 sec, 1 min, 2 min and 4 min time lags, albeit at lower percentages with the longer time lags of 2 and 4 min (Fig. 1). Age (GLM, $z = 2.1$, $p < 0.001$), quantity of cookies (GLM, $z = 1.5$, $p < 0.01$), and time lag (GLM, $z = 3.5$, $p < 0.001$) affected the success of children. Two-year-olds failed more often in exchanging (percentage of success = 59.9%) than those aged 3 (74.7%, Tukey's test, $p < 0.01$) and 4 (89.0%, Tukey's test, $p < 0.001$). Children reached a significantly higher level of return for the largest cookies than for the smallest quantity cookies (2-fold quantity: 71.6% success rate; 8-fold quantity: 77.0%; Tukey's test: $p < 0.05$). We observed that more children were successful in exchanging for the 15-sec time lag (86.5%) than for the 30 sec (79.2%, Tukey's test, $p < 0.01$) and longer time lags (all: 67.3%; Tukey's test, $p < 0.001$ for all comparisons). The percentage of children who exchanged the initial item at 30 sec (79.2%), 1 min (75.8%) and 2 min (68.5%) was significantly higher than those who exchanged at 4 min (57.6%, Tukey's test, $p < 0.001$ for all comparisons). Also, children with siblings were more successful than only children (74.6% vs. 69.2%; GLM, $z = 1.7$, $p < 0.05$). For time lags of 1, 2 and 4 min, children aged 3 and 4 years were better at exchanging when the largest quantity of cookie (8-fold) was offered in return (GLM triple interaction age x quantity x delay, $z = 1.2$, $p < 0.05$; Fig. 2). This effect was not observed with the 2-year-old children (Fig. 2).

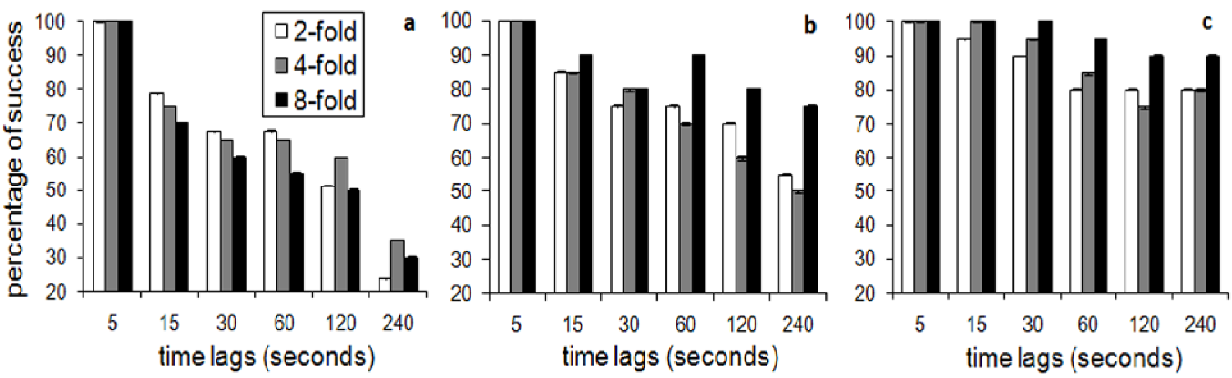

Fig.2. Percentage of successful children aged of 2 (a), 3 (b) and 4 years (c) for each quantity of cookie (2, 4, and 8 times the quantity of the initial piece of cookie) at each time lag (from 5 sec to 4 min) in Experiment 1. Error bars represent standard errors of the mean.

To ensure that the reward was attractive enough, it was increased in Experiment 2 to 40 times the quantity of the initial piece of cookie. The time lags tested then reached 4, 8 or 16 min. Only 55.6% of children tested successfully waited for 16 min. The percentage of children succeeding for the 4-min time lag increased in comparison with Experiment 1, especially for children aged 2 (Experiment 1 vs. 2 = 30.0% vs. 37.5% of success) or 3 (61.7% vs. 87.5% of success; Fig. 1). Age (GLM, $z = 16.4$, $p < 0.001$) and time lag (GLM, $z = 6.0$, $p < 0.05$) affected the success of children. The percentage of successful children significantly decreased for the 16-min time lag in comparison with the 4-min time lag (41.7% vs. 70.8%, Tukey's test, $p < 0.05$). Failure to exchange was more frequent in 2-year-olds than in children aged 4 (25.0% vs. 83.3%, Tukey's test, $p < 0.001$). Only two 2-year-olds succeeded at 16 min.

3.2. Timing of error

The results showed that the age of children affected the timing of error in every failed trial in Experiment 1 (GLM, $z = 6.0$, $p < 0.01$) and 2 (GLM, $z = 11.5$, $p < 0.001$). Children aged 4 gave up waiting earlier (after 4.2% of the delay in Experiment 1, 2.4% in Experiment 2) than children aged 2 (after 24.4% in Experiment 1, 17.9% in Experiment 2, Tukey's test, $p < 0.01$) and 3 (after 21.2% in Experiment 1, 52.1% in Experiment 2, Tukey's test, $p < 0.001$). Figure 3 presents the timing of error in children who had successfully waited for at least 2 min but failed at the next time lag. If children were able to anticipate that the time lag would increase at each trial, they may have taken the decision to either wait or to give up earlier than their known capacity (2 min) to wait. This would then be illustrated by timing of error well below 2 min. This was observed in Experiments 1 and 2 for the 4-year-old children who gave up waiting before their 2 min capacity (giving up after 2.9% of the time lag in Experiment 1, 6.2% in Experiment 2). In 2- and 3-year-olds, giving up occurred after the threshold of 2 min was reached (2 years: after 50.3% of the time lag in Experiment 1, 50.2% in Experiment 2; 3 years: after 52.0% of the time lag in Experiment 1, 79.3% in Experiment 2).

To add more information about the decision mechanisms we also recorded whether children verbalized their choice with sentences such as "I wait/I eat it" in response to the experimenter's offer (to "either eat the initial item immediately, or wait a while to have more"). When considering the mean of all age groups together, records indicate that 46.0% and 26.1% verbalized their decision in Experiments 1 and 2 respectively. In Experiment 1, 2- and 3-year-old children verbalized significantly less often than the mean (Binomial test, 2 years: 15.8%, $p < 0.001$; 3 years: 41.7%, $p < 0.01$) contrary to the 4-year-olds who verbalized more often (Binomial test, 80.0%, $p < 0.001$). In Experiment 2, 2-year-old children verbalized significantly less often than the mean (Binomial test, 3.3%, $p < 0.001$) contrary to the 3- and 4-year-olds who verbalized more often (Binomial test, 3 years: 35.0%, $p < 0.001$; 4 years: 40.0%, $p < 0.001$).

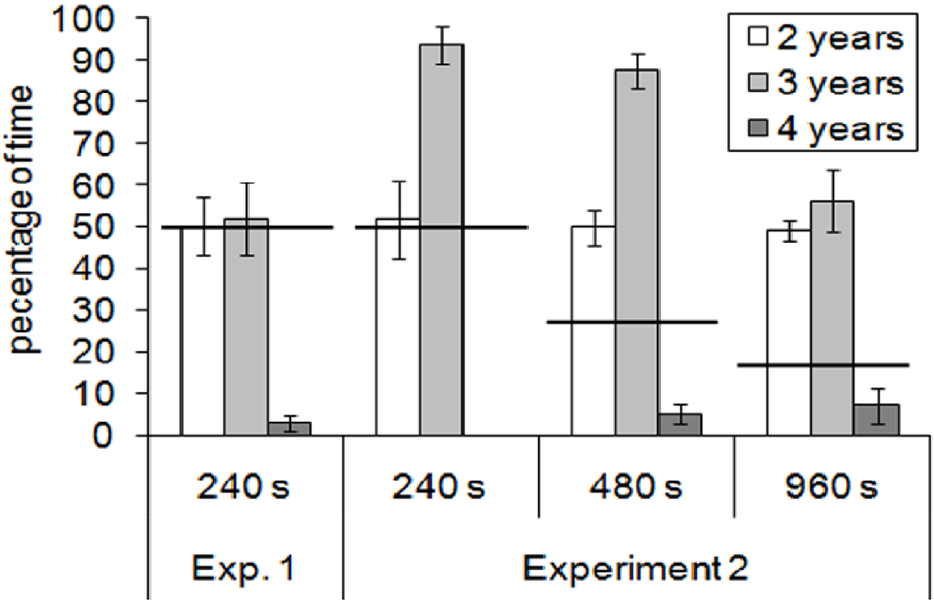

Fig.3. Mean error time (expressed as the percentage of time elapsed before giving up according to the total time in the trial) at each age in Experiment 1 for 4-min time lag (all sizes of cookies combined) and Experiment 2 for 4-, 8- and 16-min time lags. We considered only children who succeeded in delaying gratification for 2 min but failed at the next time lag. The children's decision to give up earlier than their known capacity to wait (2 min) is represented by a timing of error below the limit of 2 min (black bars). Error bars represent standard errors of the mean.

3.3. Waiting strategies

In Experiment 1, children who distracted themselves during the waiting period often exchanged more successfully (percentage of success: 75.3%) than children with a passive attitude during waiting (24.7%) (GLM, $z = 1.6$, $p < 0.001$). We observed an effect of the interaction between the age and the strategy used by children on success in both Experiment 1 (GLM, $z = 2.0$, $p < 0.01$) and 2 (GLM, $z = 1.1$, $p < 0.01$). The older the children were, the more distractive strategies were used (including touching, playing with, tasting or pretending to taste the piece of cookie, talking with the parent, playing alone), leading to higher success rates (mean success for distractive strategies from 2- to 4-year-olds: 46.2% to 75.1% in Experiment 1, 19.8% to 62.5% in Experiment 2; Fig. 4). The results also showed that the "not treat-focused" strategies improved the success of children in Experiment 2 compared to the "treat-focused" strategies (GLM, $z = 3.1$, $p < 0.01$). This was more specifically the case for the strategy "talk with the parent" (percentage of success for all ages = 55.2%; Tukey's test, $p < 0.01$) and "play alone" (41.7%; Tukey's test, $p < 0.01$; Fig. 5).

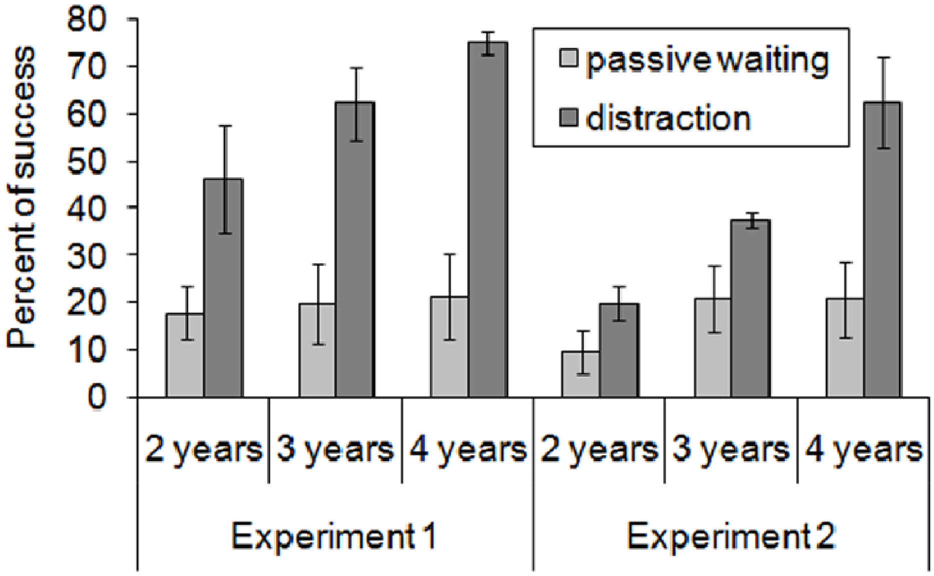

Fig.4. Distractive and passive waiting strategies used in Experiments 1 (all sizes of cookies and all time lags combined) and 2 (4-, 8- and 16-min time lags combined) at each age. Trials where children failed by eating the initial item before 3 s had elapsed were removed from this analysis. Error bars represent standard errors of the mean.

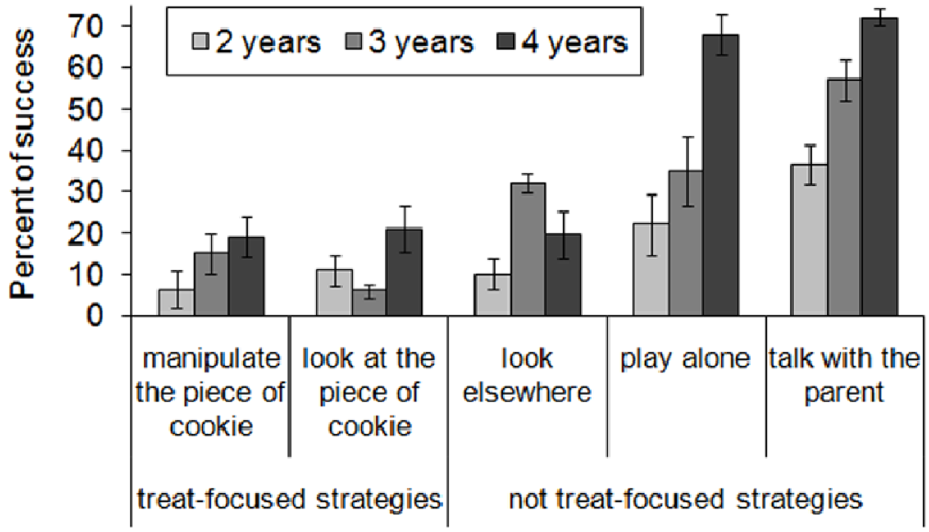

Fig.5. Treat-related strategies in Experiment 2 (all sizes of cookies and all time lags combined) at each age. Trials where children failed by eating the initial item before 3 sec had elapsed were removed from this analysis. Error bars represent standard errors of the mean.

4. Discussion

Children aged 3 to 4 years accepted longer time lags for the largest rewards. This quantity effect was not found in 2-year-old children. Still, all age groups succeeded more when the delayed reward was 40 times larger than the initial item. Older children successfully waited for up to 16 min, and although rarely observed, waiting this long was also within the reach of children as young as 2 years old. Older children chose to give up waiting earlier than younger ones, indicating a better anticipation of the increase in the time lag. Contrary to previous works concerning delay of gratification (see Silverman, 2003), no difference was found according to sex.

The performances of 2-year-old children in waiting were lower whatever the time lag compared to older age groups, and no improvement was obtained by increasing the quantity of reward to eight-fold the initial item. It is unlikely that these performances were due to a lack of numerosity discrimination. Before the age of 2, children easily differentiate small food quantities of up to about three items (Butterworth, 2005; Feigenson et al., 2002), and recognize larger quantities above four items, albeit in an imprecise way (Brannon, 2002; Feigenson & Carey, 2000; Feigenson et al., 2002, 2004; Lipton & Spelke, 2004; Strauss & Curtis, 1984; Xu, 2003; Xu & Spelke, 2000). It can be noted that, before testing, all children selected the largest of two options (one versus several pieces of cookie) when no delay was involved. Thus, failure in younger children was not due to a lack of preference for larger rewards, but could rather be explained by a difficulty to control the impulse to eat the item in their possession during the waiting period. One explanation is that immaturity in executive functions including memory, causal reasoning, and more specifically inhibition of immediate choice (Carlson & Moses, 2001), impaired decision quality. Young children generally find it difficult to resist temptation (Kochanska et al., 2001; Vaughn et al., 1984). Failure to continue waiting after several minutes (as mostly observed in our study) showed that young children are capable of controlling themselves to some extent, but this control is not limitless. A second possibility in line with cognitive changes in the preschool period (Olson, 1993) is that younger children lack the capacity to compare the immediate situation with the possible future situation. Integrating the temporal element of the task may be difficult as young children may only have an imprecise understanding of time at their disposal compared to older children (Lemmon & Moore, 2001). Two-year-old children can imagine and talk about themselves in the future, but previous studies reveal that they do not understand the connection between the present and the future, and how current events affect future ones (Harner, 1976; Lemmon & Moore, 2007; Poole, Miller, & Church, 2006). When offered rewards 40 times higher than the initial item in Experiment 2, however, some children as young as 2 years old tolerated time lags of up to 16 min, showing that they could, to some extent, act in their best future interest.

Children aged 3 and 4 were more capable of adjusting their waiting durations to the quantity of rewards. They sustained longer time lags for the largest quantity of food. The group of 4-year-olds contrasted with the 3-year-olds, as the former could give up early in the trial despite a known capacity to wait for longer. Giving up or continuing to wait appears to result from a decisional process as the 4-year-olds also verbalized about their intention. They anticipated that there would be some delay, and decided early on whether the reward was worth it or not. For them, failure to wait was probably less related to limited self-control than in younger children. From around the age of 4, children have temporal appreciation of the self in the past and future (Friedman, 2000, 2003; Lemmon & Moore, 2001; Povinelli, 2001). Their episodic memory, one of the executive functions necessary to mental time travel into the past and future (Tulving, 2005), is also more mature than in younger children (Nelson, 1993; Perner & Ruffman, 1995). The notion of time in 3-year-olds may differ from that of older children (Droit, 1994, 1995a,b; Friedman, 1990). Here, they did not anticipate the duration of the expected delay for as clearly as the 4-year-olds could have done, but they succeeded more often than the 2-year-olds at waiting throughout the time interval. This indicates improved self-control compared to the youngest children, which may also be illustrated by the time of error results (see Fig. 3). Indeed, when trying to wait, 3-year-olds tended to fail later on in the task than the youngest children. Interestingly, several studies showed that better self-control is linked to a higher ability to estimate time intervals (Darcheville, Riviere, & Wearden, 1992; Levine & Spivack, 1959; Siegman, 1961). The combination of both factors may impede the success of 2- and 3-year-olds while facilitating the success of older children. The ability to take future interest into account to guide current decision is also related to the ability to engage in causal reasoning at around 4 years (Das Gupta & Bryant, 1989; Mitchell & Riggs, 2000). In our delay-of-gratification task, older children were probably able to reason about current and future rewards, i.e. “If I eat one piece of cookie now then I will not have two later”, and thus be able to make the optimal decision.

When observing the behavior of children during the waiting period, we found that children who diverted their attention were better at delaying gratification than those waiting passively. Treat-focused distractive strategies were, however, less efficient than distractive behaviors which were not focused on the initial item, such as talking with parents and playing alone. Treat-focused strategies were shown to hinder delay in previous studies (Metcalfe & Mischel, 1999; Mischel & Ayduk, 2004; Mischel et al., 1972) where increasing success was achieved by spontaneous or instructed distraction (Miller & Karniol, 1976; Mischel et al., 1972, 1989, 1996; Toner & Smith, 1977). Language progress is closely related to children’s increasing capacity to delay gratification (Vaughn et al., 1984). Vygotsky (1962) demonstrated that private speech, a mental tool commonly used for guiding and managing thought and behavior, follows a developmental pattern until the age of 6-7. We noted that the 3- and 4-year-olds verbalized their choice, saying “I wait/I eat it”, helping them to focus and maintain their attention more efficiently than younger children. This result was also found in other studies (Coates & Hartup, 1969; Flavell, Beach, & Chinsky, 1966; Fuson, 1979; Meichenbaum & Goodman, 1971). The age effect found in previous experiments regarding the use of other distractive strategies (Mischel & Mischel, 1983; Yates, Yates, & Beasley, 1987) is also corroborated in this delay-of-gratification task as older children diverted their attention more frequently, leading to a higher success rate. Interestingly, previous work reported that 4-year-olds were not as good as 8-year-olds in using distractive methods (Yates et al., 1987). Our results show that children as young as 4 years old were better at adopting strategies helping them to cope with impulsivity than previously found. Few 2-year-olds, however, used efficient distracting strategies, confirming that it is difficult for young children to recognize the efficiency of distraction to facilitate waiting (Johnson & Kopp, 1981). Interestingly, having siblings in the family is another factor that is positively correlated to an increased tolerance to delay. It is known that the presence of siblings can be related to an enhancement of intellectual development, creative potential (Albert & Runco, 1989; Cicirelli, 1975; Runco & Bahleda, 1987), autonomy and skills in persistence (Jiao, Ji, & Jing, 1986; Miller & Maruyama, 1976). This improved efficiency was also detectable in our experimental set up. It may be noted that bargaining is an integral part of social games between siblings, allowing them to gain experience in exchanging earlier than only children.

In a study carried out by Lemmon and Moore (2007), children aged 3 selected the immediate sticker reward more often when offered a choice between one sticker now and two or four later. Although these results are not directly comparable with ours due to differences in procedures, the fact remains that children accepted to wait in our study. In some respects, it could be expected that our task was more challenging as it involved refraining from eating a food item from the very beginning of the transaction; nevertheless, more than half the children successfully waited for at least 2 min. It is likely that the social component of this exchange task, i.e. engaging in bartering with a partner, had a positive impact on the children's tolerance to delay. It would be worthwhile to test children in a food exchange paradigm that does not involve a social component, but use the same ratios and time lags, with automated procedures for instance. As they get older, children are encouraged to be prosocial and patient (waiting their turn during school activities, waiting for the end of the meal to have a cookie). Most theories about bargaining also state that potential punishment increases cooperation in mutually rewarding exchanges (Molm, 1994, 1997). Two-year-old children only start experiencing negative consequences when rules are transgressed (Dunn, 1988), thus older children should be more inclined to do what a partner expects of them in the hope of avoiding potential retaliation or punishment. There is also some evidence that the ability to make future-oriented decisions is associated with the development of a theory of mind (Moore, Barresi & Thompson, 1998). For instance, Moore and Macgillivray (2004) reported that performance on standard theory of mind tasks in 4-year-olds was correlated with opting for delay. At around 4 years of age, children develop a parallel understanding of other individuals' beliefs and thoughts (Perner, 1991; Sullivan & Winner, 1993; Tomasello & Rakoczy, 2003; Wellman, 1990). This capacity is directly related to a better judgment of partner expectations. Thus, we cannot exclude that social factors such as the presence of a partner and the possibility of attributing mental states to her may largely affect children's performances in a delayed exchange task.

Given the long cognitive development necessary before children acquire the skills to successfully delay gratification, we expected similarities between their performances and those of non-human primates tested in the same task. Children aged 3 and 4 sustained long time lags significantly more often for the largest food items (eight times) than for smaller rewards, as previously reported for brown capuchin monkeys (Ramseyer et al., 2006) and chimpanzees (Dufour et al., 2007). Using behavioral strategies to cope with impulsivity, as we found in 3- and 4-year-old children, is not unique to humans since chimpanzees also used self-distraction in a variant of this paradigm (Evans & Beran, 2007). Besides, whereas 2-year-old children could not anticipate the duration of delays before exchanging, long-tailed macaques and chimpanzees appeared capable of doing so (Dufour et al., 2007; Pelé et al., 2010). Similarities exist between older children and non-human primates in the calculation of what value of reward is worth waiting for, anticipating the waiting period and using a waiting strategy, but only a small minority of the non-human primates tested could wait the full 16 minutes, a time-lag reached by most 4-year-old children.

The age-related performances found in this study are consistent with an increased ability to evaluate whether a reward is worth waiting for by taking both time and control over impulsivity into account (Kopp, 1982; Logue et al., 1996; Piaget, 1954; Vaughn et al., 1984), leading to optimal decision-making in older children. Given the delays we used, we did not reach the maximum limits of delaying gratification in children. Our study has nevertheless established that self-control is the first skill to be mastered by children before integrating the temporal element. In essence, this means that children can make early decisions about prospective rewards, and control their impulsivity even when faced with an uncertain or unclear temporal perspective. The ability to control impulsivity is a developmental process that has consequences not only for the individual but also for society in general (Baumeister et al., 1994). Children known to exert better self-control are also those who are seen to attain higher socio-educational levels (Mischel et al., 1989). Our study can help distinguish how far anticipation and impulsivity are involved in choices made by children. It could also have educational implications for designing support activities aimed at children aged 3 or more who show difficulties in focusing their attention and controlling their impulsivity. Adequate advice about the best strategies to solve such tasks could also help children in their school achievement. Reacting at an early stage in the school sector could help diminish later behavioral misconduct in adolescents and adults (alcohol, drug, violence, risky sexual behavior; Madden et al., 1997; Tangney, Baumeister, & Boone, 2004; Wulfert et al., 1999). Lastly, investigating whether the present results could have further implications in the context of hyperactivity disorders would be another significant line of development for research.

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CHAPITRE 5

LE CALCUL DU PROFIT DANS L'ECHANGE

SYNTHESE DE L'ARTICLE 3

L'aptitude des enfants à ajuster un investissement à travers le calcul du bénéfice

Article en révision pour *PloS ONE*

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Les enfants s'avèrent capables de contrôler leur impulsivité pour obtenir une récompense différée dans le temps. Ils peuvent ajuster le temps d'attente qu'ils souhaitent investir en fonction de la valeur de la récompense à obtenir. Pourtant, établir une relation entre la qualité de l'aliment à recevoir et le coût lié à l'attente n'est pas suffisant pour optimiser une transaction. Dans un échange, l'écart temporel entre le don et le retour n'engendre pas seulement un temps d'attente mais également un risque de perdre. Plus l'attente est longue, plus le partenaire est susceptible de modifier le contrat initial d'échange, de détériorer le bien ou ne rien retourner. Lorsque je compare mes résultats à ceux d'expériences passées, il semble que la présence du partenaire au cours de la transaction proposée et son engagement en tant qu'acteur actif de l'échange, ait un effet positif sur la tolérance à attendre des enfants. Si la dimension temporelle et le contrôle de l'impulsivité sont des éléments essentiels dans la maximisation d'une transaction, la composante sociale apparaît déterminante dans le choix d'investissement.

L'étude de la prise de décision des individus lors des interactions avec d'autres personnes est un sujet majeur de l'économie. La manière dont les enfants réagissent face au comportement d'un autre partenaire – souvent anonyme – est un domaine de recherche qui s'est beaucoup développé au cours de ces dernières années. Dans le réseau d'échange particulièrement dense que les sociétés humaines ont développé, il n'est cependant pas rare de devoir interagir simultanément avec plusieurs partenaires faisant des offres différentes et cela à partir de règles de décision opposées. On sait que les enfants ont les compétences nécessaires pour choisir, sur la base des interactions passées, le partenaire le plus fiable parmi plusieurs. En revanche, on ne dispose d'aucune information concernant leur capacité à optimiser leur bénéfice en calculant le montant à investir avec chacun des partenaires. La présente étude a pour but de tester la capacité des enfants à calculer leur investissement de façon optimale dans une situation économique. J'ai recherché l'âge auquel les enfants sont capables d'ajuster leur investissement en fonction des offres potentielles de différents partenaires.

J’ai étudié des enfants âgés de 3 à 10 ans dans une tâche expérimentale où des expérimentateurs retournaient des récompenses en quantités différentes. Chaque enfant recevait initialement 4 items alimentaires qu’il pouvait garder ou échanger. Le premier expérimentateur offrait le double de la quantité de bonbons initialement rendue par l’enfant tandis que le second offrait systématiquement une quantité maximale de bonbons quel que soit l’investissement initial de l’enfant. Pour maximiser leurs gains, les enfants devaient ajuster leur investissement de manière différente en fonction des expérimentateurs, en donnant le maximum de bonbons au premier et le minimum au second. Aucun enfant de 3 ans ne s'est révélé capable d’ajuster son comportement en fonction de l'expérimentateur. Ces derniers rendaient rarement tous les items et conservaient souvent au moins un bonbon. Près d'un tiers des enfants âgés de 5 ans et la presque totalité des 7 et 10 ans ont réussi à optimiser leur gain en suivant différentes règles de décision avec chaque expérimentateur ; ils ont rendu un maximum de bonbons à l’expérimentateur offrant le double de récompenses et un minimum à celui offrant toujours une quantité fixe et maximale de récompenses.

La capacité des enfants à calculer un investissement à partir de l’offre se développe essentiellement entre 4 et 7 ans. Avant cet âge, des mécanismes sociaux tels que le manque de confiance accordée à un partenaire étranger pourraient amener les enfants à se concentrer sur une évaluation de la fiabilité du partenaire plutôt que sur la transaction. Il apparaît d’ailleurs que des biais comme l’aversion à la perte puissent influencer leur prise de décision, les conduisant parfois à ne pas prendre des décisions optimales, au même titre que les adultes. Certaines capacités cognitives pourraient également être impliquées dans le développement des aptitudes à l’investissement : le développement de la théorie de l’esprit aiderait les enfants à juger plus efficacement la fiabilité et les attentes du partenaire d’échange ; l’entrée à l’école s’accompagne d’une amélioration des compétences numériques permettant probablement aux enfants de calculer plus précisément leur investissement en fonction des deux partenaires.

Children Base their Investment on Calculated Pay-off

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Abstract

To investigate the rise of economic abilities during development we studied children aged between 3 and 10 in an exchange situation requiring them to calculate their investment based on different offers. One experimenter gave back a reward twice the amount given by the children, and a second always gave back the same quantity regardless of the amount received. To maximize pay-offs children had to invest a maximal amount with the first, and a minimal amount with the second. About one third of the 5-year-olds and most 7- and 10-year-olds were able to adjust their investment according to the partner, while all 3-year-olds failed. Such performances should be related to the rise of cognitive and social skills after 4 years.

Keywords: decision-making; calculation; exchange; economics; children

Introduction

How individuals make choices in the context of interactions with other people is a major topic within economics, and thinking from this discipline has strongly influenced research on decision-making. Trading with multiple partners following different exchange rules is commonplace in the dense social exchange networks developed within human societies. When facing partners offering different expected pay-offs, investors are expected to optimize their satisfaction by adjusting their decision to the most rational choice [1]. Despite the increasing interest of economists in how adults and adolescents decide to invest according to the behavior of other persons [2], we still do not know how this ability appears and develops in an individual. No study to date has investigated the competence of children to calculate investment based on the offers made by partners.

Trust is known to represent a "social lubricant" in the economic world [3], and most models of economic interactions have demonstrated that decision-making is influenced by social preferences such as trust and reciprocity [4]-[7]. The experimental trust game, originally known as the investment game [8], has been used in numerous studies to model the economic behavior of people when trading. In this test, a player typically decides what proportion of an initial monetary endowment will be given to an anonymous player. This amount is then tripled and the recipient decides how much of the tripled amount will be kept and how much will be returned to the first player. Experimental results provide evidence that decision-making is affected by cultural origins [9]-[11], and individual factors such as gender or age [12]-[17]. For instance, men from western societies invest the most [18], [19], and therefore appear to be the most trusting [20], [21] and the most confident in their investment decisions [20], [21]. Adult subjects were also more confident than teenagers [17]. Several studies have shown that reciprocity, trust and fairness affect the decisions of children [24]-[26], but the influence of age on investment decisions in an exchange situation remains little documented (see [27]).

In every transaction, partners not only decide how to trade with one another, but also choose with whom they trade. People may consider alternative, better partners if the current partners do not meet the expected cooperative conditions. In the context of public good provision games, for instance, adults usually adjust their investment following observation of contributions made by partners [28], [29]. In the investment game, interacting several times with the same partner can create a context in which individuals develop trust in previously unknown persons. To explain how trust relationships can evolve over time, researchers have commonly used repeated games in which participants interact several times with the same partner [30]. In studies where subjects can choose their partner, results show that people prefer partners who have already provided them with some form of benefit, and the choice made is based on the past result of their interaction [2], [31], [32]. In contrast, imposing exchange partners on individuals may decrease the level of trust or result in more time being required before participants trust each other [33]. As trusting behavior evolves with age, older children may accept to trade with unknown partners more easily than younger ones would, or they only may decide to take part in the transaction once they have estimated whether the partners were trustworthy.

When confronted by informants who differ by their level of reliability, children consistently prefer the one having given the more accurate information in the past [34]-[37]. Interestingly, an increasing number of works examine economic skills and the influence of partner's reliability in non-human primates [38]-[41]. One study in monkeys showed that a single individual out of twenty-one was able to adapt his investment according to the profitability of two different human partners [41]. It appears that taking the quality of partners into account when trading requires complex cognitive skills. In humans, and especially in children, it is likely that this competence develops in relation with the development of the cognitive abilities needed in any transaction: giving to an unfamiliar person, judging the partner's reliability by reasoning about their mental state, and estimating the value of goods [1], [42].

Studies have shown that children can spontaneously give objects before the age of one [43]-[45]. By 14-18 months of age, they readily interact with unfamiliar people [45] and take part in exchanges with unknown experimenters [46], [47]. Progressive development is also seen in attribution of mental states. At the beginning of the second year of life, children can share goals and read other people' intentions, i.e., the plan of action needed to reach goals [45], [48]-[50]. From 4-5 years of age, children start to understand the beliefs and thoughts of others, which may help them to recognize untrustworthy and dishonest partners [51]-[54]. Regarding numerical skills, children under the age of two can make value judgments by recognizing small discrete quantities [55]-[58], and larger numerosities, albeit in an imprecise way [59]-[63]. At around the age of 2, they are able to count to about six and detect a violation of counting [64]-[67], but children cannot master the same counting principles as adults before six years of age, i.e. the sequence of number words, the one-one correspondence between objects and words, and the cardinal principle [68], [69]. By the age of 5 or 6, they solve verbal calculation problems requiring arithmetic skills [70]-[72], although younger children can already predict the outcomes of simple additions and subtractions [73]-[76].

We aimed to identify the developmental stage at which children adjust their investment in the context of an economic transaction. We tested children between the ages of 3 and 10 in an exchange task requiring them to calculate the amount of food items they gave initially, in order to maximize the food amount to be returned by two different experimenters. The experimental procedure was similar to that used with monkeys [41]. One experimenter gave back a reward twice the amount of the child's initial investment, whereas the other always returned the same amount, whatever the child's initial investment. To maximize pay-offs, children had to respond in different ways to each experimenter, offering a maximal amount to the first one, and a minimal amount to the second.

Results

Returned Items

The mean number of returned items varied according to individuals ($F_{24,575} = 5.5$, $p < 0.001$; Figure 1), age and partner (3 years: mean number of sweets ± sd = 2.35 ± 0.09, 5 years: m = 3.06 ± 0.07, 7 years: m = 2.58 ± 0.08, 10 years: m = 2.75 ± 0.1, $F_{1,575} = 9.4$, $p < 0.001$; doubling partner: m = 3.29 ± 0.08; fixed partner = 2.08 ± 0.09, $F_{1,575} = 58.2$, $p < 0.001$). Given the interaction between the individuals and partners ($F_{24,575} = 2.7$, $p < 0.001$), we compared the performances of each child according to the quality of partners.

Comparing the performances of 3-year-old children according to the quality of partners did not yield significant differences (Figure 1). Children seldom returned all initial items, often keeping at least one sweet (90.3% of returns).

Among 5-year-old children, five failed to adapt the amount of sweets given according to the quality of their partner (Figure 1). By contrast, three children showed significantly different behavior with each experimenter. One of them adapted his strategy from the first set of sessions; he quickly learned to give back a minimal number of sweets (one) to the fixed partner, and a maximal number (four) to the doubling partner. The other two children modified the amount of returned sweets in the course of experiments, learning to give one sweet to the first partner and four to the other from the 8^{th} set of sessions onwards (Figure 1).

Among 7-year-old children, one boy did not display significant differences in his behavior according to partner's quality; he returned some sweets to both of them (Figure 1). All the other children were able to adjust their behavior according to the quality of partners, most of them learning in the first half of the study to give back a minimal amount to the fixed partner, and a maximal amount to the doubling one (Figure 1).

Among 10-year-old children, one failed to discriminate between experimenters; he repeatedly gave back around four sweets to both partners. All the others adapted their return from the first sets of sessions by giving back a minimal amount of sweets to the fixed partner, and a maximal amount to the doubling one (Figure 1).

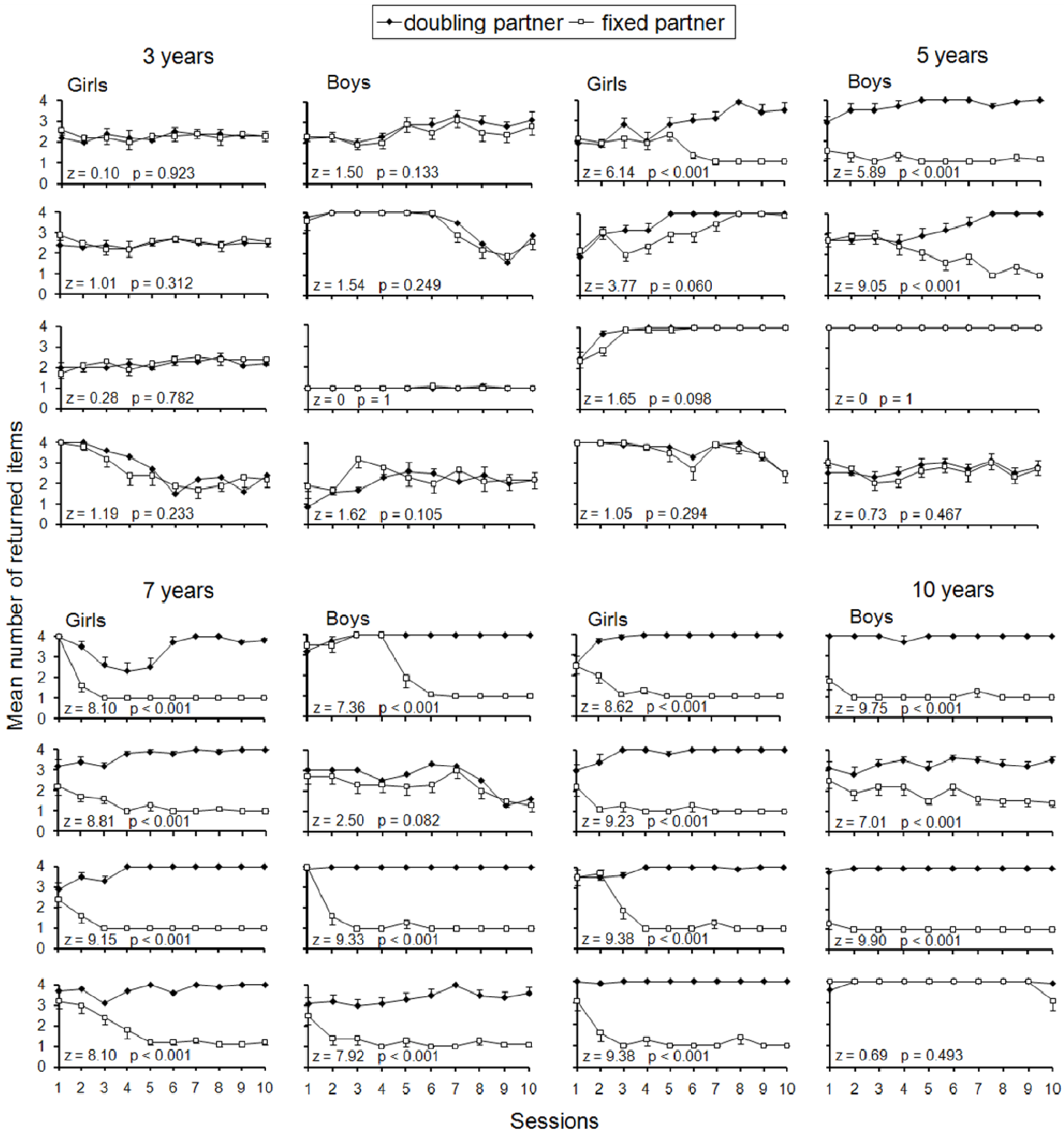

Figure 1. Number of sweets returned by children (n = 8 subjects per age group). No 3-year-old children successfully adapted their strategy according to the quality of partners. At the age of 5, three subjects adapted their strategy according to the quality of partners. Seven subjects successfully adapted their strategy according to the quality of partners at the age of 7 and 10 respectively (Wilcoxon tests, n = 10). Each plot represents the mean number of sweets returned in one session of ten trials, along with standard errors.

Table 1. Children's net income according to the quality of partners and difference between the numbers of sweets received from each partner.

Subjects	Sex	Net incomes (mean number ± SD)		Difference between the number of sweets received from each partner	P-value (Wilcoxon test, N = 10)
		Doubling partner	Fixed partner		
Three years					
Ste	Girl	6.3 ± 0.08	9.6 ± 0.11	327	< 0.001
Aud	Girl	6.4 ± 0.07	9.3 ± 0.10	286	< 0.001
Mil	Girl	6.2 ± 0.08	9.6 ± 0.13	343	< 0.001
Cam	Girl	6.8 ± 0.14	9.0 ± 0.18	224	< 0.001
Lou	Boy	6.7 ± 0.10	9.5 ± 0.10	285	< 0.001
Sim	Boy	7.4 ± 0.10	8.6 ± 0.14	114	< 0.001
Matt	Boy	5.0 ± 0.01	10.9 ± 0.01	598	< 0.001
Math	Boy	6.0 ± 0.13	9.4 ± 0.17	334	< 0.001
Five years					
Chl	Girl	6.8 ± 0.12	10.1 ± 0.15	330	< 0.001
Gla	Girl	7.5 ± 0.09	9.0 ± 0.12	143	< 0.001
Mas	Girl	7.8 ± 0.06	8.3 ± 0.07	49	< 0.001
Mar	Girl	7.7 ± 0.09	8.4 ± 0.10	72	< 0.001
Mil	Boy	7.7 ± 0.07	10.8 ± 0.09	306	< 0.001
Lea	Boy	7.2 ± 0.08	10.0 ± 0.12	277	< 0.001
Lou	Boy	8.0 ± 0	8.0 ± 0	0	1
Ami	Boy	6.7 ± 0.10	9.4 ± 0.10	275	< 0.001
Seven years					
Ami	Girl	7.4 ± 0.11	10.6 ± 0.10	323	< 0.001
Fat	Girl	7.7 ± 0.06	10.7 ± 0.07	299	< 0.001
Ana	Girl	7.8 ± 0.06	10.8 ± 0.07	303	< 0.001
Ass	Girl	7.8 ± 0.10	10.3 ± 0.11	247	< 0.001
Ben	Boy	7.9 ± 0.04	9.8 ± 0.14	191	< 0.001
Leo	Boy	6.6 ± 0.12	9.8 ± 0.12	315	< 0.001
Art	Boy	8.0 ± 0	10.6 ± 0.10	262	< 0.001
Leon	Boy	7.0 ± 0.13	8.7 ± 0.39	172	< 0.001
Ten years					
Ali	Girl	7.8 ± 0.06	10.7 ± 0.07	289	< 0.001
Aga	Girl	7.8 ± 0.06	10.8 ± 0.07	299	< 0.001
Yae	Girl	7.9 ± 0.06	10.6 ± 0.14	246	< 0.001
Mou	Girl	8.0 ± 0	10.6 ± 0.11	263	< 0.001
Flor	Boy	8.0 ± 0	10.9 ± 0.05	292	< 0.001
Yan	Boy	7.3 ± 0.08	10.2 ± 0.10	286	< 0.001
Tho	Boy	8.0 ± 0	11.0 ± 0.03	299	< 0.001
Adi	Boy	7.9 ± 0.03	8.1 ± 0.05	14	< 0.05

Net Incomes

By experimental design, a child's net income should differ according to the quality of partners. Only one boy of 5 years old did not experience a significant difference of total income between experimenters. For all the other children, income was higher with the fixed than with the doubling partner (Table 1). The difference between the numbers of sweets gained from each partner varied from 14 to 598 sweets (Table 1). It is worth noting that by the age of 5, children regularly counted the net income received during the exchange.

Because some children were from the same school, we could not control potential communication between them about experiments, especially in older children. When looking at the proportion of successful children tested at school versus those tested at home who did not know each other, we found similar proportions in decision patterns, both in 7-year-old children (83% of success at school vs. 100% of success at home), and 10-year-old children (80% vs. 100%).

Discussion

No 3-year-olds were able to adjust their behavior according to the quality of partners. About one third of the 5-year-old children, and almost all children aged 7 and 10 succeeded in optimizing pay-offs by following different decision rules according to experimenters. The fact that the performances of the children tested at school were not better than those of subjects tested separately at home casts doubt on any possibility of information transmission between children belonging to the same school. It should be added that successful children did not adjust their investment according to the quality of partners from the first trial of a session; they learned to maximize their pay-off after several trials of the first or following sessions. Our results confirm that the ability to calculate investment based on partners' offers develops between 4 and 7 years of age.

It is unlikely that failures observed in 3-year-old children were due to their inability to differentiate between the food amounts returned by experimenters, since children are able to differentiate between discrete quantities from their first year of life [59]-[62], [73], [77]. In the present study, children sometimes returned a different number of sweets to experimenters, thus getting an opportunity to learn that partners did not respond in the same way. Despite having experienced a difference in net income of about three sweets between partners, younger children did not adjust their return according to experimenters’ qualities.

In terms of calculation skills, children aged 3 to 4 are able to resolve basic subtractions that involve small number sets [70]-[72], [78]-[80]. Similar abilities are observed in monkeys [81]. Here, children aged 3 are comparable to most macaques and capuchin monkeys tested in the same task [41] as they could remove part of the items before investing, but failed to adapt their return to partners. A single monkey out of twenty one was able to adapt his strategy to both partners, which sets the performances of monkeys somewhere between those of 3- and 5-

year-old children. This also suggests that calculation abilities may not be a limiting factor for succeeding in such tasks.

In our experiments, children did not merely have to choose between two options, but also had to draw different decision rules from the contrasting conduct of two partners, which was more demanding. The ability to follow multiple directions or to switch decision rules develops slowly during childhood [82], [83]. When asked to sort objects according to color, 3-year-old children are still unable to inhibit this first representation when required to follow an alternative one based on the shape of objects [84]-[87]. Our study shows that adequate use of opposite decision rules is possible from the age of 5, and is fully mastered from the age of 7. Interestingly, 10-year-old children needed fewer testing sessions (i.e. less than three sessions) than younger ones (i.e. between one and five sessions) before succeeding. It cannot be excluded that it was enough for subjects to separately adjust to each of the partners they were faced with, without comparing their returns. However, younger children failed in the present task despite the fact that, at this age, they should be able to understand the intentions of each experimenter (see [50], [88]) as a partner requiring a certain amount of food to give rewards.

The development of a theory of mind and arithmetic skills may partly explain increasing performances in children. The success of several 5-year-old children is consistent with the fact that 4- and 5-year-old children understand that others may have thoughts and beliefs different from their own [51]-[54], [89], and this ability can be used to detect the reliability of a partner. With regard to arithmetic, it is known that the first years of schooling markedly affect the cognitive skills of children regarding language, literacy and numeracy [90]. Although it appears sufficient to recognize magnitude – even in an imprecise way – for children to adjust their return to partners, the task may ask for a more demanding ability when it comes to understanding the relation function between investing and the return of each partner (when children have to discriminate between ratio differences). School-related changes in counting and arithmetic abilities may lead children to be more efficient when calculating investment. We did not observe children using counting to remove items before exchanging, but most subjects over the age of 5 spontaneously counted the total number of received sweets at each trial. While Jordan, Huttenlocher and Levine (1994) [91] found that counting objects may not be necessary to solve non-verbal tasks, it could help children to differentiate the net incomes received according to the quality of partner and could improve decision-making. A marked increase of performance in arithmetic problem solving is reported from the age of 5 or 6 onwards [68], [71], [72]. Given this long age-related development, it may not be surprising that children only solved the task from the age of 5 onwards. Thus, counting and understanding that people can think differently may improve performance on this task.

Social factors could also have affected the performances of children, and may explain better results found in 5-year-olds. In particular, trusting behavior is commonly believed to guide the choices of economic agents in investment situations [8], [92]. Repeated experiences can establish a trust relationship between exchange partners [30] and this leads children to invest their attention towards how to gain more from the task rather than concentrating on the unknown partner. With increasing age, children could also prioritize the potential to gain more, even if they did not trust experimenters. On the other hand, it is possible that the capacity of younger children to focus on the task was impaired by failure to overcome their wariness of partners who were unknown and potentially untrustworthy. A recent study revealed that 3-year-olds evaluate trustworthiness of partners based on the inaccuracy of information, whereas 4-year-olds rely both on accuracy and inaccuracy [93]. As partners were always trustworthy in our study, systematically giving children an accurate reward, it is quite possible that younger children may have experienced difficulty distinguishing between them. The number of sweets that they kept could also reflect their hesitation to put their trust in experimenters. Contrary to older children, 3-year-olds kept at least one sweet in almost all the trials, thus showing a preference to avoid losing their initial savings rather than acquire gains. Such loss aversion relates to the endowment effect, a cognitive bias commonly found in economics; it leads people to attribute a higher value to objects they own than to objects that they do not possess. A number of experimental studies have demonstrated that adult investors may behave in a way that may not be rational [42], [94]-[96]. Our results showed that children as young as 3 years old also violate the predictions of optimal decision-making models.

Although older children understood how to maximize their benefits, they did not appear perfectly rational since they did not follow an optimal rule on every trial. They often supported their decision verbally by asserting that they preferred to win less for a specific trial, or to set their sights on the contents of a cup that did not contain the maximal amount of sweets. It should be emphasized that children were rewarded regardless of the number of sweets invested; no exchange also rewarded them with the four sweets that they kept. The lack of negative reinforcement for giving one quantity or another can explain that successful children were not always optimizing investors. Such choices probably reveal the importance of play or exploration in their performances.

The present results show that children between the ages of 4 and 10 are in the process of learning how to behave in economic situations. Both cognitive and social factors are likely to be involved in their ability to calculate their investment according to the offers made by partners, and biases appear to influence their decision-making. More research will be necessary to confirm the present results in a larger sample of subjects, and further investigate the relationships between cognitive development and improving economic skills. In particular, it would be worthwhile to study children in an experimental situation that does not involve a social component, for instance, by testing them using two automated dispensers instead of experimenters.

Methods

Ethics Statement

The project was approved by both the Education Department of the Bas-Rhin (reference DIVEL1/09-670/IJ) and the district inspector for education. Parents were given a letter describing the general purpose of the study and written parental consent was required for children to participate in the tests. Participation was on an unpaid, voluntary basis, but children kept the sweets that they won during the sessions.

Participants

We studied 32 children (16 males and 16 females) aged 3 to 10. This sample was divided into four age groups of eight children: 3-year-old (mean age ± SEM = 41.4 ± 4.0 months), 5-year-old (m = 66.5 ± 0.9), 7-year-old (m = 88.0 ± 3.6), and 10-year-old (m = 125.6 ± 3.4). The sex ratio was balanced for representativeness; we tested equal numbers of girls and boys in each of the four age groups, i.e. four girls and four boys. An additional child was excluded from tests because he did not pay any attention to the experiments.

Participants were European, from middle-class backgrounds, with French as their first language. A majority of children belonged to the Robertsau preschool and elementary school in Strasbourg, France. We tested seven children separately (two 3-year-olds, two 7-year-olds and three 10-year-olds) at their home, i.e., outside the frame of the school.

Experimental Design

We studied children in two conditions involving different experimenters. In the first case, the experimenter was a doubling partner, meaning that she always returned twice the number of rewards given by the subjects; potential rewards were presented in four cups containing either two, four, six or eight rewards. In the second condition, the experimenter was a fixed partner, meaning that she always returned eight rewards, regardless of the number of rewards given by subjects (one to four); potential rewards were presented in four cups, each containing eight sweets.

Each child took part in two sessions, one session of 10 trials each, with each of the experimenters. A session was composed of 10 trials separated by pauses of 5 sec. Children were given 5 min between the two sessions to fully understand the different conduct of the two experimenters. The net income, i.e. the amount of the rewards kept by the children plus those received, could vary within any one session from 24 to 48 sweets with the doubling partner, and from 24 to 66 sweets with the fixed partner (Table 2). We counterbalanced the role of experimenters, i.e. within each age-and-sex group, one experimenter was the doubling partner with two children, and was the fixed partner with the other two. We also alternated the intervention order of partners from one set to another. To help children learn to distinguish between both conditions, we associated them with different cues. We divided the table into two parts, each devoted to a different set of four cups, with a different color for each condition.

Table 2. Number of rewards acquired from both experimenters and children's net income according to the number of items returned by children. Within any one session, the subjects' net income is the amount of items kept by the child plus those received after return. Subjects maximize their gain by giving more (4 sweets, net income 8) to the doubling partner, and less to the fixed partner (1 sweet, net income 11).

Number of sweets returned	Doubling partner		Fixed partner	
	Reward	Net income	Reward	Net income
0	0	4	0	4
1	2	5	8	11
2	4	6	8	10
3	6	7	8	9
4	8	8	8	8

Test Procedure

We recorded whether subjects had siblings or twins. We videotaped testing sessions whenever written consent was obtained. Children were tested individually in a quiet room (4 m x 3 m) adjoining their classroom. The child was led to the testing room and introduced to the two experimenters. The child then sat on a chair opposite the experimenters at a rectangular table (0.8 m x 0.5 m).

Before testing, the experimenter gave the child the possibility to exchange one reward for two. If they failed, the experimenter repeated the trial once. If the child failed again, the test was stopped. When the child was successful, the experimenter then offered her/him the possibility of exchanging two rewards for four. If s/he failed, we repeated the offer once. All subjects reached this stage, and were considered ready for testing.

The two sessions lasted approximately 15 min. The first trial began when the first experimenter (doubling or fixed partner) placed and filled the four plastic cups with the different rewards. The experimenter then gave the child four sweets by placing them on the surface of the table while saying, “Here are four sweets and here are more sweets”, showing the cups of sweets. After 3 sec, she pointed to the four sweets, held out her hand, palm up, in front of the child and asked, “How many of them do you want to exchange?” (Note that pilot trials run with children aged between 4 and 12 years revealed that the sentence “Do you want to exchange any of them?” implied that the transaction may be risky, leading children either to accept exchanging all the items or to refuse exchanging any of them. We opted for a more precise question that made clear that the children did not have to return all the items).

Every time the child returned one or several sweets, the experimenter thanked them and presented the corresponding cup to the child saying “OK, here are the rewards. Do you want to try again?” before starting another trial. When the child kept or consumed all sweets, the experimenter said “OK, you can eat/keep the sweet(s). Do you want to try again?” After the session, the experimenter said “OK, that was great. Now you’re going to play another game with my friend". The second experimenter (doubling or fixed partner) drew attention to the change of condition by placing and filling four other plastic cups with a different amount of rewards, and then began the second testing session.

Control of Information Transfer

To avoid any exchange of information between children tested within the same school, the experimenter asked the child not to talk about testing with other children after the first two sessions were completed. It is also important to note that younger children were not verbally mature enough to have elaborate discussions with school friends [97] about how to gain more rewards during experiments.

Statistical Analysis

We used a one-way repeated-measures ANOVA (Mauchly’s test for sphericity = 0.74) to assess the effect of the individuals, age, sex and partner on the mean number of returned items. To test whether subjects responded differently to the fixed and doubling partners, we compared their performances at the individual level using the Wilcoxon matched-pairs test (exact procedure [98]) with SPSS software version 17 (SPSS Inc., Chicago IL, U.S.A.). The significance level was set as 0.05. Values are given as means and standard errors of the means.

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Author Contributions

Conceived and designed the experiments: BT SS VD. Performed the experiments: SS. Analyzed the data: SS. Wrote the paper: SS BT VD MHB.

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CHAPITRE 6

LA PRISE DE RISQUE DANS L'ECHANGE

SYNTHESE DE L'ARTICLE 4

Les facteurs de décision chez les enfants dans une situation d'échange à risque

Article soumis pour publication

◆◆◆

Les études précédentes ont montré que la décision d'investir lors d'échanges avec des expérimentateurs inconnus pourrait être liée à la capacité des enfants à juger dans quelle mesure leurs partenaires sont dignes de confiance en ce qui concerne le retour d'investissement. Au-delà de l'estimation des risques liés à la fiabilité du partenaire, les enfants doivent également calculer les risques de gain et de perte inhérents à toute transaction différée. L'évaluation des bénéfices ou des pertes potentiels pourrait être un pré-requis cognitif à l'aptitude à optimiser les gains.

Cette dernière étude s'inscrit dans une thématique majeure de l'économie expérimentale, celle du choix individuel en situation de risque. Les enfants tendent à prendre plus de risque que les adultes. Au cours des transactions économiques nécessitant l'évaluation des possibilités de gain et de perte, il se peut que les enfants aient un seuil de tolérance à la perte plus élevé que celui des adultes, les autorisant à aller plus loin dans leur prise de risque. On peut également penser que les mécanismes nécessaires au jugement des pertes potentielles et à la compréhension des conséquences de leurs décisions ne deviennent matures qu'après un certain âge. J'ai eu pour but d'étudier la faculté des enfants à maximiser leur bénéfice dans une transaction comportant un risque de perte. J'ai analysé les facteurs de décision en fonction de l'âge et confronté les choix observés à ceux prédits par les théories économiques majeures de prise de décision chez l'être humain à savoir la Théorie de l'Espérance d'Utilité (EUT) et la Théorie des Perspectives (CPT). L'objectif était également de préciser si les biais cognitifs rencontrés chez les adultes lors des choix économiques (aversion à la perte ou attirance pour le risque par exemple) pouvaient être décelés à un âge précoce.

J'ai testé 288 enfants âgés de 3 à 9 ans dans une tâche d'échange où je leur offrais un biscuit de dimension moyenne en présentant six récompenses potentielles de dimensions différentes : les récompenses représentaient soit un gain, soit une perte, soit étaient équivalentes au biscuit initialement offert. Si l'enfant acceptait de rendre le biscuit en sa possession, il recevait de manière aléatoire l'une des six récompenses. Afin de mesurer si les probabilités de gain et de perte influencent la prise de décision des enfants à s’engager dans l’échange, différentes combinaisons de récompenses ont été proposées aux enfants durant le test. Les résultats montrent que les enfants de plus de 5 ans s’engagent plus souvent dans un échange risqué que les enfants de 3 et 4 ans. Ces derniers n’ont pas été capables d’adapter leur taux d’échange en fonction des combinaisons de récompenses contrairement aux enfants plus âgés. La proportion de choix de la loterie face au gain certain est plus importante lorsque les choix sont proposés en séquence décroissante que lorsqu’ils le sont en séquence croissante d’espérance mathématique. Cet effet est connu dans la littérature sous le nom d’effet de présentation (*framing effect*). Parmi les facteurs de décision, la probabilité de perte apparaît comme la plus importante chez les enfants de plus de 5 ans. L’analyse des performances observées à la lumière de la théorie de l’espérance d’utilité révèle un comportement de préférence pour le risque chez les plus de 5 ans. La cohérence de nos observations avec les principes de la théorie des perspectives nous apprend enfin que ces derniers sont averses aux pertes.

Les enfants de plus de 5 ans sont donc capables d’évaluer le risque de gain et de perte relatif à une transaction risquée afin de maximiser leur bénéfice. Quand on confronte leur choix aux théories économiques, il apparaît qu’ils possèdent une aversion à la perte, un biais cognitif susceptible de limiter leur maximisation des gains au même titre que chez les adultes. En effet, un coefficient d’aversion aux pertes de l’ordre de 2 implique que face à une décision risquée avec une possibilité de perdre, les individus n’acceptent de participer que si cette décision peut également induire un gain d’une taille au moins deux fois supérieure à celle de la perte. Une telle attitude les amène à conserver leur investissement plus longtemps, ce qui peut conduire à des rendements moindres à long terme. En cas de crise financière, la perspective d’une perte importante peut également mener les individus à investir de façon excessive et dangereuse. L’aversion aux pertes a été détectée dans la plupart des pays. Il existe cependant chez les adultes de fortes différences interindividuelles dont les facteurs de variation (niveau de confiance, de richesse, d’éducation) pourraient se mettre en place dès l’enfance.

Decision-making in Children under Risk

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Abstract

Taking risk is an integral part of children's activities. We compared the response of children aged between 3 and 9 years to the theoretical model of Expected Utility Theory (EUT) to investigate the rationality of their decision-making and what factors underlie their choice to trade in a food-gambling task. We gave children the opportunity to exchange a piece of cookie with an experimenter for pieces of larger, equal or smaller sizes. The chances of losing or gaining were manipulated via successive combinations of rewards presented in six aligned cups. Results showed that children aged 3 to 4 years old were unable to maximize their benefit by adapting their exchange behavior to the combinations of rewards. From 5 years children traded according to the offered combinations, and their decisions were negatively induced by the probability of losing. Better abilities in estimating probabilities may help children to adjust their behavior. Children’ observed decisions are subject to a framing effect, those starting with winning combinations exchanged more than those starting with losing combinations. Confronting data to the EUT model indicates that children aged over 5 were risk-seekers but also revealed inconsistencies in their choices. We show that, according to Cumulative Prospect Theory (CPT), they exhibited loss aversion. These findings demonstrate that adult-like economic biases occur early in childhood.

Keywords: gamble; exchange; decision-making; economics; children; EUT; CPT

1. INTRODUCTION

Throughout our daily activities we face choices involving some degree of uncertainty. This is true in different social contexts and in particular for most transfers of goods or services. The expected outcome of helping someone may be uncertain, for instance, and it can be that even the promise of return by the partner should not be trusted. Such circumstances occur early in life and taking risk is an integral part of children's games; a common finding is that children are greater risk takers than adults (e.g., Reyna & Ellis 1994; Schlottmann 2000; Harbaugh *et al.* 2002; Levin & Hart 2003). It could be that they fail to understand the risky nature of their surroundings, but it may be also that they have a better tolerance to loss, or a poorer understanding of the consequences of one own decision.

Classical economy developed different models of decision-making to account for behaviors of individuals under risk. A situation is qualified as risky when one can evaluate the odd of winning and losing, but cannot predict the exact outcome of the decision (Knight 1921). The Expected Utility Theory (EUT), introduced by Von Neumann and Morgenstern (1944) states that individuals choose among risky prospects by comparing their expected utility values, based on their respective probabilities (see Mas-Colell *et al.* 1995, and electronic supplementary material part III). A rational individual who is offered a choice between a lottery and a certain amount is supposed to choose the option with the higher expected value to maximize his expected utility. Facing two choices offering the same expected utility, risk-averse individuals select the certain outcome and risk-prone select the lottery. When identical options are presented in different formats or in different wording, rational individuals should not alter decisions (Tversky & Kahneman 1981).

Adults are generally rational decision-makers (Nofsinger 2005), but their decisions sometimes deviate from EUT predictions (Tversky & Kahneman 1981; Plott & Smith 2008). For instance, human buy lottery tickets although, according to EUT, the expected value of the game (the chance to win) is negative. Overweighing the probability of unlikely outcomes is one of the cognitive biases seen in risky contexts (Tversky & Kahneman 1974, 1981; Kahneman & Tversky 1979). The consequences of these biases are important in medicine where errors in probabilistic reasoning sometimes lead overconfidence in assessing the odds of a particular diagnosis (Eddy 1982). These biases are also detected in the financial world where it may involve strong losses (DeLong *et al.* 1990; Shiller & Summers 1990; Daniel *et al.* 1998; Shiller 2002). Several errors in the judgment of risk in adolescents have also been reported (Griffiths 1990, 1995; Lambos *et al.* 2007). Children appear to develop an understanding of risky economic situations similar to the adult one at around 11-12 years of age (Murnighan & Saxon 1998; Reyna & Ellis 1994; Harbaugh *et al.* 2002; Levin & Hart 2003). Children as young as 2 years of age can enter in exchanges with experimenters (Steelandt *et al.* 2012), and from 4-5 years they display a good intuitive understanding of probability concepts in risky decision-making (Anderson 1991; Schlottmann 2001; Denison *et al.* 2006). Harbaugh *et al.* (2002) tested 5- to 13-year-old children in a game where they could choose between a sure outcome (gain or loss) and a lottery with the same expected value. Winning led to obtain tokens that could be used afterwards to buy toys. They found that children underweighted low-probability events and overweighed high-probability ones. However, these results cannot be generalized in the context of EUT since children based their value judgment on secondary reinforcement and not on a direct evaluation of utility. Besides, most experimental studies show important variation about how children evaluate risky contexts. Classical economic models may need to be adjusted to explain more reliably the decisions of children.

In this work, we tested the attitude towards risk of children aged between 3 and 9 years in a simple choice between a lottery and a certain outcome. Children were first endowed with an initial piece of cookie that they could exchange for the content of one cup chosen at random among six visible. The food rewards contained in the cups could be larger, equivalent, or smaller in size than the initial endowment making it possible to evaluate directly the utility of the outcome. We manipulated the chances to win or lose and confronted the observed choices to the prediction of rationality from the EUT model, i.e. the maximization of the expected utility. By investigating how young children make decisions under risk, we aimed to determine the age at which economic biases may occur, and which factors underlie their choice to trade or not.

2. METHODS

(**a**) ***Participants and conditions***

Participants were 288 children (144 boys, 144 girls) from 3 to 9 years old, equally divided between six age-groups (3- to 8-year-olds) of 48 children each (24 girls and 24 boys) (see electronic supplementary material part I). Participants were European from middle-class backgrounds, with English as their first language. The experiment took place at the Living Links to Human Evolution' Research Centre in Edinburgh zoo. Ethical authorization to work with children was given by the University of St-Andrews ethics committee, UTREC (reference n°PS5528). Children were recruited upon their visit to the "Budongo trail".

Children were first familiarized to the exchange task in an initial training phase (see electronic supplementary material part II). Tests were conducted in a small area (2.5 x 2 m) limited by four occluders allowing an entire visual seclusion from public. Children were individually tested while seated on a chair or on their parent's lap in front of a square table (1 x 1 m). The apparatus consisted of six aligned plastic cups containing pieces of cookies of various dimensions.

(**b**) ***Exchange procedure***

In each trial the experimenter first presented in one hand the initial piece of cookie of 4 x 0.5 x 0.5 cm, and in the other six aligned plastic cups containing pieces of cookie of various dimensions: 1 x 0.5 x 0.5 cm (small size), 4 x 0.5 x 0.5 cm (medium size) and 4 x 2 x 0.5 cm (large size - sequence of four 4 x 0.5 x 0.5 cm pieces of cookies) (figure 1). The experimenter gave the initial medium piece of cookie to the child, and held out her empty hand offering the child the chance to give the initial item back "Here is a piece of cookie and here are others cookies. Do you prefer to keep the cookie or do you want to swap it to have one of these one?". If the child returned it, s/he received the content of one cup chosen randomly. If the child chose to keep the initial item, the experimenter ended the trial, allowing the child to consume the initial item or store it into a bag. Whatever the choice of the child, the experimenter proceeded with the next trial. The probability to lose and to gain was manipulated via 11 combinations of two trials each (table 1). A first half of children were run in Condition A presenting a step by step decrease in the chances to win from combinations # 0 to # 10 then a step by step increase in the chances to win from combinations # 10 to # 0. The other half was run in Condition B presenting first gradually increasing chances to win then decreasing chances.

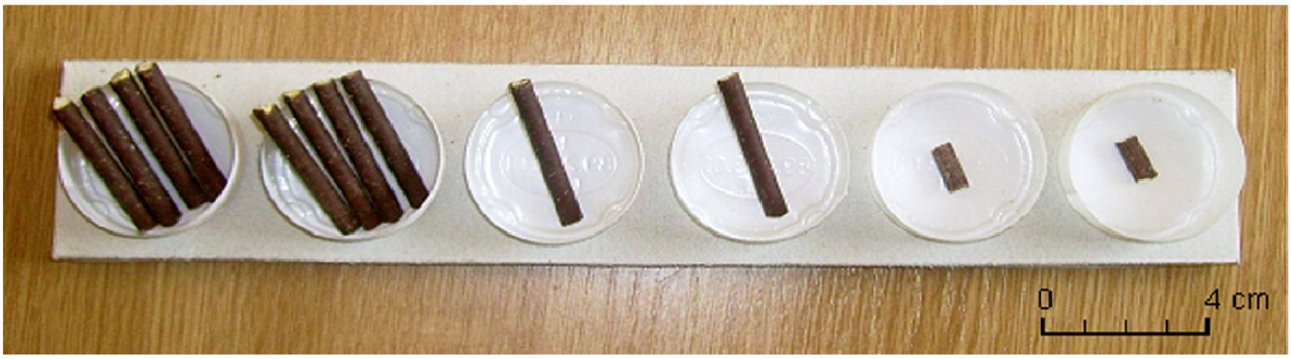
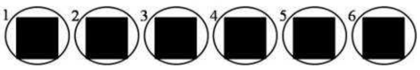
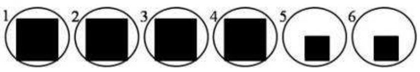
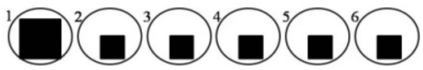
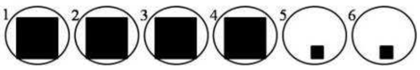
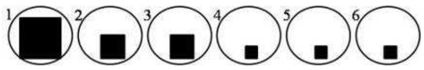
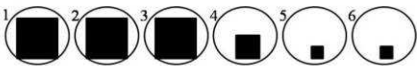
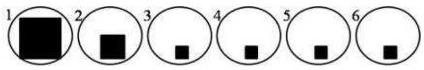
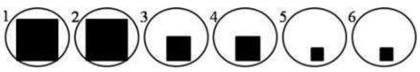
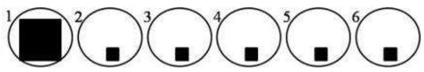
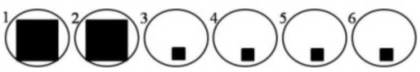
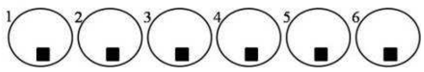


Figure 1. Six plastic cups containing two pieces of cookie of 4 x 2 x 0.5 cm (sequence of four 4 x 0.5 x 0.5 cm - left position), two pieces of cookie of 4 x 0.5 x 0.5 cm (middle position) and two pieces of cookie of 1 x 0.5 x 0.5 cm (right position) corresponding to the combination of rewards #4.

Table 1. Number (#) and content of cups for each combination of rewards. Small black squares represent pieces of cookie of dimension 1 x 0.5 x 0.5 cm, medium black squares represent pieces of cookie of 4 x 0.5 x 0.5 cm, and large black square represent pieces of cookie of 4 x 2 x 0.5 cm (sequence of four 4 x 0.5 x 0.5 cm pieces of cookie).

Combinations of rewards			
#	Content of cups	#	Content of cups
0			
1		6	
2		7	
3		8	
4		9	
5		10	

(c) ***Analysis procedure and theoretical predictions***

Under EUT, we assume that subjects evaluate values of outcomes in terms of utility, measured by the area of each piece of cookie, because they are consumption amounts (Clearfield & Mix 1999; Mix *et al.* 2002). The item area of each option are weighted by their respective probabilities *p* and compared by the individuals as follows (see electronic supplementary material part III and table S1):

$$u(W) = \sum_{i=1}^{n} p_i u(x_i)$$

The utility function can take different mathematical forms, but we chose $u(y) = y^{\delta}, \forall y$, where *y* is the quantity of item and δ is the risk aversion parameter. Under the assumption that children were risk neutral ($\delta = 1$), they should exchange rather than keep the medium item from combination # 0 to # 8 when the expected utility was equal to or higher than the utility of the certain initial amount (see electronic supplementary material part III and table S1). Conversely, children should refuse to exchange in the last combinations (# 9 and # 10) because the expected utility was lower than the utility of the certain outcome. As subjects are not always neutral when facing risk (for risk neutral individuals, $\delta = 1$), we need to assess a risk aversion parameter δ. Children are risk averse ($\delta < 1$) when, between two options with identical expected values, they preferred the safer option, and risk-seeking ($\delta > 1$) when they choose the risky option (McCoy & Platt 2005). Detecting at which combination children become indifferent between the risky and the certain item can be used to deduce the risk aversion parameter values.

3. RESULTS

The decision to exchange was affected by age (GLM, $z = 2.6$, $p < 0.001$), the younger children exchanging less than the older children (figure 2). This was particularly true for the 3- and 4-year-olds (percentage of return = 25.8% and 42.2%) compared to other groups (5 years: 54.3%; 6 years: 58.2%; 7 years: 56.3% and 8 years: 56.9%; see electronic supplementary material table S2). Children exchanged more (GLM, $z = 1.4$, $p < 0.001$) for “winning only” (64.1%, combination # 0) and “zero chances to lose” combinations (54.5%, combination # 6) than for “losing only” combination (26.2%; combination # 10). A combined effect of age and combination affected their responses. Before 5 years, children discriminated only between “no chances to win” (combination # 10) and “no loss” (combinations # 0 and/or # 1). Above 5 years, all age groups discriminated between “no loss” (combination # 0) and “no win” (combination # 1), and both these combinations were significantly discriminated from most of the others (see electronic supplementary material table S3). With respect to conditions – condition A with increasing chances to win then decreasing chances, and condition B with decreasing chances then increasing – we observed a framing effect; children starting with winning combinations exchanged more often than children starting with losing combinations (GLM, $z = 2.2$, $p < 0.05$). Exchange rates were low for combinations with highest probability of loss (# 9 and # 10) regardless of the condition (GLM interaction condition x combination, $z = 1.2$, $p < 0.001$).

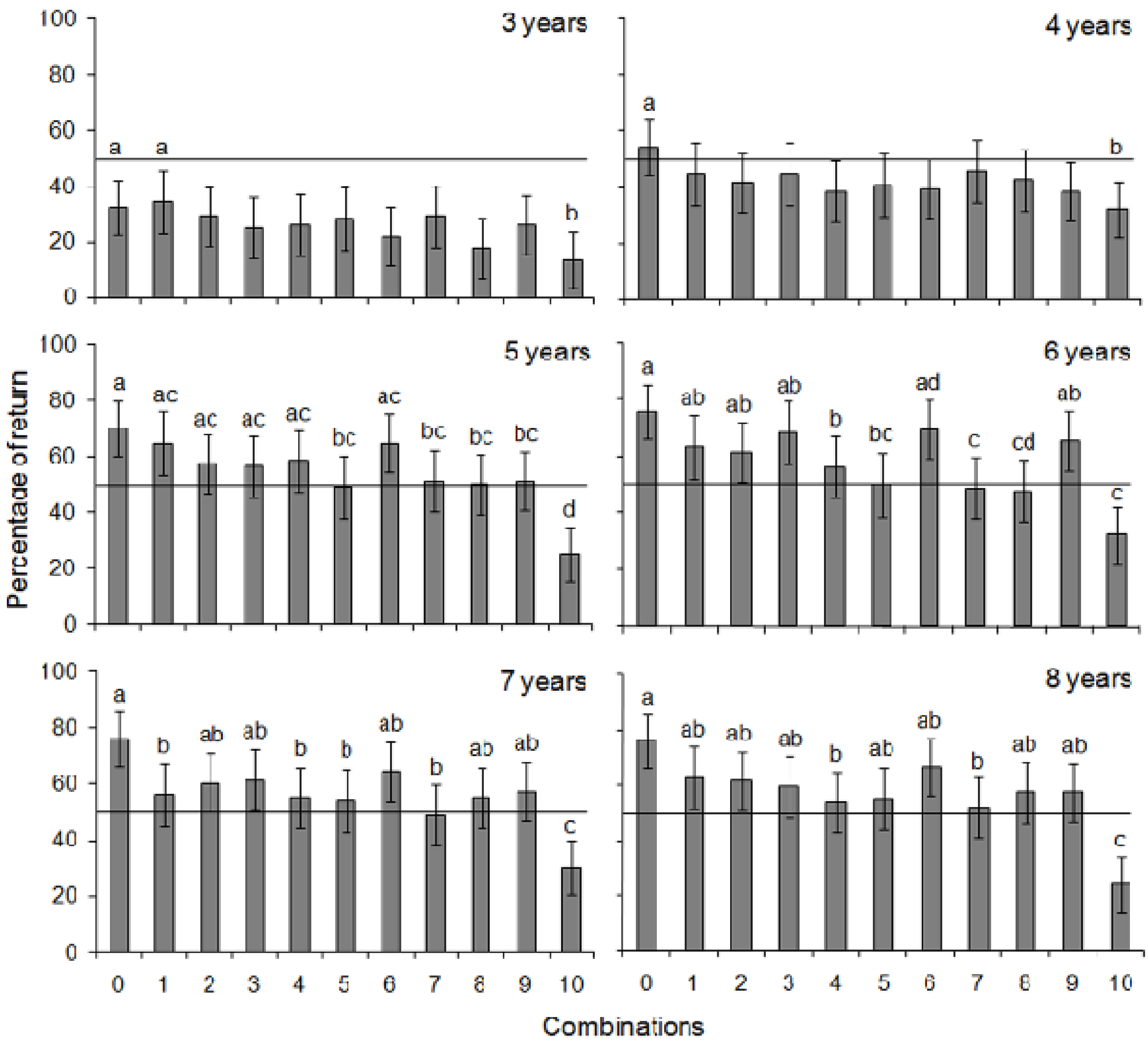


Figure 2. Percentage of returned items for each age according to the combination of rewards. The bar indicates the threshold of 50% of exchange. Combinations with no common letters differ significantly at P < 0.05.

We further assessed the effect of age, probability of gain P_G, probability of losing P_L, and variables resulting from previous outcomes (O_P: outcome received at the previous trial, O_S: cumulative outcome since the start of the mid-condition , O_{CUM}: cumulative outcome since the start of the testing session) on the response of children. There was no significant effect of outcomes on the percentage of exchange (GLM, O_P: $z = 0.7$, $p = 0.18$; O_S: $z = 0.1$, $p = 0.99$; O_{CUM}: $z = 0.1$, $p = 0.94$). Age (GLM, $z = 5.8$, $p < 0.001$), and probabilities of gaining (GLM, $z = 4.5$, $p < 0.001$) or losing (GLM, $z = -6.7$, $p < 0.001$) significantly affected responses (table S4). The probability of losing affected the responses of the 5-, 6- and 7-year-olds more than any other factor. The 8-year-old children took both the probability of gaining and the probability of losing into account. A similar trend was observed in 7-year-olds. The percentage or return decreased with decreasing expected utility and children exchanged significantly less often when the expected utility was inferior to the certain amount (i.e. 1, for the combinations # 9 and # 10).

Table 2. Student's t-tests on the percentage of return for each combination. Italic values indicate that the mean number of return for a combination is *significantly* smaller than 50%; non-italic values indicate that the mean number of return for a combination is *significantly* higher than 50%. In dark grey: combinations for which children accepted to exchange for a specific combination, but refused for the following one; in light grey: combinations offering the same evaluation in the EUT at which children should exchange at the same rate.

Combinations #	Number of cups			3-4 years		5-6 years		7-8 years		mean percent of return
	Large	Medium	Small	t value	p	t value	p	t value	p	
0	6	0	0	-1.73	0.09	7.09	<0.001	7.83	<0.001	64.07
1	4	2	0	-2.31	*<0.05*	4.23	<0.001	2.21	<0.05	54.34
2	4	0	2	-3.78	*<0.001*	2.44	<0.05	3.14	<0.01	51.90
3	3	1	2	-3.85	*<0.001*	2.92	<0.01	2.75	<0.01	52.30
4	2	2	2	-4.58	*<0.001*	1.85	0.07	1.18	0.25	48.09
5	2	0	4	-3.86	*<0.001*	-0.15	0.88	1.16	0.25	46.52
6	1	5	0	-5.05	*<0.001*	4.80	<0.001	4.32	<0.001	54.53
7	1	2	3	-3.29	*<0.01*	0	1	0.13	0.90	46.01
8	1	1	4	-4.78	*<0.001*	-0.31	0.76	1.73	0.09	45.13
9	1	0	5	-4.58	*<0.001*	2.42	<0.05	1.96	<0.05	49.31
10	0	0	6	-7.97	*<0.001*	-6.42	*<0.001*	-6.18	*<0.001*	26.22
mean percent of return				33.95 (3 years = 25.76; 4 years = 42.15)		56.34 (5 years = 54.27; 6 years = 58.42)		56.62 (7 years = 56.34; 8 years = 56.91)		

In view of the previous results, we conducted analyses on the three age categories: 3-4 years, 5-6 years, and 7-8 years to test whether their response fitted with EUT. We compared the frequency of choices of the lottery against 50%, i.e. the frequency obtained if children decided randomly whether to exchange or not. In accordance with EUT the percentage of returned items for each age decreased from the combination of rewards # 0 to # 10. All children presented a percentage of return significantly smaller than 50% only for combination # 10 (table 2), which was not consistent with EUT predicting that, under risk neutrality (δ = 1), children should not exchange for combinations # 9 and # 10 (see electronic supplementary material part III and table S1). Given that risk neutrality could not explain the behaviour of children, we inferred the risk aversion parameter by detecting the combination at which the percentage of return became significantly lower than 50% (i.e. the moment at which they judged the transaction too risky). The low return rates of 3-4 years for most combinations (inferior to 50%) did not allow finding this value. For children aged 5-6 and 7-8 years, only the certain loss combination (# 10) was the one for which the percentage dropped under 50% (table 2); we found $\delta \geq 1.17$ which is > 1 and indicates that they were risk-seekers. Thus, risk seeking children could be sequentially consistent with EUT. Note that in the context of EUT children should also exchange at the same rate for combinations # 5 and # 6, offering the same evaluation in the EUT (i.e. 1.5, see electronic supplementary material table S1). Contrary to this prediction, children aged 5-6 and 7-8 years exchanged more often for the combination # 6 than # 5 (table 2). Under EUT, no risk parameter value can explain both refusal to exchange for combination # 10, and preference to exchange for combination # 6 compared to # 5.

To account for children's deviation from the rational choice predicted by EUT, we investigated whether their response can be better explained by another theoretical model, the Cumulative Prospect Theory (CPT, see electronic supplementary material part IV and table S5). In this model, value is assigned to gains and losses relative to a reference point rather than to final wealth (Tversky & Kahneman 1992). Choices can depend on the level of the loss aversion parameter and the level of the weighting function parameter, i.e. how children distort probabilities. Although the utility of combinations # 5 and # 6 is equivalent, the presence of the potential for loss (presence of small pieces of cookies) in combination # 5, and its absence in combination # 6, may explain the responses of children. To examine this hypothesis, we first made the assumption of no probability distortion (fixing arbitrarily $\gamma = 1$), and we determined the corresponding level of the loss aversion parameter (λ) based on the return rate of the combinations # 5 and # 6. The return rate of children aged 5-6 and 7-8 was higher than 50% for combination # 5 and # 6 (albeit not significant for combination # 5, table 2), thus we search the value of λ for which children accepted the gamble for both combinations, and for which they exchanged more for combination # 6 than # 5. We found $1 < \lambda \leq 2$ for both age categories (figure 3a); this indicates that children aged over 5 were highly loss averse: when a loss was at stake, subjects accepted to exchange if the net potential gain was higher than at least 1 to 2 times the loss.

If we make the assumption of no loss aversion (fixing arbitrarily $\lambda = 1$), we can employ the Kahneman and Tversky's probability weighting function in order to find γ, the probability distortion parameter. For both age groups, we determined the value of γ for which children accepted the gamble for combinations # 5 and # 6, but exchanged more for combination # 6 than # 5. We found $0.32 < \gamma < 1$ for both age groups (figure 3b). This value points at a strong probability distortion. The function takes the shape of an inverse S-shaped with an inflexion point close to a probability of 0.15; individuals perceived low probabilities under 0.15 higher than their actual value, and high probabilities over 0.15 lower than their actual value (see electronic supplementary material figure S2B). However, for these values of γ we cannot explain why children rejected the gamble for combination # 10.

The loss aversion parameter λ and the probability distortion parameter γ can also be assessed together. For both categories, we determined the values of λ and γ based on the conditions previously used, i.e. the return rate of combinations # 5 and # 6, and the combination after which children rejected the gamble. We found that values of γ were acceptable only when $\lambda > 1$ (figure 3c), indicating that loss aversion was critical in the choices of 5-6 and 7-8 years old. For the probability distortion parameter, all values of γ were acceptable (< or > 1; figure 3c). For instance, $\lambda = 2.5$ and $\gamma = 0.6$ meant that children were loss averse, and overweighed low-probability events while underweighting high-probability ones. As another example for acceptable values, $\lambda = 1.5$ and $\gamma = 1.3$ meant that children were loss averse, and underweighted low-probability events while overweighting high-probability ones. These results on loss aversion hold if the probability weighting function is either convex (or concave) for gains, and concave (or convex) for losses. Therefore, the non-linearity of the value function (loss aversion) override the non-linearity of the weighting function, making loss aversion the main discriminatory criterion in choices of children aged over 5.

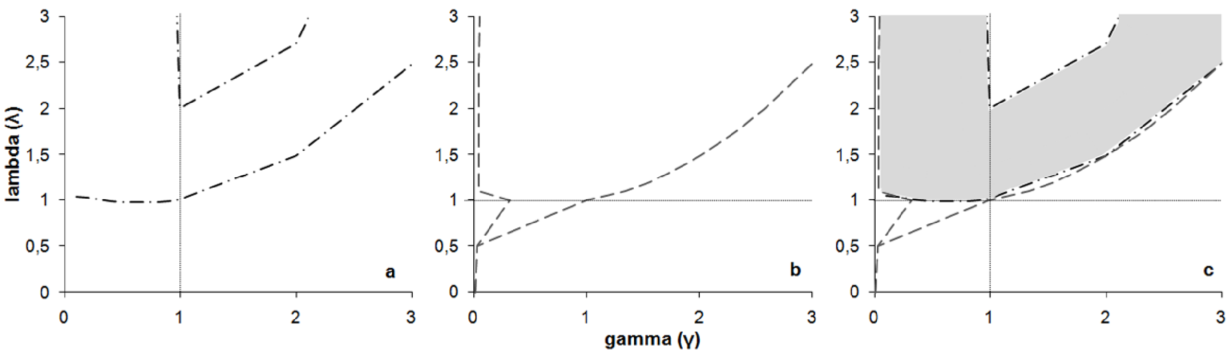


Figure 3. Estimation of the loss aversion parameter λ and the probability distortion parameter γ: a. Under the assumption of no probability distortion (fixing arbitrarily $\gamma = 1$, grey continuous line), $1 < \lambda \leq 2$; b. Under the assumption of no loss aversion (fixing arbitrarily $\lambda = 1$, grey continuous line), $0.32 < \gamma < 1$; c. Acceptable values for both loss aversion and probability distortion parameters (grey area).

4. DISCUSSION

All children engaged in a trading game providing a typical risky economic situation. Children aged 3 to 4 years old displayed an exchange rate inferior to 50%, so we could not identify risk-related biases in their decision-making. At this age, children display good performances in delay-of-gratification tasks, including the exchange task (Mischel *et al.* 1989; Steelandt *et al.* 2012); thus, the ability to control impulsivity, i.e. keeping the initial endowment instead of eating it, was not a limiting factor in this study. Lesser abilities in probabilistic evaluation may explain this failure as they only discriminated between the no gain and no loss combinations. In everyday life children commonly encounter binary choices ("you will have or you won't have a dessert"), but are seldom submitted to choices offering probabilities ("you have a one in five chance to have a dessert"). Failure in adapting their return to combinations may also be due to the use of heuristics, i.e. intuitive judgment; for example they may have used a rule consisting in summing the content of the six cups ("I see a lot of cookies, I try").

Children aged 5-6 years were able to adapt their return according to the combinations of rewards. Responses were mainly based on the probability of losing. This finding is consistent with the development of probability estimation by age 5 (Anderson 1991; Reyna & Brainerd 1994; Schlottmann 2001; Pange & Talbot 2003). Although probably incomplete (Schlottmann & Anderson 1994; van Leijenhorst *et al.* 2008), the understanding of probabilistic rules in 5-year-old children, and its development with age, allowed them to attempt optimizing their benefits. Better performances were observed in older children, aged 7-8 years, as they were more discriminative with the combinations. Still, the decision was not always optimal given that some children kept on exchanging for the "no win" combination, and refused for the "no loss" combination.

Our results show that decision-making was affected by several judgment errors. We detected a framing effect; children starting with high probabilities of gain exchanged more than children starting with low probabilities of gain. Variations in framing are known to affect significantly decisions and risk-aversion in adults (Holt & Laury 2002; Lévy-Garboua *et al.* 2011). Individuals are risk-averse when presented with value-increasing options, but more risk-taking when faced with decreasing values (Thaler 1985; Linveille & Fischer 1991; Kessler *et al.* 1996). Recent studies have reported that behavioral responses to framing may vary according to the set-up used (Lévy-Garboua *et al.* 2011). For example, high incentives to win can have more impact on risk aversion than low incentives. Future research will have to compare the framing effects detected in children with those found in adults.

When confronting data to the expected utility model which states that agent are rational decision-makers, we found that even if children aged over 5 appeared to behave consistently with EUT model with a risk-seeking attitude, some results could not be explained in this framework. Instead, the CPT model could explain better the biases observed. Specifically, implementing a loss aversion parameter strongly explained deviations from rational behavior. The acceptable values of loss aversion parameter is comprised between 1 and 2, which is closed to Kahneman and Tversky's experimentally validated value of 2.25 for adults and adolescents (Kahneman & Tversky 1979; Tversky & Kahneman 1992). This means that, facing a risky decision, children accept to exchange if the net potential gain is higher than at least 1 to 2 times the loss. In adults studies showed strong inter-individual differences in loss aversion, depending on the initial wealth and the level of trust and education (Feldman 2011). The value of the parameter found in children suggests that these factors may already affect their behavior when facing risk. A second parameter known to affect decision-making in risky situations is probability distortion. It is often reported for adults in circumstances involving extreme probabilities such as lotteries (Barberis & Huang 2008). Here, we found probability distortion with children overweighting or underweighting probabilities. However, the value function (loss aversion) overrode the nonlinearity of the weighting function. This makes loss aversion the main process explaining children's decision-making.

From an early age, children exhibit deviations from rational decision-making that appear to be similar to adults. In the latter, some biases such as loss aversion were shown to conduct to negative profitability (Feldman 2011). Loss aversion can induce investors to keep their investment for too long instead of selling assets, resulting in lower ex-post long-term earnings, a well-known pattern of bias referred as to the disposition effect (Odean 1998). The prospect of an important loss can lead people to excess risk taking. Adult-like loss aversion in children confirms that economic biases appear early in childhood. More generally, this finding may have educational implications for dealing with risk-oriented attitudes. Children aged over 5 years old can detect and try to adjust to a risky situation, but they also start to take more risk. This period appears determinant for parents and teachers when teaching children about risky behaviors and their negative consequences.

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Electronic supplementary material

I/ Participants and conditions

The sample of 288 children was divided into six age-groups: 3 years old (mean age ± SEM = 42.3 ± 2.2 months), 4 years old (mean age = 54.3 ± 4.2), 5 years old (mean age = 65.5 ± 1.9), 6 years old (mean age = 78.0 ± 3.4), 7 years old (mean age = 89.3 ± 3.6) and 8 years old (mean age = 100.0 ± 4.0). Equal numbers of girls and boys were tested in each of groups. Twelve additional children whose parents had given consent were tested, but were excluded from the dataset analyzed for being outside of the appropriate age ranges, or for not paying attention to the tests. Eleven children had already participated in previous experiments and were familiar with the exchange procedure (Steelandt *et al.* submitted).

A letter and an information sheet describing the general purpose of the study were given to the parents who gave signed consent for their children's participation. No financial remuneration was offered, but children received the sweets they won during the testing session. A video camera recorded the session after parental written consent had been obtained.

II/ Exchange procedure

The experimenter was unfamiliar to the children. Before testing the experimenter introduced herself to the child to put them at ease. Only one parent was allowed to stay with the child during testing. Parents were instructed not to interfere by initiating communication or interactions during testing; if a child sought interaction with parents, they were asked to draw the child's attention back to the experimenter without directing her/his response or give any hints of what s/he was supposed to do. If the child wanted to interact with the experimenter, she repeated the instructions and encouraged her/him to redirect her/his attention to the task. During testing children were seated on a chair across from the experimenter.

The experiment lasted approximately 20 minutes. During the training phase, each child was asked to indicate a preference for either a small piece of cookie of dimension 1 x 0.5 x 0.5 cm or a larger piece of cookie of dimension 4 x 0.5 x 0.5 cm. Each child selected the larger reward. Then, the child was given the small piece of cookie, and was invited to return it to obtain the larger one. If the child exchanged successfully, the test started. If s/he failed, the request was repeated twice. If nothing happened after 5 s, testing ending. The child was given a plastic bag to save cookies s/he had obtained before the start of a new trial.

III/ Expected Utility Theory

Economic theoretical models require individuals to respect first-order stochastic dominance which translate in our study by always exchanging when 100% chances of winning and never exchanging when 100% chances of losing. In our dataset, 24.7% of the children always accepted to exchange at the combination # 0 (no loss) and always refused at the combination # 10 (no gain). Because the percentage of return at each combination between these children and the whole population was similar according to age, we further included the data of all the tested children in the models.

Von Neumann and Morgenstern (1944) introduced the Expected Utility Theory stating individual preferences with a mathematical function named as "utility function". The utilities values of options are weighted by their respective probabilities and compared by the individuals to determine their choice. Let $x = ((x_i, p_i), i = 1,\ldots,n)$ denote a lottery where x_i is the i-th outcome, and p_i the corresponding probability. Rational individual who is offered a choice between the lottery x and a certain amount W is supposed to choose the option with the higher expected value maximizing their expected utility and to keep the certain amount if:

$$u(W) > E[u(x)] \Leftrightarrow u(W) > \sum_{i=1}^{n} p_i u(x_i)$$

The utility function may take different mathematical forms, but we choose $u(y) = y^{\delta}$, $\forall$ y, where y is the quantity of item and δ is the risk aversion parameter. Evaluating each item value y is a straightforward way to measure the item area. Thus, smaller pieces of cookies of 1 x 0.5 x 0.5 cm were valued 0.25, pieces of cookie of 4 x 0.5 x 0.5 cm were valued 1, and larger pieces of cookie 4 x 2 x 0.5 cm were valued 4. As children could obtain one randomly chosen piece of cookie among the six offered, the evaluation of each combination of rewards is described in table S1. For instance, the combination # 3 containing 2 small, 1 medium and 3 large rewards was evaluated $E[u(\#3)]=(2/6\times0.25^{\delta}) + (1/6\times1^{\delta}) + (3/6\times4^{\delta})$ in EUT.

In each trial the experimenter offered the medium item, and children had to choose between keeping it or giving it back in order to obtain one cup of rewards. According to EUT children should prefer the gamble to the medium item if the expected utility of the gamble exceeded the utility of the certain outcome (table S1). For instance, in #3 the gamble was preferred if $E[u(\#3)] > (1)^{\delta}$.

IV/ Cumulative Prospect Theory

Under CPT, subjects evaluate the opportunity to play the lottery $x = ((x_i, p_i), i = 1,\ldots,n)$ by computing a valuation function $V(x)$ defined as follows:

$$V(x) = V(x^+) + V(x^-) = \sum_{i=m+1}^{n} \pi_i^+ v(x_i) + \sum_{i=1}^{m} \pi_i^- v(x_i)$$

where $x^+ = max(0,x)$; $x^- = -max(0,-x)$

The first element of CPT is to define x in terms of net gains and losses, and to rank the outcomes of the lottery in increasing order. The evaluation function is defined over these two domains with different decisions weights π_i and a specific value function $v(.)$. The value function is analogous to the utility function of EUT but is defined differently over gains and losses:

$$v(y)=\begin{cases} y^{\alpha} & \text{if } y \geq 0 \\ -\lambda y^{\beta} & \quad\; y < 0 \end{cases}$$

with $\lambda > 1$ (loss aversion) and $0 < \alpha, \beta \leq 1$ (diminishing sensitivity)

The value function is generally concave on gains, convex on losses, and kinked at 0. The loss aversion parameter λ indicates that subjects are loss averse if λ > 1, which means that in any choice where a loss of *k* is at stake, subjects accept the bet if the net potential gain is higher than λ times *k*. Tversky and Kahneman (1992) experimentally identified a median value of λ = 2.25, indicating pronounced loss aversion. In our study this value would mean that children accepted to lose a medium piece of cookie if s/he could gain a piece of cookie with a size 2.25 times the medium piece of cookie.

Here, gains and losses were amounts of cookies that were directly consumed by children in excess or less than the reference consumption amount 1. To simplify, we used α=β=1 (for piecewise linear functions, figure S1). For instance, for children using CPT in their choice, combination # 3 was perceived as an opportunity to realize 3 gains (3 large instead of 3 medium items), each evaluated 3 (4 - 1), and to incur 2 losses (2 small instead of 2 medium items), each evaluated -0.75 (0.25 - 1).

The second element explaining the choice of children using CPT in decision-making is the weighting parameter. Individuals use weights of outcomes instead of probabilities, represented by a non-linear function $w(.)$ that is defined separately on the cumulative probability distribution of gains (+) and losses (-):

$$\pi_1^- = w^-(p_1)$$

$$\pi_i^- = w^-(F_x(x_i)) - w^-(F_x(x_{i-1})) = w^-\left(\sum_{j=1}^{i} p_j\right) - w^-\left(\sum_{j=1}^{i-1} p_j\right) \qquad \mathit{for}\ 2 \leq i \leq m$$

$$\pi_n^+ = w^+(p_n)$$

$$\pi_i^+ = w^+(1 - F_x(x_{i-1})) - w^+(1 - F_x(x_i)) = w^+\left(\sum_{j=1}^{n} p_j\right) - w^+\left(\sum_{j=i+1}^{n} p_j\right) \qquad \mathit{for}\ m \leq i < n$$

where F_x is the cumulative distribution function of lottery *x*. The probability weighting function put forward in the literature is generally inverse S-shaped. To simplify, we used $w^+(.) = w^-(.) = w(.)$ and made our computations with the Tversky and Kahneman (1992) probability weighting function:

$$w(p) = \frac{p^{\gamma}}{(p^{\gamma} + (1-p)^{\gamma})^{1/\gamma}}$$

where γ is the probability distortion parameter, w (0) = 0 and w (1) = 1

This specific probability weighting function takes the shape of an inverse S if $0 < \gamma < 1$, which is a common characteristic of all weighting functions (Gonzalez & Wu 1999). In this function, γ both controls for the level of the inflexion point and for the curvature. Tversky and Kahneman (1992), Camerer and Ho (1994) and Wu and Gonzalez (1996) have estimated the weighting function to a value of 0.56, 0.61 and 0.71, respectively. Figure S2A gives an example with a value $\gamma = 0.6$ estimated by Tversky and Kahneman, meaning that subjects perceive low probabilities (under 0.35) higher and high probabilities (over 0.35) lower than their actual value. In adults studies showed risk-seeking over small-probability gains and high-probability losses, and risk-aversion over high-probability gains and small-probability losses (Tversky & Kahneman 1992).

The evaluation of each combination deeply depends on values chosen for γ and λ. Table S6 presents CPT evaluations of all combinations of rewards with no probability distortion, i.e. $\gamma = 1$, and with no loss aversion, i.e. $\lambda = 1$. For instance, for $\gamma = 1$ (no probability distortion as $w(p)=p$) and $\lambda = 2.25$ (loss aversion), we would get V(# 3) = 1.88 which would indicate that, according to CPT, children should accept to exchange the initial item. A negative value would indicate that children should keep the initial item.

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Wu, G. & Gonzalez R. 1996 Curvature of the probability weighting function. *Manag. Sci.* **42**, 1676–1690.

Table S1. Evaluation of each combination of rewards following the Expected Utility Theory (δ is the risk aversion parameter), with δ = 1 (neutral facing risk behavior). From combination # 0 to # 7, the expected utility is superior to the certain amount, and children should exchange. For combination # 8, the expected utility is equal to the certain amount. For combinations # 9 and # 10, the expected utility is inferior to the certain amount, thus children should not exchange.

#	EUT	δ = 1	EUT evaluation
0	$4^{\delta}.(6/6)$	4	**EU > certain amount**
1	$4^{\delta}.(4/6)+1^{\delta}.(2/6)$	3	
2	$4^{\delta}.(4/6)+0.25^{\delta}.(2/6)$	2.75	
3	$4^{\delta}.(3/6)+1^{\delta}.(1/6)+0.25^{\delta}.(2/6)$	2.25	
4	$4^{\delta}.(2/6)+1^{\delta}.(2/6)+0.25^{\delta}.(2/6)$	1.75	
5	$4^{\delta}.(2/6)+0.25^{\delta}.(4/6)$	1.5	
6	$4^{\delta}.(1/6)+1^{\delta}.(5/6)$	1.5	
7	$4^{\delta}.(1/6)+1^{\delta}.(2/6)+0.25^{\delta}.(3/6)$	1.125	
8	$4^{\delta}.(1/6)+1^{\delta}.(1/6)+0.25^{\delta}.(4/6)$	1	**EU = certain amount**
9	$4^{\delta}.(1/6)+0.25^{\delta}.(5/6)$	0.875	**EU < certain amount**
10	$0.25^{\delta}.(6/6)$	0.25	

Table S2. Comparisons of the mean percentage of return between the different age-groups using Tukey HSD pairwise comparison post-hoc tests.

	Tukey HSD pairwise comparison test	
age	Z value	p
3-4	3.37	0.13
3-5	5.94	< 0.001
3-6	6.96	< 0.001
3-7	6.40	< 0.001
3-8	6.30	< 0.001
4-5	2.59	< 0.05
4-6	3.61	< 0.05
4-7	3.03	< 0.01
4-8	2.96	< 0.01
5-6	1.03	0.91
5-7	0.42	0.99
5-8	0.39	0.99
6-7	-0.62	0.99
6-8	-0.64	0.98
7-8	-0.03	1

Table S3. Tukey HSD pairwise comparison post-hoc tests for combinations significantly differing by the mean percentage of return.

	3 years		4 years		5 years		6 years		7 years		8 years	
combinations	Z value	p	Z value	p	Z value	p	Z value	p	Z value	p	Z value	p
1-0									-3.29	<0.05		
4-0							-3.43	<0.05	-3.30	<0.05	-3.29	<0.05
5-0					-3.58	<0.05	-4.14	<0.0	-3.30	<0.05		
7-0					-3.24	<0.05	-4.42	<0.001	-4.27	<0.001	-3.58	<0.05
8-0					-3.41	<0.05	-4.56	<0.001				
9-0					-3.24	<0.05						
10-0	-3.63	< 0.05	-4.05	<0.01	-7.19	<0.001	-6.56	<0.001	-6.50	<0.001	-7.13	<0.001
10-1	-3.97	< 0.01			-6.46	<0.001	-4.90	<0.001	-3.63	<0.05	-5.47	<0.001
10-2					-5.40	<0.001	-4.16	<0.001	-4.47	<0.001	-5.33	<0.001
10-3					-5.24	<0.001	-5.33	<0.001	-4.61	<0.001	-5.07	<0.001
10-4					-5.55	<0.001	-3.57	<0.05	-3.63	<0.05	-4.39	<0.001
10-5					-4.13	<0.01			-3.63	<0.05	-4.53	<0.001
7-6							-3.31	<0.05				
8-6							-3.46	<0.05				
10-6					-6.46	<0.001	-5.61	<0.001	-4.75	<0.001	-6.00	<0.001
10-7					-4.45	<0.001					-4.12	<0.001
10-8					-4.29	<0.001			-3.77	<0.01	-4.80	<0.001
10-9					-4.45	<0.001	-4.89	<0.001	-3.91	<0.01	-4.80	<0.001

Table S4. Influence of the probability of losing P_L (getting a small piece of cookie in this trial), the probability of gaining P_G (getting a large piece of cookie in this trial), and the interaction P_L x P_G on the exchange behaviors of children.

Variables	3 years	4 years	5 years	6 years	7 years	8 years
P_L	z = -1.081 (p = 0.28)	z = -0.345 (p = 0.73)	z = -4.267 (p < 2e-5)	z = -3.303 (p < 9e-4)	z = -2.554 (p < 0.05)	z = -3.777 (p < 2e-4)
P_G	z = 1.407 (p = 0.16)	z = 1.499 (p = 0.13)	z = 0.305 (p = 0.76)	z = 1.370 (p = 0.17)	z = 1.670 (p = 0.10)	z = 0.991 (p = 0.32)
P_L*P_G	z = 0.683 (p = 0.50)	z = -0.364 (p = 0.72)	z = 1.414 (p = 0.16)	z = 0.861 (p = 0.39)	z = 1.866 (p = 0.06)	z = 1.994 (p < 0.05)

Table S5. Evaluation of each combination of rewards following the Cumulative Prospect Theory (without probability distortion and loss aversion).

#	CPT no probability distortion: $\gamma = 1$	CPT no loss aversion: $\lambda = 1$
0	0	6.(1-w(1))
1	3	6.(1-w(1/3))
2	4-0.5λ	6.(1-w(1/3))-3.375.w(1/3)
3	3-0.5λ	6.(1-w(1/2))-3.375.w(1/3)
4	2-0.5λ	6.(1-w(2/3))-3.375.w(1/3)
5	2-λ	6.(1-w(2/3))-3.375.w(2/3)
6	1	6.(1-w(5/6))
7	1-0.75λ	6.(1-w(5/6))-3.375.w(1/2)
8	1-λ	6.(1-w(5/6))-3.375.w(2/3)
9	1-1.25λ	6.(1-w(5/6))-3.375.w(5/6)
10	1-1.5λ	6.(1-w(1))-3.375.w(1)

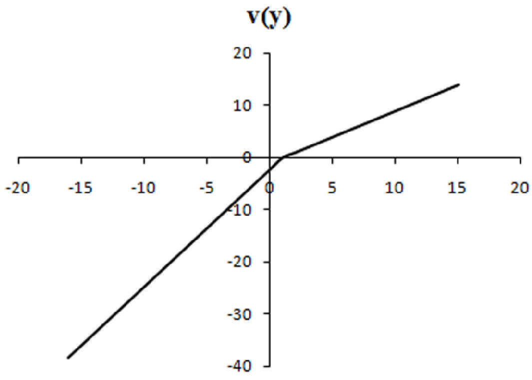


Figure S1. Kahneman and Tversky evaluation function for $\alpha = \beta = 1$, $\lambda = 2.25$, and a reference point of 1.

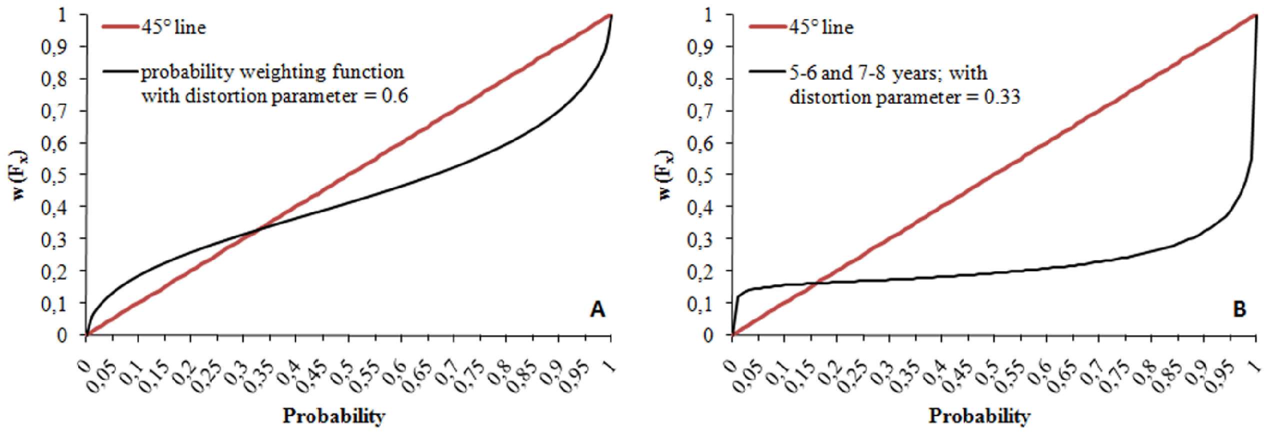
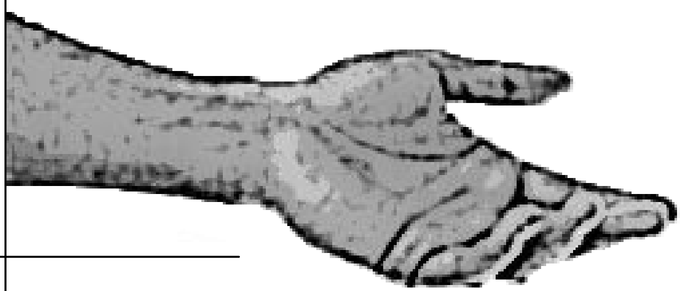


Figure S2. A. Kahneman and Tversky probability weighting function for $\gamma = 0.6$ The inflexion point is close to a probability of 0.35; individuals perceive low probabilities under 0.35 higher than their actual value and high probabilities over 0.35 lower than their actual value. B. Probability weighting function for children aged over 5 years ($0.32 < \gamma < 1$). For $\gamma = 0.33$, the inflexion point is close to a probability of 0.15; individuals perceive low probabilities under 0.15 higher than their actual value and high probabilities over 0.15 lower than their actual value.

CHAPITRE 7

DISCUSSION GENERALE



Au cours de cette thèse, j'ai cherché à déterminer comment les compétences économiques se mettent en place chez l'enfant. Dans un premier temps, j'ai étudié le développement du don et de l'échange chez les enfants pour savoir s'ils pouvaient les utiliser comme moyens permettant de maximiser leur gain (Chapitre III). Dans une seconde partie (Chapitre IV), j'ai étudié la capacité des enfants à s'engager dans une transaction offrant un profit différé dans le temps. La troisième partie (Chapitre V) a eu pour objectif de tester la capacité des enfants à calculer leur investissement de façon rationnelle sur la base de différentes offres. Enfin, dans la dernière partie (Chapitre VI), j'ai étudié la faculté des enfants à maximiser leur bénéfice dans une situation économique risquée.

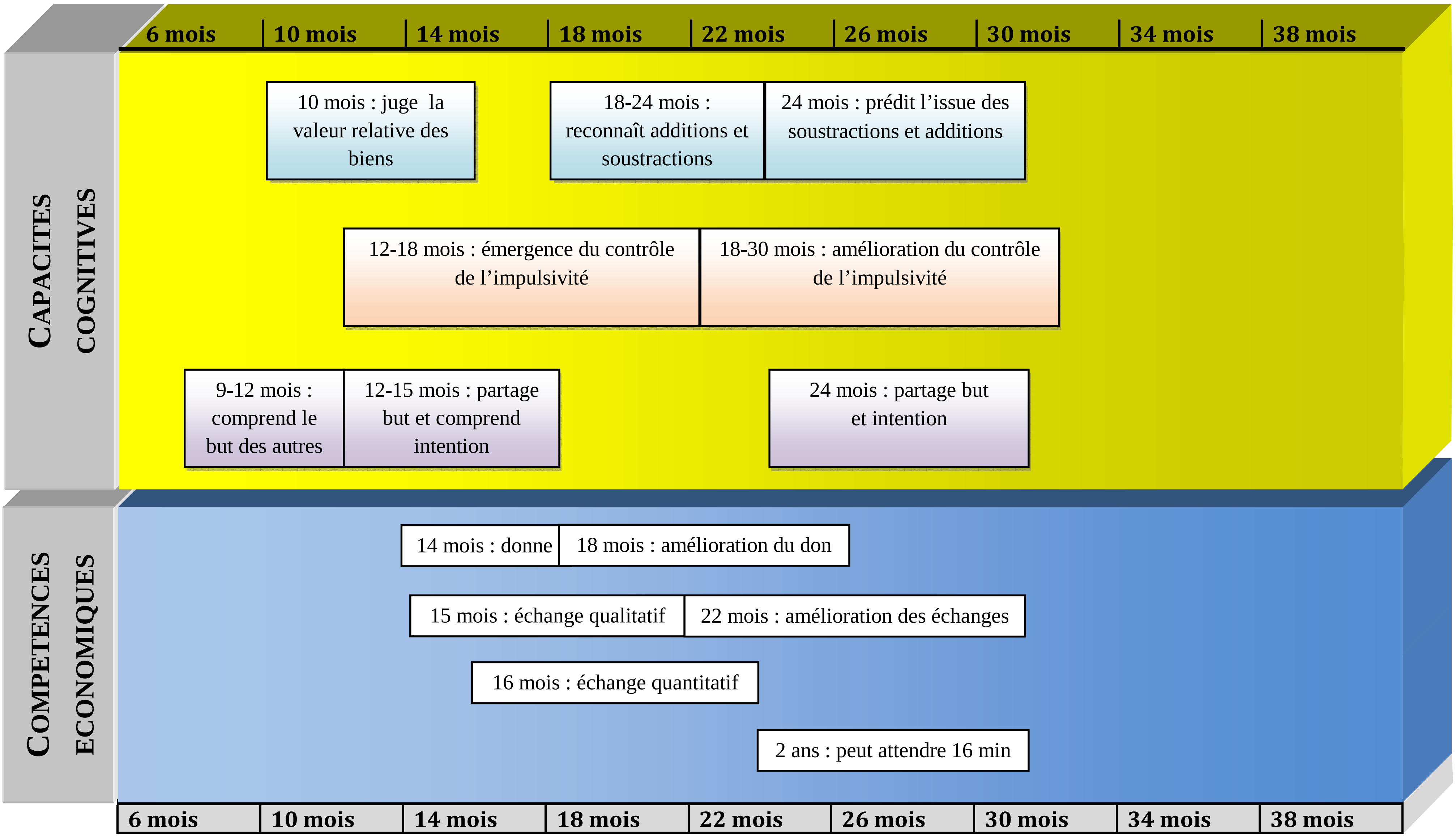
Au terme de ce travail, plusieurs éléments de réponse peuvent être apportés concernant les performances économiques des enfants. Il apparaît tout d'abord que les compétences de base nécessaires à l'optimisation des bénéfices au cours d'une transaction se mettent en place progressivement au cours du développement. L'acquisition des premières compétences, telles que l'aptitude à donner ou à s'engager dans un échange, s'amorce dès la première année de vie avant même que l'enfant puisse communiquer de manière efficace avec son environnement. Vers cinq ans, les principales compétences économiques semblent acquises chez la plupart des enfants, bien que certaines nécessitent encore quelques années de développement pour arriver à l'optimisation des conséquences de leurs décisions. La fin de la petite enfance laisse place à des agents économiques capables de maximiser leur satisfaction au cours d'un échange avec une autre personne à travers le contrôle de l'impulsivité, le calcul de l'investissement et l'appréciation du risque lié à la transaction.

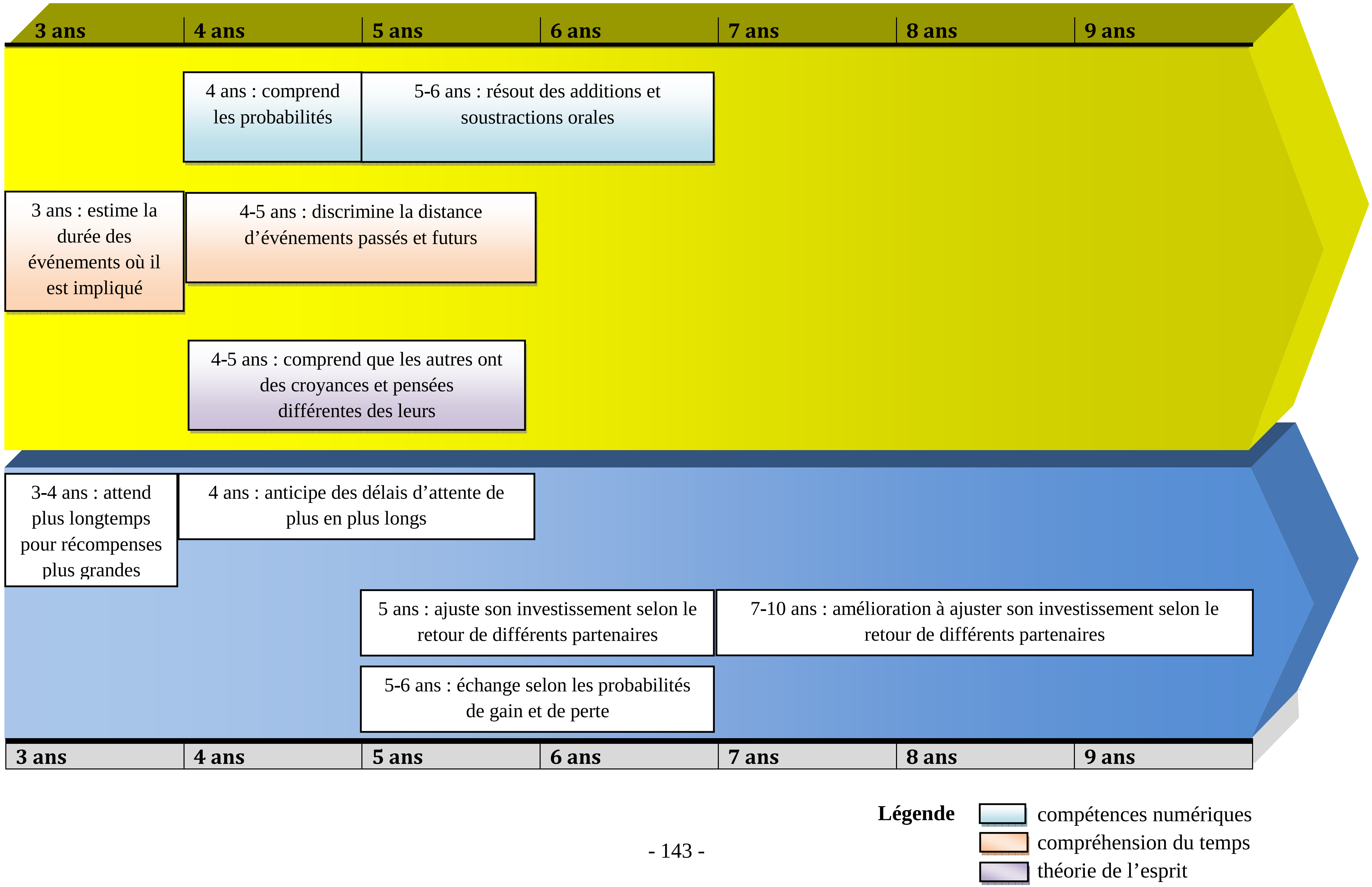
Le développement des compétences économiques se réalise en parallèle à l'acquisition des outils cognitifs. Le fait que dans des environnements socioculturels variés les enfants suivent une séquence similaire de développement socio-cognitif suggère que l'apprentissage est contraint par des mécanismes innés. Il en est probablement de même pour les compétences économiques, ce qui peut expliquer les différentes périodes d'acquisition mises en évidence dans cette étude.

1. LE DEVELOPPEMENT DES COMPETENCES ECONOMIQUES

Les recherches menées au cours de ce travail ont permis de préciser les compétences économiques des enfants : leur engagement dans une interaction avec un partenaire inconnu, leur tolérance face à une transaction offrant un profit différé dans le temps, leur capacité à calculer un investissement sur la base de l'offre de différents partenaires, et leur aptitude à maximiser le bénéfice dans une situation risquée. L'acquisition de ces compétences correspond à ce que l'on connaît des stades de développement des capacités de calcul numérique, de jugement temporel et de compréhension des états mentaux d'autrui. La figure 2 présente sur une même échelle temporelle les parallèles trouvés entre les périodes de développement des compétences économiques mises en évidence dans cette thèse et les stades connus de développement des capacités cognitives et sociales chez l'enfant. Mes résultats mettent en évidence deux grands stades dans le processus de développement des compétences économiques, vers 2 ans et 4-5 ans.

Figure 2 : Période d'émergence et de développement des compétences économiques (données issues des études réalisées au cours de cette thèse) et des capacités cognitives et sociales connues des enfants âgés de 6 mois à 10 ans.




3 ans
4 ans
5 ans
6 ans
7 ans
8 ans
9 ans
4 ans : comprend les probabilités
5-6 ans : résout des additions et soustractions orales
3 ans : estime la durée des événements où il est impliqué
4-5 ans : discrimine la distance d'événements passés et futurs
4-5 ans : comprend que les autres ont des croyances et pensées différentes des leurs
3-4 ans : attend plus longtemps pour récompenses plus grandes
4 ans : anticipe des délais d'attente de plus en plus longs
5 ans : ajuste son investissement selon le retour de différents partenaires
7-10 ans : amélioration à ajuster son investissement selon le retour de différents partenaires
5-6 ans : échange selon les probabilités de gain et de perte
3 ans
4 ans
5 ans
6 ans
7 ans
8 ans
9 ans
Légende
compétences numériques
compréhension du temps
théorie de l'esprit

1.1. Le bouleversement de la deuxième année

Toute transaction implique un transfert de valeurs sous forme d'objets (ARTICLE 1) ou d'items alimentaires (ARTICLES 1 à 4). Par conséquent, il était nécessaire que les enfants soient en mesure d'évaluer ce qui est donné et reçu au cours des échanges proposés afin de faire des choix optimaux. Dès leur première année de vie, les enfants savent discriminer et juger la valeur de quantités discrètes d'items (Butterworth, 2005 ; Lipton & Spelke, 2004). L'aptitude à estimer la valeur des récompenses, qui est un pré-requis indispensable à la maximisation des bénéfices, n'a donc pas représenté un facteur limitant pour les enfants.

L'analyse des résultats de la première étude montre que les enfants reconnaissent très tôt leur propre intérêt au cours d'une transaction puisque des enfants refusant de donner un objet à un partenaire acceptent de s'engager dans l'échange lorsque celui-ci leur propose une récompense en retour (ARTICLE 1). Les enfants peuvent donc utiliser les autres personnes dans le but de maximiser leurs gains. Cependant, la réponse principale des enfants révèle aussi une attitude pour le don dénuée d'intérêts propres. La plupart des jeunes enfants peuvent en effet donner facilement à un expérimentateur non familier, et chez les plus timides, le fait d'avoir des frères et sœurs permettrait de contrebalancer cette timidité. La maximisation des bénéfices est plus tardive lors des échanges quantitatifs et qualitatifs, les enfants acceptant de s'engager dans l'échange à partir de 15 et 16 mois respectivement (ARTICLE 1). Il est intéressant de noter que cette compétence se voit acquise durant l'émergence de l'aptitude à attribuer des états mentaux à autrui, c'est-à-dire entre 9 et 18 mois (Tomasello, 2007). Au cours de cette période, les enfants comprennent que leurs partenaires sont des agents intentionnels, ce qui les aide à s'engager dans des activités sociales (Tomasello, 1995). Peu avant deux ans, ils améliorent cette faculté et partagent activement avec le partenaire à la fois les buts et les intentions des actions (Bratman, 1992 ; Tomasello, 2007 ; Tomasello et al., 2005), ce qui peut rendre compte de l'augmentation des performances d'échange vers 18-22 mois (ARTICLE 1). L'acquisition précoce d'une théorie de l'esprit explique également que la plupart des enfants aient accepté de s'engager dans les différentes transactions avec un partenaire inconnu. Ils étaient en mesure de comprendre le but recherché et la manière de l'atteindre : utiliser l'échange pour maximiser le bénéfice même s'il leur fallait attendre un certain temps (ARTICLE 2), et cela même si le partenaire ou la transaction rendait l'issue de l'interaction incertaine (ARTICLES 3 et 4). Ajoutons que la compréhension de ce que pense ou croit le partenaire au cours de l'interaction apparaît beaucoup plus tardivement (Gopnik & Astington, 1988 ; Tomasello & Rakoczy, 2003 ; Wellman, 1990) et ne serait donc pas nécessaire pour qu'un enfant maximise ses gains en acceptant de s'engager dans un échange. Il n'en demeure pas moins que cette aptitude est un mécanisme qui peut permettre de mieux reconnaître les attentes du partenaire et les possibilités de tricherie associées à la transaction (cf. section suivante). Outre l'effet probable de la compréhension du rôle des autres dans l'amélioration des performances des enfants, un meilleur contrôle de soi pourrait également leur permettre d'atteindre de meilleures performances (ARTICLE 1). La progression des enfants dans la première expérience coïncide en effet avec ce que l'on sait de l'amélioration des performances en termes de contrôle de l'impulsivité après 18 mois.

L’étude de la dimension temporelle de l’échange apporte également de nouveaux éléments de réponse dans ce domaine. Seuls deux enfants de 2 ans (sur 24) confrontés à une longue période d’attente ont été capables d’attendre pour obtenir une récompense finale. Les performances des enfants de 3 et 4 ans se sont avérées nettement meilleures (ARTICLE 2). Cela nous apprend que l’aptitude à contrôler l’impulsivité au cours d’une transaction pourrait émerger peu avant 2 ans. Plusieurs études ont constaté une acquisition de la maîtrise de soi entre 12 et 18 mois puis une amélioration rapide entre 18 et 30 mois (Kopp, 1982 ; Piaget, 1952, 1954 ; Vaughn et al., 1984). Mes résultats viennent confirmer cette évolution dans un contexte social d’échange dans lequel les enfants sont fréquemment impliqués (échange différé de cartes ou de billes à la récréation par exemple).

Notons que la fin de la première année de vie voit l’acquisition du langage, dans le sens de la communication linguistique (Owens, 2008 ; Tomasello, 2008). Avant même qu’ils puissent communiquer de manière efficace au travers du langage (West & Rheingold, 1978), les enfants de 14 mois comprennent comment maximiser leur bénéfice en s’engageant dans un échange (ARTICLE 1). Même si l'apprentissage du langage se poursuit au-delà des 3 ans, c’est principalement avant cet âge que les transformations de la communication verbale orale sont les plus remarquables tant en compréhension qu'en production. L'acquisition du langage par l'enfant se déroule en parallèle avec le développement de nombreuses aptitudes sociales et cognitives (Carpenter et al., 1998). Notamment, la réalisation de certaines interactions coopératives s’améliore avec son développement (Clark, 1996) ; bien que le langage ne soit pas indispensable à l’enfant pour partager le but d’une autre personne, son développement facilite l’engagement actif des enfants avec leur partenaire (Carpenter et al., 1998 ; Tomasello et al., 2005), et plus tardivement la compréhension de leurs états mentaux (Flavell, 1999 ; Malle, 2002). Vygotsky (1962) a également mis en avant l’importance du langage en tant qu’instrument utilisé dans le contrôle de l’impulsivité ; mes données supportent cette idée, puisque les enfants qui utilisaient des stratégies de distraction consistant à communiquer avec leur parent avaient de meilleures performances d’attente (ARTICLE 2).

Un long processus de développement apparaît nécessaire pour que l’enfant devienne un agent économique capable d’optimiser ses décisions. Le premier changement majeur se situe durant la deuxième année de vie quand l’enfant comprend que s’engager dans l’échange peut lui permettre de tirer des bénéfices immédiats ou différés dans le temps. Cette compétence se développe durant une période clé d’acquisition de plusieurs facultés cognitives (évaluation des biens échangés et compréhension du but de la transaction), située juste avant 2 ans et mise en avant par plusieurs chercheurs (Eckerman & Peterman, 2001 ; Piaget, 1972 ; Tomasello, 2007).

1.2. Vers la période décisive des 4-5 ans

L’aptitude précoce des enfants en termes d’évaluation des quantités leur permet de comparer sans difficulté la valeur des items donnés et reçus (Butterworth, 2005 ; Lipton & Spelke, 2004). Pourtant, l’optimisation du comportement lors de transactions requérant un calcul de l’investissement (ARTICLE 3) ou lors de transactions risquées (ARTICLE 4) nécessite le développement de capacités arithmétiques plus élaborées telles que compter ou estimer des probabilités de gain et de perte. L'école joue un rôle majeur dans l'apprentissage littéraire et mathématique entre 3 et 11 ans (Esquivel et al., 2007). Bien que les enfants étaient en mesure de maximiser la satisfaction retirée de leurs transactions au cours d'un investissement en se basant uniquement sur des mécanismes approximatifs de calcul (rendre ou garder le plus ou le moins d'items possibles selon le partenaire), les plus de 5 ans comptaient spontanément le nombre de récompenses finales obtenues (ARTICLE 3). Chez ces derniers, des capacités arithmétiques plus avancées (Butterworth, 2005 ; Jordan et al., 1992 ; Levine et al., 1992) ont pu les aider à comparer les gains nets reçus des différents partenaires et ainsi guider leur décision. C'est également vers 5 ans que se développe la compréhension du concept de probabilité (Acredolo et al., 1989 ; Denison et al., 2006 ; Schlottmann, 2001), une capacité ayant probablement contribué au succès des enfants plus âgés qui ont adapté leurs choix aux combinaisons de récompenses offrant des probabilités variables de gains et de pertes (ARTICLE 4).

Les enfants sont capables d'attendre entre 5 s et 16 mn afin de maximiser leurs gains (ARTICLE 2). A 4 ans, ils font preuve d'anticipation quand ils sont soumis à des délais d'attente croissants. L'analyse du temps de renoncement dans la seconde étude montre en effet qu'ils prennent rapidement la décision d'attendre ou non en fonction de la durée (ARTICLE 2), ce qui indique qu'ils anticipent que l'obtention de la récompense leur demanderait d'attendre plus longtemps qu'à l'essai précédent. J'ai pu démontrer des mécanismes de décision similaires chez les enfants de 3 et 4 ans chez qui la valeur de la récompense offerte définissait leur décision de s'engager dans la transaction : ces derniers soutenaient des délais plus longs lorsque la récompense, plus importante, valait la peine d'attendre, c'est à dire représentait une quantité égale à au moins huit fois la quantité de l'item initial (ARTICLE 2). Un tel comportement est rationnel, dans une acceptation coûts/bénéfices, quand le coût de l'attente est supérieur au bien-être ou au bénéfice retiré immédiatement. On peut expliquer les performances croissantes avec l'âge par la notion qu'ont les enfants de la durée. L'aptitude à estimer la durée d'événements ou à comprendre le lien entre une décision présente et ses conséquences futures s'améliore après 4 ans (Friedman, 2003 ; Lemmon & Moore, 2007 ; Poole et al., 2006). Certains auteurs suggèrent également qu'un meilleur contrôle de soi pourrait être lié à la capacité à estimer les intervalles de temps entre deux événements (Darcheville et al., 1992 ; Siegman, 1961) ; cette compréhension tardive des durées pourrait expliquer les meilleures performances observées chez les enfants plus âgés. Ajoutons que mon étude corrobore parfaitement les résultats de recherches montrant que les enfants qui se donnent les moyens de freiner leur impulsivité par des comportements d'auto-distraction peuvent attendre plus longtemps (Miller & Karniol, 1976 ; Mischel et al., 1989, 1996 ; Toner & Smith, 1977). En effet, les enfants plus âgés qui tentaient régulièrement de se distraire avaient plus de facilité à tolérer une longue période d'attente ; en particulier, ceux optant pour des stratégies non focalisées sur la nourriture étaient plus performants (ARTICLE 2).

Dans un échange, une certaine maîtrise de soi peut aider à une prise de décision optimale. On constate en effet que c'est entre 3 et 5 ans que les enfants parviennent à maximiser leur bénéfice en calculant leur investissement face aux différents retours de partenaires d'échange (ARTICLE 3) ; c'est également à partir de 5 ans que les enfants ajustent leur comportement face aux risques de gains et de pertes de la transaction en cours (ARTICLE 4). Un contrôle de l'impulsivité mieux maîtrisé avec l'âge pourrait permettre aux enfants de prendre le temps de la réflexion avant de s'engager dans l'échange, leur évitant ainsi de se précipiter dans un choix de consommation immédiat du ou des item(s) offert(s) avant même que l'échange ne soit proposé par l'expérimentateur.

Il n'est pas rare de voir des enfants s'engager avec deux camarades dans deux transactions à la fois (échange de stickers) puis décider d'opter pour l'une ou l'autre des transactions ou d'adapter leurs échanges en conséquence (Barrett & Buchanan-Barrow, 2005). La troisième étude révèle que c'est assez tardivement au cours de l'enfance, entre 4 et 7 ans, que les enfants sont en mesure d'optimiser leur satisfaction en ajustant de façon rationnelle leur investissement sur la base du retour de différents partenaires d'échange (ARTICLE 3). Ce résultat a une implication majeure concernant la gestion de deux conflits économiques en parallèle par les enfants : une telle compétence demande une période de développement de plusieurs années avant d'être totalement maîtrisée.

Malgré des facultés qui apparaissent matures dans plusieurs domaines, l'étude de la prise de décision des enfants met en évidence de nombreuses erreurs cognitives. Mes résultats montrent que certains biais rencontrés chez les adultes (Kahneman & Tversky, 1979 ; Kahneman et al., 1982) peuvent être détectés très tôt chez les enfants ; ces bais influencent leurs décisions, les conduisant à ne pas prendre des décisions optimales. C'est le cas par exemple de l'aversion à la perte détectée chez les enfants de 3 ans qui, pour éviter de perdre totalement leur dotation initiale, préféraient garder au moins un item alimentaire à chaque essai (ARTICLE 3). Ce même biais est décelé plus tard dans la quatrième étude chez les plus de 5 ans qui acceptaient de s'engager dans une transaction risquée si le gain potentiel était supérieur à au moins une à deux fois la perte de l'item initial (ARTICLE 4). Ainsi, on peut constater que certaines situations sont favorables à une détection plus précoce des biais cognitifs. La situation d'échange risquée proposée aux enfants a mis en évidence un effet de présentation (*framing effect*), un biais classique chez les adultes, indiquant que la manière dont sont présentés les termes d'un choix détermine les réponses des individus (Tversky & Kahneman, 1981). J'ai en effet observé qu'une succession de combinaisons avec une probabilité décroissante de gains incitait les enfants à échanger plus souvent que ceux testés initialement avec des combinaisons présentant une importante probabilité de perte (séquence croissante de gains - ARTICLE 4). Ce biais est similaire à l'erreur de raisonnement « de la série gagnante » fréquemment retrouvée chez les joueurs de casino (Croson & Sundali, 2005 ; Tversky & Kahneman, 1971). Un joueur manifeste le biais de « la série gagnante » lorsqu'une succession de gains lui fait surestimer ses chances de gagner au prochain tour. Une différence cependant existe avec ce que j'ai pu observer dans le sens où les enfants débutant avec des combinaisons offrant des probabilités importantes de gains n'étaient pas assurés d'avoir une suite de bénéfices. Des biais cognitifs, présents à l'âge adulte et susceptibles de limiter la maximisation des gains, peuvent donc déjà être détectés entre 3 et 5 ans.

2. LE DEVELOPPEMENT SOCIAL ET SES INFLUENCES

Nous venons de voir que le développement des compétences économiques se réalise de façon parallèle à celui des facultés cognitives. Le développement des capacités sociales paraît suivre le même cours et constitue un indice supplémentaire en faveur d'une évolution majeure des compétences vers 4-5 ans. L'implication active d'un partenaire d'échange tout au long de la transaction a ajouté une composante sociale jusqu'ici négligée dans les recherches. Malgré le caractère non familier du partenaire et le risque d'une potentielle défection de sa part, les enfants ont accepté de s'engager dans les différentes transactions (ARTICLES 1 à 4). Les résultats obtenus indiquent que la maîtrise de la compréhension des états mentaux vers 4-5 ans pourrait également jouer un rôle important dans l'amélioration des performances économiques des enfants. C'est la période de développement au cours de laquelle les enfants commencent à considérer les autres comme des agents mentaux susceptibles de posséder des croyances et des pensées qui diffèrent des leurs et de la réalité (Tomasello & Rakockzy, 2003 ; Wellman, 1990). Une meilleure compréhension des autres représente pour l'enfant un moyen efficace de déterminer si le partenaire est digne de confiance et détecter d'éventuelles tricheries de sa part. La confiance facilite la coopération sociale (Berg et al., 1995 ; Fehr & Rockenbach, 2003 ; Fukuyama, 1995 ; Putnam, 1993) et, considérée comme subjective, elle permet de s'engager sur la base de croyances et d'attentes (Gambetta, 1988). Les enfants plus âgés ont pu ainsi accorder leur confiance au partenaire (toujours honnête dans la mesure où il ne changeait pas les règles de retour initialement annoncées), ce qui leur a permis de ne pas se limiter à l'évaluation de sa fiabilité et de calculer leur investissement en temps (ARTICLE 2) ou en biens (ARTICLE 3) et les risques liés à la transaction (ARTICLE 4).

Deux des études ont mis en évidence l'importance de l'environnement social dans lequel les enfants évoluent. J'ai montré que les enfants ayant des frères et sœurs s'engageaient plus facilement dans le don et l'échange avec leur parent ou un partenaire étranger (ARTICLE 1), et qu'ils étaient capables d'attendre plus longtemps pour obtenir une récompense (ARTICLE 2). De nombreux travaux nous avaient déjà appris que l'interaction entre frères et sœurs est un facilitateur de socialisation qui leur permet de s'engager plus facilement que les enfants uniques dans une transaction avec un partenaire non familier (Grusec & Hastings, 2007). Par ailleurs, le troc et le don sont parties intégrantes des jeux sociaux entre enfants de la même famille qui expérimentent donc plus souvent les interactions économiques et apprennent les normes associées à de tels échanges. La fratrie favorise également la capacité des enfants à se contrôler : attendre son tour ou laisser se terminer une conversation sont autant d'expériences leur permettant d'être plus tolérants que les autres enfants face à l'attente.

On sait que le milieu social influence le potentiel créatif des enfants et le développement de la théorie de l'esprit (Cicirelli, 1975 ; Jiao et al., 1986 ; Miller & Maruyama, 1976 ; Runco & Bahleda, 1987). Par exemple, les enfants ayant des frères et sœurs prennent conscience des états mentaux d'autrui plus tôt que les enfants uniques, et ils réussissent plus précocement les tâches de fausse croyance qui leurs sont proposées (Gasser & Keller, 2009 ; Youngblade & Dunn, 1995). La vitesse de développement de la théorie de l'esprit est influencée par des conversations plus fréquentes au sujet d'expériences passées et futures (Sutton & Keogh, 2000). La participation à des jeux de simulations sociales de situations économiques, tels que les jeux de faux semblant (Caravita et al., 2009), se révèle particulièrement favorable aux enfants qui endossent différents rôles et comprennent que ces rôles induisent différents comportements (Vygotsky, 1978). Le développement précoce de la théorie de l'esprit associé à l'expérience socio-communicative apportée par la présence d'une fratrie donne donc un avantage considérable aux enfants pour appréhender plus rapidement le rôle que le partenaire va jouer au cours de la transaction, évaluer sa fiabilité et comprendre que sa coopération est nécessaire pour maximiser leurs bénéfices (ARTICLES 1 à 4).

Au-delà de l'influence du nombre de frères et sœurs, il serait nécessaire de poursuivre les recherches en étudiant la place occupée par l'enfant au sein de la fratrie (réalisée à ce jour uniquement dans la première étude) ainsi que l'âge et le sexe des frères et sœurs. Il se peut en effet que des enfants ayant une différence d'âge marquée n'aient pas la même influence l'un sur l'autre que des enfants d'âges rapprochés. De nombreuses études ont montré que, par rapport à leurs aînés, les enfants derniers nés développent des compétences sociales plus rapidement car ils ont à la fois les adultes et leurs frères et sœurs comme modèles et stimulateurs (McArthur, 1956 ; Miller & Maruyama, 1976 ; Sutton-Smith & Rosenberg, 1966). Enfin, des enfants de même sexe pourraient présenter des interactions plus riches que des enfants de sexes différents (Dunn & Kendrick, 1981). Chez les investisseurs adultes, on a mis en évidence des différences de comportements selon les sexes en matière d'épargne et d'investissement, les hommes ayant tendance à être plus optimistes, à avoir plus confiance en leurs qualités d'investisseur et à prendre plus de risque que les femmes (Mangot, 2005). Bien que l'effet du sexe des enfants sur leurs comportements d'échange n'ait pas été démontré dans mon travail, la première étude a mis en évidence une interaction avec la présence de frères et sœurs dans la fratrie (ARTICLE 1) : les filles avec des frères et sœurs avaient tendance à s'engager dans une transaction plus souvent que les filles uniques et les garçons ayant ou non des frères et sœurs. Les choix économiques des enfants pourraient donc dépendre en partie d'une relation étroite entre leur sexe et l'environnement familial et social dans lesquels ils évoluent.

3. COMPARAISON AVEC LES AUTRES PRIMATES

Le modèle expérimental de l'échange utilisé chez les primates non humains a permis de comprendre dans quelle mesure ils pouvaient s'engager dans des transactions et quelles facultés étaient nécessaires à leurs émergences. Dans ce travail de recherche, les procédures expérimentales similaires appliquées aux enfants fournissent ainsi une base comparative importante. Les données acquises et les difficultés rencontrées chez d'autres espèces dans ces mêmes tâches permettent de mieux appréhender les réponses des enfants et de souligner les contraintes qu'ils ont pu expérimenter.

S'engager dans des transactions sur la base de dons et d'échanges d'objets et de nourriture est une activité maîtrisée à la fois par les très jeunes enfants (ARTICLE 1) et les primates non humains (Drapier et al., 2005 ; Lefebvre, 1982 ; Ramseyer et al., 2006 ; Westergaard et al., 2004). Tous possèdent les compétences d'évaluation de la valeur des biens nécessaires à l'optimisation des bénéfices. Alors qu'ils ont des difficultés à contrôler leur impulsivité dans des tâches de choix de gratification retardée (Mischel et al., 1989 ; Rosati *et al*., 2007 ; Szalda-Petree *et al*., 2004), il apparaît que les enfants (ARTICLE 2), les singes capucins, les macaques et les chimpanzés (Dufour et al., 2007 ; Pelé et al., 2010, 2011 ; Ramseyer et al., 2006) peuvent accepter des délais plus importants lorsque la procédure implique une composante sociale, c'est-à-dire au cours d'un échange économique. La seconde étude révèle en particulier que les enfants âgés de 3 et 4 ans attendent plus longtemps pour des récompenses plus importantes, de la même manière que les singes capucins (Ramseyer et al., 2006) et les chimpanzés (Dufour et al., 2007). Il apparaît également que la difficulté des enfants de 2 ans à intégrer l'élément temporel de la tâche ne constitue pas une limite chez des enfants plus âgés et chez les primates non humains. Des similitudes entre espèces ont également été trouvées en ce qui concerne le comportement des individus au cours de l'attente. Utiliser des stratégies comportementales pour combattre son impulsivité n'est pas exclusif des chimpanzés (Evans & Beran, 2007) puisque les enfants de 3 et 4 ans tentent régulièrement de détourner leur attention de l'item initial ou de la récompense par des comportements d'auto-distraction (ARTICLE 2).

Un résultat majeur de la seconde étude concerne les capacités d'anticipation constatées chez les primates non humains et les enfants : alors que les 2-3 ans ne parviennent pas à anticiper les délais d'attente de plus en plus longs (ARTICLE 2), les autres espèces de primates en ont été capables (Dufour et al., 2007 ; Pelé et al., 2010), soulignant chez ces derniers des capacités comparables en termes d'anticipation à celles d'enfants âgés d'au moins 4 ans. Les résultats n'ont pas permis de révéler la limite supérieure à partir de laquelle une classe d'âge donnée ne tolère plus l'attente. Quelques enfants de 2 ans ont en effet été capables d'attendre 16 min, la limite maximale fixée dans cette étude. Il serait nécessaire de renouveler cette expérience avec des enfants de moins de 14 mois, bien qu'une difficulté puisse résider dans le besoin de maintenir leur attention et leur intérêt tout au long de la séance de test. La plupart des enfants de 3 et 4 ans se sont révélés capables de contrôler leur désir de consommer l'item initial durant 16 min, un temps atteint par quelques sujets non humains uniquement ; un tel résultat suggère que les enfants de 3-4 ans présentent une aptitude à tolérer une gratification retardée qui est en général supérieure à celle des capucins, macaques et chimpanzés.

Au cours de la troisième étude, j'ai montré que, contrairement aux 3 ans, les enfants de 5 ans étaient en mesure d'ajuster leur investissement en fonction de la profitabilité de deux partenaires d'échange (ARTICLE 3). Chez les primates, seul un macaque de Tonkean a pu réussir cette tâche (ARTICLE 5 de l'annexe) indiquant des performances semblables à celles des enfants de 3 à 5 ans. Les enfants de plus de 4-5 ans présentent donc de meilleures capacités à calculer leur investissement que les primates non humains. Bien que ces derniers soit capables de prendre en compte la fiabilité des partenaires d'échange sur la base de leurs expériences communes passées (Brosnan & de Waal, 2009 ; Chen et al., 2006 ; Mitchell & Anderson, 1997), il est vraisemblable qu'un plus haut niveau de compréhension des états mentaux d'autrui, développé chez les enfants vers 4-5 ans, leur procure des indices supplémentaires qui leur permettent d'adapter leur stratégie d'échange face à plusieurs partenaires.

L'analyse des résultats de la quatrième étude montre que les enfants, au même titre que les primates non humains, peuvent s'engager avec un expérimentateur dans un échange de nourriture comportant un risque de perte. Chez les enfants de plus de 5 ans (ARTICLE 4), comme chez les orangs-outangs, les macaques de Java et les capucins bruns (Pelé et al., soumis), la probabilité de perte influence la décision de s'engager dans une transaction risquée. On observe enfin une aversion à la perte commune aux capucins bruns (Chen et al., 2006) et aux enfants de plus de 5 ans (ARTICLE 4), un biais qui paraît limiter la rationalité de leur choix.

4. PERSPECTIVES

Au cours de ce travail, j'ai étudié chez l'enfant des compétences nécessaires pour optimiser une transaction économique : donner et échanger, accepter de recevoir un bien différé dans le temps, adapter son investissement au comportement des partenaires d'échange, accepter ou non le risque inhérent à l'échange. Cette liste n'est pas exhaustive et d'autres compétences peuvent être utiles lors d'interactions économiques. On sait par exemple que l'aptitude à négocier est couramment mise en œuvre chez les enfants dans le cadre familial (chantage avec les parents) ou scolaire (marchandage de cartes à jouer durant les récréations). Etre capable de faire monter le prix d'un bien que l'on souhaite revendre à une autre personne serait donc un outil important dans la maximisation des bénéfices (Vickrey, 1961). En dehors de toute considération morale, un second atout résiderait dans l'aptitude à tromper le partenaire sur le bien vendu, ou faire attribuer à l'acheteur plus de valeur au bien vendu, des pratiques couramment utilisées chez certains vendeurs ou dans les stratégies de marketing. Comprendre à quel âge les enfants peuvent utiliser le mensonge pour arriver à tromper l'autre sur la valeur d'un objet reste encore à définir. A l'inverse, il est fondamental d'être en mesure de juger rapidement et avec précision de la fiabilité d'un partenaire pour optimiser ses investissements. On peut noter que les études réalisées au cours de cette thèse impliquaient un ou plusieurs partenaires honnêtes qui offraient systématiquement la récompense espérée (ARTICLES 1 à 3) ou qui ne changeaient pas les règles de retour initialement établies (ARTICLE 4). La confiance jouant un rôle majeur dans la décision d'investir, il est probable que les enfants ne s'engageraient pas de la même manière dans des échanges dans lesquels le partenaire n'est pas digne de confiance. L'étude du développement de telles compétences devrait faire l'objet de recherches ultérieures.

Par ailleurs, le risque lié à la transaction elle-même a un impact important sur les décisions des enfants. Nos résultats ont permis de déceler que les enfants âgés de 3 à 5 ans peuvent présenter une certaine aversion à la perte (ARTICLES 3 et 4), un biais couramment détecté chez les adultes. La réticence à perdre l'item initialement reçu n'est cependant pas le monopole de tous les enfants, et on observe des différences interindividuelles importantes. Il est vraisemblable que la valeur accordée aux biens et aux services échangés diffère d'un enfant à l'autre – et également d'une culture à une autre. Les enfants ne sont pas prêts à céder un même objet pour le même prix, ce qui laisse entrevoir la nécessité de mesurer pour chacun d'entre eux leur attachement à l'item initial avant de pouvoir conclure sur leur aptitude à s'engager dans une transaction et à maximiser la satisfaction qu'ils en retirent. Dans cette optique, on peut se demander si les enfants auraient plus de facilité à céder un item qui est donné à chaque essai (comme je le proposais dans les différentes études) ou bien l'un des items gagnés précédemment et faisant alors partie de leur cagnotte personnelle. On sait en effet que les adultes ont tendance à prendre plus de risque avec l'argent qu'ils viennent de gagner, qu'il ne considère pas encore comme le leur (effet « argent du ménage »). L'âge auquel les enfants pourraient développer ce même biais reste à déterminer.

Mes recherches ont révélé l'importance de l'environnement familial et en particulier la présence d'une fratrie sur les performances des enfants. Les données recueillies n'ont pas permis d'établir le rôle pourtant non négligeable des parents qui participent à l'apprentissage de l'économie chez leurs enfants et les familiarisent avec les concepts économiques en portant leurs discours sur les notions d'argent, de publicité ou de profit (Chan & McNeal, 2003 ; Rose et al., 1998). Les enfants parlant régulièrement de l'économie avec leurs parents pourraient ainsi appréhender plus rapidement les notions de pertes et de bénéfices. Le milieu scolaire joue un rôle complémentaire à celui des parents dans la mise en place des compétences économiques. On observe de grandes variations culturelles dans l'enseignement : l'absence d'école, une scolarisation tardive, des programmes d'éducation scolaire différents ou l'inadéquation du système scolaire aux besoins des individus sont autant de facteurs pouvant provoquer des décalages plus ou moins importants dans l'âge d'acquisition des outils cognitifs nécessaires au développement des compétences économiques.

Un dernier point à approfondir concerne les différences interculturelles. Mes résultats reposent sur l'étude d'enfants occidentaux en France et au Royaume-Uni. Il convient de se demander dans quelle mesure les conclusions tirées de ce travail sont généralisables à des sociétés non occidentales. Il est probable que le développement des aptitudes cognitives nécessaires à l'acquisition des compétences économiques soit guidé par les contraintes du milieu dans lequel l'enfant évolue, c'est-à-dire la transmission des normes culturelles, les habitudes sociales et les règles morales rencontrées au sein de cultures différentes. Il se peut également que la transmission du savoir nécessaire aux interactions économiques soit adaptée à la manière de vivre de chaque groupe, les compétences étant acquises uniquement si elles sont nécessaires à l'économie locale. Notons que l'interview des populations est longtemps restée le moyen le plus répandu pour appréhender l'étendue des aptitudes cognitives de différents groupes culturels. Les approches actuelles, plus expérimentales, se devront d'être standardisées afin d'adapter les tests cognitifs à des enfants scolarisés ou non (Alcock et al., 2008). Poursuivre ce travail chez des cultures qui diffèrent par leurs normes économiques, culturelles et sociales permettrait d'évaluer le degré de généralité des résultats obtenus dans cette thèse.

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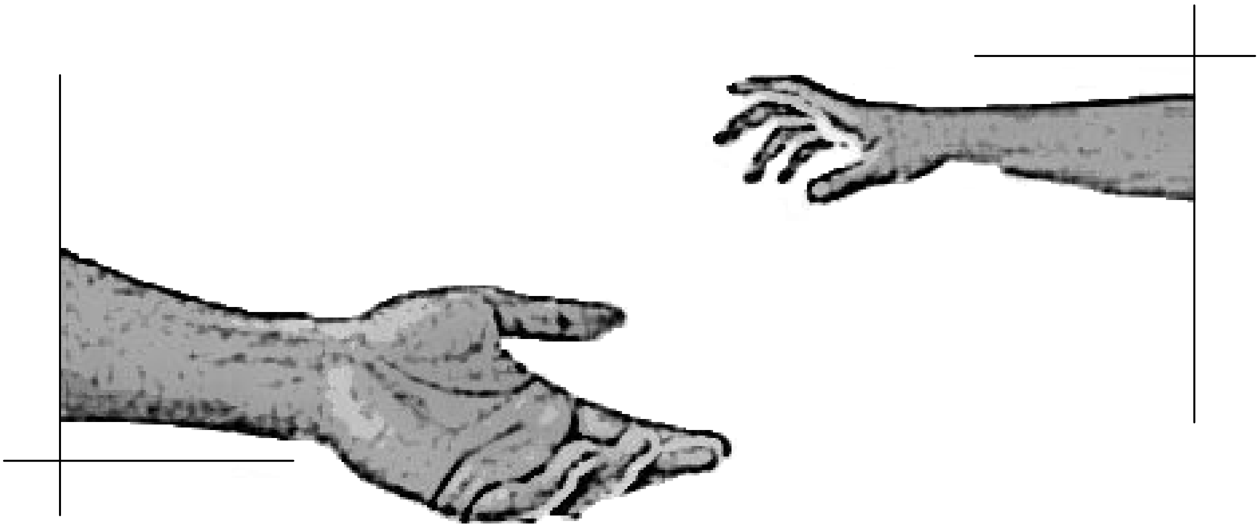

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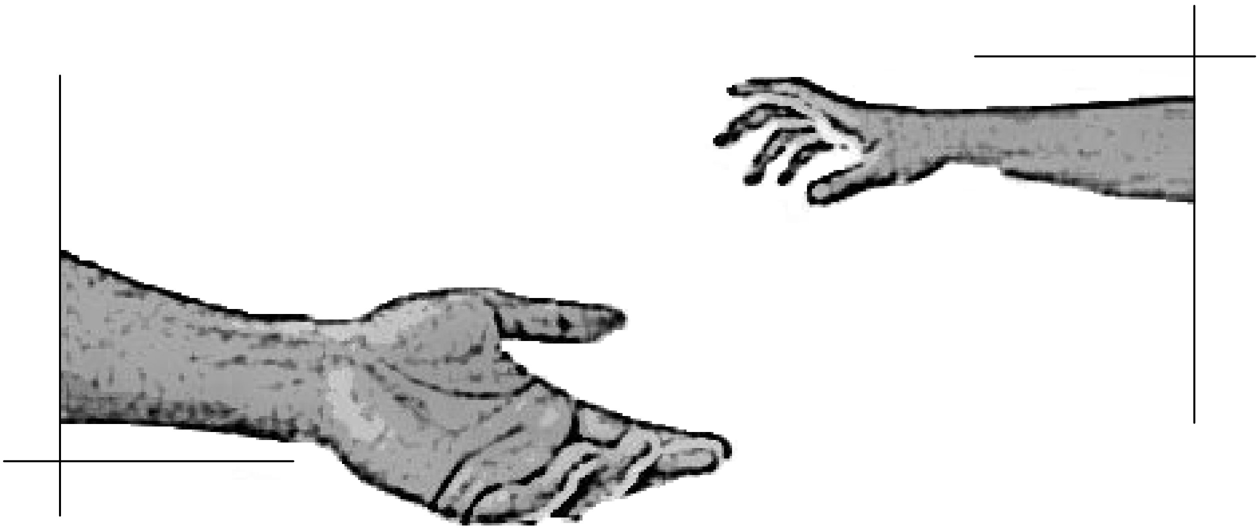
ANNEXES



ANNEXE 1

◆◆◆

Lettre d'invitation et feuille d'information

Exemple de l'étude DELAI

(Edimbourg)

University of St Andrews

School of Psychology

Dear Parent/Guardian,

By this letter we wish to kindly invite you and your child to take part in a research on the developmental aspect of the ability to exchange in children. The study is currently run at Edinburgh Zoo and is designed to assess the degree of self-control exhibited by a child while waiting for a sweet. Self-control improves during childhood, and this is the reason why we need to test children aged between 14 months and 5 years-old.

We are two researchers from the University of St-Andrews, based at the research centre *Living Links* at Edinburgh zoo. The centre is a place designed to understand both the behaviour of monkeys and the behaviour of human beings. Practically, your child's participation will involve him/her working with one researcher. The research is designed to resemble games so that your child enjoys the experience. Your child will be offered various sweets and proposed to wait a while to obtain more attractive ones. People who have carried out similar work previously have found that children have been very keen to take part. Of course, should your child wish to, he/she will be free to withdraw at anytime and you can withdraw your child's participation at any point. The results will be treated with complete confidentiality and only us will have knowledge of individual responses. We do not initially wish to videotape your child. However, the need may arise throughout the project. In some cases, certain behaviours might be of interest to us and we may wish to use the footage to illustrate these points. The tapes will be seen only by us (V. Dufour and S. Steelandt) and be kept only for the duration of the project (from 3 to 5 years). All information will be kept in accordance with the confidentiality rules of the British Psychological Society. At no point will any information be written or published that could identify your child.

Support for this research has been obtained from Edinburgh zoo. The research has received Ethical approval from the Local Education Authority and the Ethics Committee of the School of Psychology at the University of St-Andrews. In addition we have gone through the Enhanced Disclosure Scotland procedure to be able to carry out this project.

If you think that your child would enjoy participating in the study please complete the slip below and the attached questionnaire.

Many thanks

Child's Name:______________________________ Date of Birth:__________________

- I am willing to allow my child to participate in the study
- I am NOT willing to allow my child to participate in the study.
- I am WILLING/ NOT WILLING for video footage involving my child to be viewed for research purposes.

Signed: ______________________________ Date:__________________

PARTICIPANT INFORMATION SHEET

Project Title
Ability to delay gratification in children

Rationale
Your child is invited to take part in the research study: *Ability to delay gratification in children*. We are interested if children display a sufficient degree of self-control to accept in advance the loss of some goods and inhibit food consumption while waiting. We wish to know how long children can wait for a reward, which is the reason why we would like to recruit children aged between 14 months and 5 years old. Before you decide it is important for you to understand why the research is being done and what it will involve.

What your involvement will entail
This research is conducted at the Edinburgh zoo with the collaboration of the University of St-Andrews. Participation to this study requires a meeting with you and your child for about 30 minutes. During this time, your child will be involved in several short fun games where he/she might obtain sweets as rewards (depending on your preferences). If you have older children, they will be allowed to participate afterwards in the experiment if they wish to do so. Otherwise, they will be entertained with games or toys in the next room.

Anonymity, Privacy & Confidentiality
The research is supported by the Royal Zoological Society of Scotland (RZSS) and has obtained the ethical approval from the University of St-Andrews' ethical committee. Also, the Enhanced Disclosure Scotland has been obtained.
Initially, we do not wish to videotape your child. However, the need may arise throughout the project. In some cases, certain behaviours might be of interest to us and we may wish to use the footage to illustrate these points. If so, your child might be videotaped only if we have your agreement. The tapes will be seen only by us (V. Dufour and S. Steelandt) and be kept only for the duration of the project (from 3 to 5 years). Personal information such as the age of the child and whether he has brothers and sisters will be kept confidential. Data collected will be handled only by the researcher and supervisor and will be stored securely.
The results from this study will be reported in general terms in the form of speech, writing, photograph or video that may be presented in manuscripts submitted for publication in scientific journals, or oral and/or poster presentations at scientific meetings, seminars, and/or conferences. Any photograph or video will only be used for such presentations if you provide permission after you are given the opportunity to view the selected photographs/videos.

Reward
We will use sweets as food rewards only if you approved (questionnaire sent with the letter). If you don't, you will have a choice for a more appropriate reward (e.g. other kind of sweets or cookies). If for any other reasons you preferred an alternate reward, we can propose to replace sweets/cookies by pictures.

Withdrawal
Your participation in this research is completely voluntary. There are no anticipated risks or discomforts related to this research. If you do decide to take part you will be given this information sheet to keep (and be asked to sign a consent form)
If you or your child feels uncomfortable with any part of this study, you have the right to terminate participation without consequence. Please remember that you are free to withdraw from the study at any time and without giving a reason. All information about you will be immediately destroyed and a gift will be offered to your child in any case for taking part in the study.

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ANNEXE 2

◆◆◆

Lettre d'invitation

Exemple de l'étude INVESTISSEMENT

(Strasbourg)

Strasbourg, le 20 octobre 2010

www.iphc.cnrs.fr

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Sous la co-tutelle de

Madame, Monsieur

Par la présente, j'aimerais obtenir votre accord concernant la participation de votre enfant dans une étude portant sur la prise de décision et l'émergence de l'échange chez l'enfant. Le but de ce projet est de déterminer la capacité des enfants à ajuster leur investissement pour maximiser leur gain. Cette capacité économique apparaît et varie probablement durant l'enfance, raison pour laquelle j'aurais besoin de tester des enfants âgés de 3 à 10 ans.

J'aimerais inviter votre enfant à participer à cette étude. Il sera testé dans sa classe plusieurs jours consécutifs (5 à 10 jours) durant 10 mn environ. Durant cette étude, votre enfant devra décider de la meilleure façon à investir 4 bonbons qui lui auront été offerts selon les offres de deux expérimentateurs qui joueront avec lui. Si votre enfant échange 1 à 4 bonbons avec le 1er expérimentateur, celui-ci lui rendra systématiquement 8 bonbons. Le second expérimentateur donnera quant à lui le double du nombre de bonbons échangés par votre enfant. Ainsi, si votre enfant est capable de maximiser ses gains, il devrait investir un nombre minimal de bonbons avec le 1er expérimentateur et un nombre maximal de bonbons avec le second. Cette étude est menée sous forme de jeux pour que votre enfant prenne plaisir à participer. La participation de votre enfant sera traitée avec confidentialité et seuls mes superviseurs et moi-même auront connaissance des performances individuelles. Votre enfant ne sera pas filmé; cependant si certains comportements sont intéressants, j'aimerais utiliser des enregistrements pour illustrer ces points. Tous les enregistrements resteront confidentiels et seront détruits à la fin du projet (de 3 à 5 ans). Votre consentement devra être obtenu pour réaliser les vidéos et/ou les diffuser à d'éventuels congrès académiques. L'identité de votre enfant restera anonyme pour tous papiers publiés. Cette recherche a obtenu l'autorisation de l'inspecteur d'académie et de l'inspecteur de circonscription de votre école.

Si vous souhaitez voir votre enfant participer à cette étude, je vous serais reconnaissante de bien vouloir compléter et retourner à l'école le formulaire détachable ci-dessous ainsi que le questionnaire joint. Je reste à votre entière disposition pour toute information complémentaire concernant ce projet et vous prie d'agréer Madame, Monsieur, mes sentiments les meilleurs.

Steelandt Sophie

Partie à compléter et à retourner signée. Merci

Titre: La prise de décision chez l'enfant : aptitude à calculer un investissement

J'accepte que ___________________ (nom de l'enfant) prenne part à cette étude.

Date de naissance de l'enfant ________________________________

Nom et Prénom du parent/responsable ________________________________

Date ____________________ Signature ____________________

ARTICLE 5

◆◆◆

Les primates non humains sont-ils capables de calculer leur investissement pour maximiser leur bénéfice ?

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Can Monkeys Make Investments Based on Maximized Pay-off?

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Abstract

Animals can maximize benefits but it is not known if they adjust their investment according to expected pay-offs. We investigated whether monkeys can use different investment strategies in an exchange task. We tested eight capuchin monkeys (*Cebus apella*) and thirteen macaques (*Macaca fascicularis, Macaca tonkeana*) in an experiment where they could adapt their investment to the food amounts proposed by two different experimenters. One, the doubling partner, returned a reward that was twice the amount given by the subject, whereas the other, the fixed partner, always returned a constant amount regardless of the amount given. To maximize pay-offs, subjects should invest a maximal amount with the first partner and a minimal amount with the second. When tested with the fixed partner only, one third of monkeys learned to remove a maximal amount of food for immediate consumption before investing a minimal one. With both partners, most subjects failed to maximize pay-offs by using different decision rules with each partner' quality. A single Tonkean macaque succeeded in investing a maximal amount to one experimenter and a minimal amount to the other. The fact that only one of over 21 subjects learned to maximize benefits in adapting investment according to experimenters' quality indicates that such a task is difficult for monkeys, albeit not impossible.

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Introduction

The foundations of decision research, and hence its contemporary shape, have been strongly influenced by thinking from disciplines like economics. Human investors adjust their decisions according to partners on the basis of expected pay-offs. They are supposed to make rational decisions and to revise their decisions in order to optimize satisfaction [1]. Animals can also maximize pay-offs. When individuals exploit an environment where resources are distributed in patches, they can leave the patch and search for a new one when the rate of pay-off falls below the average rate for the entire area [2], [3]. Rational strategies are then defined as those increasing fitness and are an outcome of natural selection [4]. The theory of biological markets in particular assumes that living beings can adjust their investment based on the offers potentially provided by several partners [5]. In non-human primates, individuals may vary their rates of grooming in exchange to access for commodities [6], [7]. They are able to invest, that is, to avoid immediately consuming some goods with the intent of winning more [8], [9]. We lack evidence, however, about their abilities to adjust quantitatively their investment to expected pay-offs.

Monkeys and great apes appear to possess many of the skills required to perform successful investments in various contexts. They can make inferences, categorize objects and understand tertiary relations [10]. They are also able to make 'more' and 'less' value judgments about discrete quantities [11]–[14]. Numerous studies showed that monkeys are good at recognizing magnitudes for values under 8. For instance, rhesus macaques reliably prefer the larger amount in choices of one versus two items, two versus three, and three versus four [15], [16]. Monkeys can also discriminate between larger numerical values when high ratios are involved [17]. Rhesus macaques can learn to select the stimulus with the larger number of dots when pairs of numerical values between 1 and 9 are presented [18], [19]. Similar results are found in squirrel monkeys and tufted capuchin monkeys with discrimination between discrete quantities of one to nine food items [20]–[24].

Non-human primates are also able to combine discrete quantities, which can allow them to adjust their investment quantitatively. When presented with two trays, each tray containing two separate sets of food items, chimpanzees and capuchin monkeys select the greater total, indicating that they consider the sum of items [25]–[27]. Both great apes and monkeys succeed in tasks where they have to choose between two covered sets of food items to which an experimenter visibly adds or removes items in unequal numbers (capuchin monkeys: [28]; chimpanzees: [13], [29], [30]; orangutans: [12]; rhesus macaques: [15]). Monkeys can differentiate between different contingencies in discrimination learning task where they have to distinguish between two cues to gain rewards [10]. They can also discriminate between experimenters who behave in different ways towards them. For instance, capuchins and macaques preferentially indicate a food location to the most cooperative partners [31], and they recognize those providing the higher pay-off [32]–[34]. Monkeys can thus use potential partners as a tool to gain more. On the other hand, while monkeys may instrumentalize conspecifics, they may limit this to anticipating their behavior and not their intentions. It should be emphasized that in most experiments they appear unable to recognize actions in term of goals contrary to great apes [35]–[37] (but see [33]).

With regard to future-oriented behaviors, several experiments show that apes and monkeys can accept to lose an immediate benefit to gain more later; they postpone gratification from some seconds to a few minutes in tasks where they are given a choice between an immediately available but less preferred reward, and a delayed but more preferred one [38]–[40]. They sustain similar delays of gratification when presented with food items accumulating at regular time intervals [41], [42]. Non-human primates also maximize their pay-offs in tests requiring them to exchange with an experimenter. Chimpanzees and capuchin monkeys can learn to attribute values to non-edible tokens and exchange them for food [43]–[45]. However, this set up implies training monkeys to understand the value of the tokens. Monkeys and great apes can also give food items to receive a qualitatively more desirable one [8], [9], [46]. In that case, the value of the food is directly measured by consumption. In a study where capuchin monkeys were allowed to eat part of an item before returning it, individuals were seen to nibble most of a food item before attempting to exchange the remains for a larger reward with a human experimenter [8], [47]. Also, non-human primates can wait longer for a return if the expected quantity of food is larger [47], [48].

Decision-making in primates relies on skills requiring them to take into account several factors involving evaluation of discrete quantities, physical or temporal cost, and partner's reliability to maximize their pay-offs. In this study, we tested tufted capuchin monkeys, Tonkean macaques and long-tailed macaques in an exchange task where each subject initially received four food rewards that they could either consume or give back. To maximize the pay-off, subjects had to adapt the amount of food items they gave initially – the investment – to the food amounts to be returned by two different experimenters. We investigated whether the subjects could invest differentially depending on the experimenter' qualities in term of income. One experimenter gave back a reward twice the amount of the subjects' initial investment (doubling partner, providing 0, 2, 4, 6 or 8 rewards if subjects returned respectively 0, 1, 2, 3 or 4 rewards), whereas the other always gave back a constant amount regardless of the subjects' initial investment (fixed partner, always providing 8 rewards regardless of the amount initially returned). To maximize food income, subjects had to respond in different ways to each experimenter, offering a maximal amount to the first one and a minimal amount to the second (Table 1).

Results

When giving less than four raisins to experimenters, subjects exhibited different ways to remove raisins from the initial amount. They either ate some and returned the remaining ones (Pis, Arn, Lad, Pao), put all of them in their mouth and spat some back (Sha, Rav, Lad, Syb, Sam), or shared the four raisins between both hands keeping the content of one and returning the content of the other (Kin, Sad, Syb). Each subject consistently used the same way across the different phases of study (except for Lad and Syb who alternated their removal procedures; they mainly used the second procedure but sometimes used the first one for Lad, or the third one for Syb).

Table 1. Number of rewards obtained from both experimenters and subjects' net income according to the number of raisins returned by subjects.

	Doubling partner		Fixed partner	
Returned number of raisins	Reward	Net income	Reward	Net income
0	0	4	0	4
1	2	5	8	11
2	4	6	8	10
3	6	7	8	9
4	8	8	8	8

Within one session, the subjects' net income, i.e. the amount of raisins non-invested by the subject plus those received after return. The subject maximises its gain by giving more (4 raisins, net income 8) to the doubling partner, and less to the fixed one (1 raisin, net income 11).

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Phase 1

In this phase, 20 subjects failed to adapt the amount of given raisins according to partners' quality during 21 sets of two sessions (Figure 1 and S1). Among subjects, seventeen consistently gave all four raisins to the doubling and fixed partners. Two other subjects (Sam, Pao) gave 1–3 raisins to both partners. A third subject (Arn) initially gave all four raisins, but after the 16th set of two sessions, he learned to give 1–2 raisins to both partners. Comparing the performances of subjects according to partners' quality in the last 10 sets of sessions did not yield significant differences (fixed partner: mean number of raisins $\pm$ sd $= 3.55 \pm 0.49$, doubling partner: $m = 3.56 \pm 0.36$, $n = 20$ subjects, $T = 53.0$, $p = 0.642$).

One subject was able to adjust his behavior according to experimenters' quality. This Tonkean macaque (Sha) was tested during 24 sets of two sessions. From the 17th set, he gave a decreasing numbers of raisins (three to one) to the fixed partner while consistently returning 3–4 raisins to the doubling partner (Figure 2). Comparing his performances according to partners' quality during the last 10 sets of sessions yielded a statistically significant difference (fixed: $m = 2.51 \pm 1.35$, doubling: $m = 3.60 \pm 0.91$, $n = 10$ sets, $T = 4.0$, $p = 0.016$).

Phase 2

In Phase 2, the 20 subjects that had previously failed to differentiate between partners' quality were tested in sessions involving a single fixed partner. Phase 2 was run to counterbalance the tendency of most subjects to return all 4 raisins in Phase 1. Among the 20 subjects, 13 maintained the main strategy used in Phase 1 (see Figure S1). The other seven subjects altered their behavior in the course of sessions. They learned to give 1–2 raisins to the fixed partner (Figure 1).

Phase 3

The seven subjects who reduced the number of raisins they gave in Phase 2 were tested again in sessions involving two different experimenters (Figure 1). Among them, six continued to give 1–2 raisins to both partners as in Phase 2. Comparing the performances of subjects according to partners' quality did not yield significant differences (fixed: $m = 1.05 \pm 0.10$, doubling: $m = 1.10 \pm 0.15$, $n = 6$ subjects, $T = 15.0$, $p = 0.144$). A seventh subject (Rav) started to stop exchanging with the doubling partner, consuming the four raisins. Yet, he kept on giving one raisin to the fixed partner. The analysis showed that he responded differently to

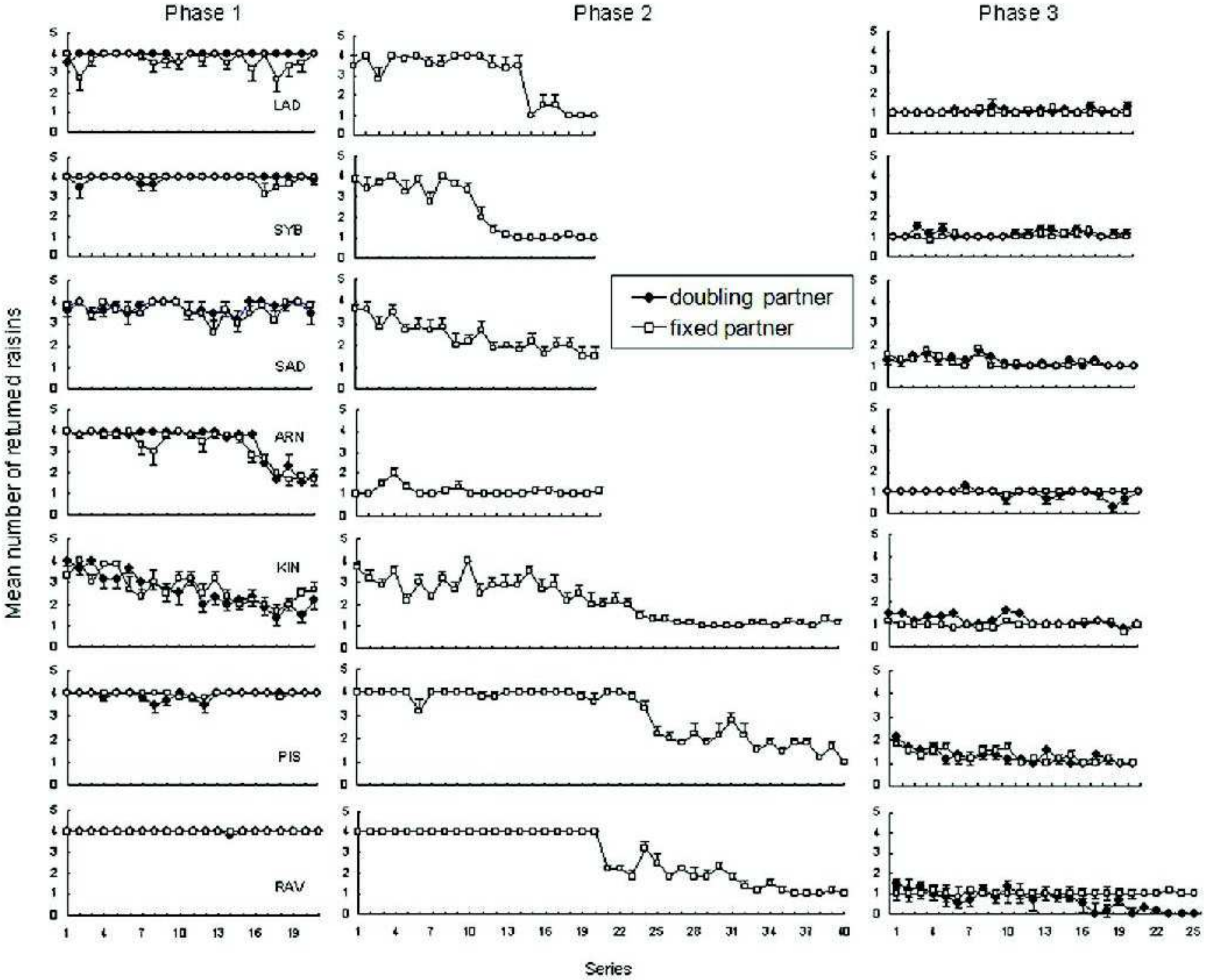

Figure 1. Number of raisins returned by seven subjects in Phases 1, 2 and 3. In Phases 1 and 3, subjects were tested with both doubling and fixed partners. In Phase 2, subjects were tested with the fixed partner only. Six subjects successfully modified their strategy in Phase 2 except for Arn who already changed of behavior at the end of Phase 1. In Phase 3, Rav returned 1 raisin then stopped exchanging with the doubling partner. Each plot represents the mean number of raisins returned in one session of six trials, along with standard errors.
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both partners' qualities (fixed: $m = 1.02 \pm 0.13$, doubling: $m = 0.17 \pm 0.39$, $n = 10$ sets, $T = 55.0$, $p = 0.005$).

The subject Sha, having differentiated between partners' quality in Phase 1, was tested in phase 3 with two new experimenters in order to confirm his response (Figure 2). His behavior progressed during the sessions. At first, he gave about 1–2 raisins to the fixed partner while generally giving 2–3 raisins to the doubling one. After several sessions, he gave 2–3 raisins to the fixed partner and four to the doubling. In the last sessions, he gave a minimal number (one) to the fixed partner and a maximal number (four) to the other partner. Analyzing his performances showed that he adopted contrasting strategies according to partners' quality (fixed: $m = 1.23 \pm 1.26$, doubling: $m = 3.63 \pm 0.72$, $n = 10$ sets, $T = 55.0$, $p = 0.005$).

Net incomes in Phases 1 and 3

By experimental design the subjects' net income should differ according to experimenters' quality. We checked that it was larger with the fixed than with the doubling partner in the last 10 sets of sessions in Phase 1 for Sha (fixed: $m = 9.49 \pm 1.01$, doubling: $m = 7.60 \pm 0.34$, $n = 10$ sets, $T = 55.0$, $p = 0.005$) and other subjects (fixed: $m = 8.42 \pm 0.77$, doubling: $m = 7.61 \pm 0.84$, $n = 20$ subjects, $T = 41.0$, $p = 0.001$), and also in Phase 3 for Sha (fixed: $m = 10.17 \pm 0.87$, doubling: $m = 7.63 \pm 0.35$, $n = 10$ sets, $T = 55.0$, $p = 0.005$), Rav (fixed: $m = 10.98 \pm 0.13$, doubling: $m = 4.18 \pm 0.39$, $n = 10$ sets, $T = 55.0$, $p = 0.005$) and other subjects (fixed: $m = 10.95 \pm 0.20$, doubling: $m = 5.10 \pm 0.27$, $n = 6$ subjects, $T = 21.0$, $p = 0.028$).

In Phase 1, Sha received a total of 2414 raisins (1046 raisins with the doubling partner; 1368 raisins with the fixed partner; difference: 322 raisins). For other subjects, the total mean of raisins was of 2187 (983 raisins with the doubling partner; 1204 raisins with the fixed partner; mean difference: 221 raisins). In Phase 3, Sha earned a total income of 2478 raisins (1059 raisins with the doubling partner; 1419 raisins with the fixed partner; difference: 360 raisins). Rav had a total income of 2071 raisins (435 raisins with the doubling partner; 1636 raisins with the fixed partner; difference: 1201 raisins). For other subjects, the total mean of

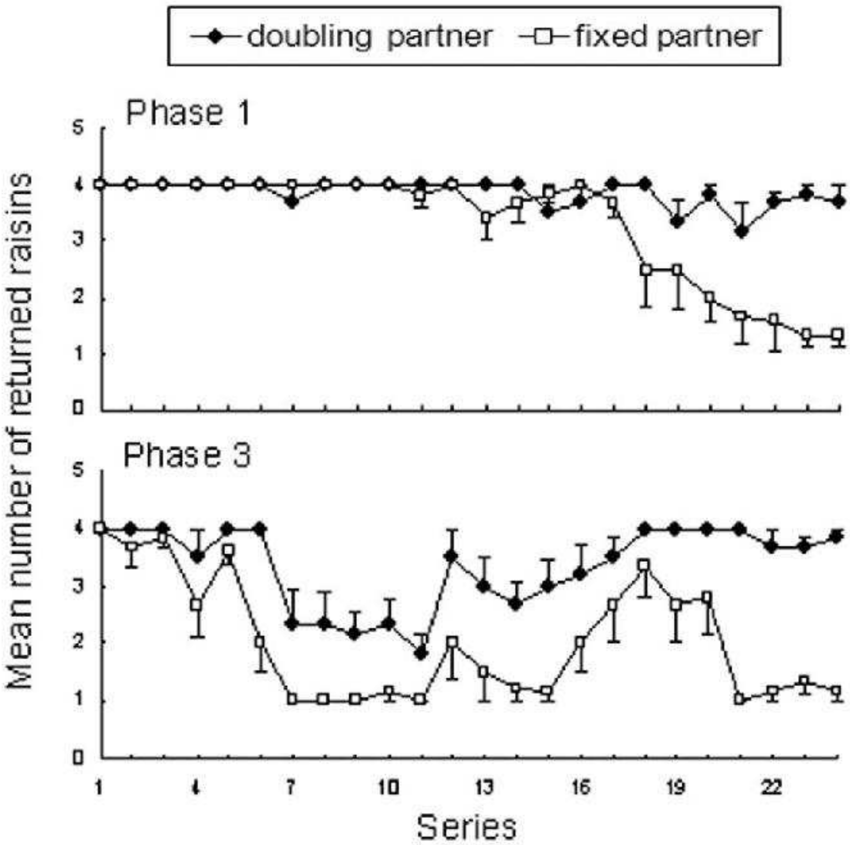

Figure 2. Number of raisins returned by the subject Sha in Phases 1 and 3.
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raisins was of 1855 (584 raisins with the doubling partner; 1271 raisins with the fixed partner; mean difference: 687 raisins).

Discussion

A single subject (Sha) could maximize pay-offs by following different rules according to experimenters' quality. Most capuchins and macaques were not able to adapt the invested amount of food items to the potential returns from each experimenter. In Phase 1, most individuals consistently gave a maximal amount to both. Such strategy maximized pay-off with the doubling partner, but was inappropriate with the fixed one. Fewer subjects showed the reverse response pattern, giving a minimal number of raisins by the end of this phase. This strategy maximized pay-offs with the fixed partner, but not with the doubling. In Phase 2, subjects had to exchange only with the fixed partner. One third of them succeeded in maximizing pay-off and learned to give a minimal amount. Among these seven subjects, only one (Rav) discriminated between partners' quality in Phase 3 but failed to understand the rule that would bring him optimal benefits with the doubling partner. The others subjects maintained the same strategy as in Phase 2 and did not adapt their investment strategy according to partners' quality.

It might be argued that the experimental set-up did not provide time enough for subjects to adjust their behavior, but the fact that Sha learned to modify his behavior after some trials weakens this interpretation. An alternative explanation is that most subjects may have been unable to differentiate between experimenters' quality according to the food amounts that they returned. However, this explanation is also unlikely since it is known that monkeys are able to discriminate two experimenters behaving differently [31]–[34]. Moreover, most subjects sometimes gave back a different number of raisins to experimenters, thus getting an opportunity to learn that experimenters did not respond in the same manner. It should be emphasized that the net income differed according to experimenters' quality, since no subjects always gave 0 or 4 raisins. In Phase 1, subjects experienced a difference of close to one raisin between experimenters; and in Phase 3, the subjects' net income with the fixed partner was more than twice than with the doubling partner. Still, they did not adjust their behavior according to the partner' quality. Moreover, former studies have shown that monkeys succeed in tasks requiring them to discriminate between quantities [11]–[24]. When required to trade tokens for rewards with two different experimenters, tufted capuchins were able to select the one providing the higher pay-off [32]. Here, subjects had to do more than just choosing between two options, they had to draw different decision rules from the contrasting conduct of two different human partners. From previous work on discrimination learning, we know that it is quite demanding for animals who learned in a training phase to select one cue in a two-choice discrimination task to learn, in a following reversal phase, that the second cue is then rewarded [10], [49]. Our experimental situation was even more challenging since it required subjects to respond in a different way at each partner's quality change. It is therefore not surprising that most subjects failed to regularly alternate their decision rule in this repeated conditional discrimination task.

In Phase 2, seven subjects – three macaques and four capuchin monkeys – sized the opportunity to remove some raisins from the initial amount in order to maximize pay-off. This corroborates results previously found in a study where capuchins were observed nibbling part of the initial item before returning it [8], [47].

Therefore, failure to learn to keep some of the food was not what hindered success in this experiment. The fact that only a third of the monkeys succeeded is not too surprising. Indeed, monkeys were rewarded regardless of the number of raisins invested - even no exchange whatsoever rewarded them with the 4 raisins they kept. Therefore, there was no negative reinforcement for giving one quantity or another. Although we aimed to test whether monkeys could learn to differentiate between two experimenters' qualities, we did not want to condition them to do so. In each phase, it was up to them to realize the differences in the rewards obtained according to the quality of the experimenter they were interacting with. Previous studies have shown that monkeys could recognize when experimenters subtracted several items from a given number of incentives [50], [51]. In the present study, some subjects consumed some of the raisins and gave the remaining to the experimenter, whereas others first gave some raisins and then ate the remaining ones. In both cases, subjects were able to remove 2–3 items from the total amount before giving 2-1 items to the experimenter. We propose that subjects' decisions rested on their ability to recognize magnitudes, albeit in an imprecise way [52], [53].

From the seven individuals who started giving back minimal amounts in Phase 2, one behaved differently with each partner's quality of Phase 3; while he consistently gave one raisin to the fixed partner, he eventually stopped exchanging with the doubling one. Thus, this capuchin monkey was able to maximize pay-offs with the fixed partner and could recognize that the doubling partner might respond in a less satisfactory way. Still, he failed to understand which rule would bring him optimal benefits with this second partner.

It must be emphasized that one Tonkean macaque succeeded in optimizing pay-offs with both experimenters. He followed different decision rules with each experimenter's quality in Phase 1, and did it again with two new experimenters in Phase 3. By the end of each phase, he invested a maximal amount with the doubling partner and he removed most items before investing with the fixed one. To our knowledge, this represents the only example of decision-making by drawing different rules based on combination of discrete quantities in monkeys, and maybe even in great apes. The fact that only one of over 21 subjects could maximize benefits in adapting investment according to experimenters' quality indicates that such a task is difficult for monkeys, albeit not impossible.

Cognitive limits can underpin the present results, but we cannot exclude that different factors related to the design of the task concurred to create additional difficulties. First, one may argue that in Phase 3, monkeys only gave a minimal amount because they had been trained to do so in Phase 2, and that training at this stage would have also included training with the doubling partner. It is likely that training with only the fixed partner influenced their response greatly. However, training in Phase 2 was carried out to counterbalance the very strong tendency of the subjects to systematically give four raisins in Phase 1. If we had exposed them to both contingencies again, this could have forbidden the outcome "give as little as possible". Thus, in the actual set up Phase 3 was run with the knowledge that the seven subjects involved had all been capable of both responses, giving either a maximum (Phase 1) or a minimum (Phase 2) number of raisins. Second, albeit statistically significant, the weak difference of net income between different experimenter's qualities (1 raisin), experienced by individuals in Phase 1 could be insufficient for monkeys to detect that they were not maximising rewards. It is known that monkeys can distinguish between weak differences of items [15], [16]. Moreover, in Phase 3 this difference was two-fold between experimenters. Nevertheless, subjects did not adjust their return according to experimenters' qualities. Finally, it is possible that some individuals may require more exposure to each partner's quality in order to learn how to adjust their return. Whenever individuals showed unstable strategies in each phase, additional sessions were run to allow for such learning to occur. This however did not lead to successful learning. Still, sufficient learning time is probably a critical requirement for the adequate mastering of such complex cognitive decision-making by most subjects. In humans, being able to follow multiple directions or to switch between decision rules develops slowly during childhood [54], [55]. Providing that sufficient learning time is allowed, and that monkeys can pay attention to differences in partners' quality, maximizing pay-off using opposite decision rule is within the reach of these species. In the present experiments we reduced the complex interactions commonly addressed by behavioral biology and economics to a simple dyadic situation in which subjects interact with a human experimenter. This is a current procedure in experimental cognition. Further research should attend more specifically to those additional factors – whether ecological, social or cognitive – liable to facilitate such learning in non-human primates and other animals.

Trading with multiple partners following different rules is characteristic of human economics; individuals make decisions based on their expectations regarding partners' responses. Here, monkeys had to adjust the amount to be returned according to their expectations about the behavior of two different experimenters. Our results may have implications regarding how non-human primates manage their relationships with conspecifics. The ability to adapt pay-offs according to the gains potentially brought by each partner could be related to the ability of individuals to invest more in one mate or another [56]–[58]. Future studies should compare monkeys and great apes to investigate whether the development of such abilities would have preceded the rise of economical transactions in humans.

Methods

Ethics Statement

Animals were given *ad libitum* access to food and water. All procedures complied with the recommendations of the Weatherall report. The research was conducted under license 67–100 from the French Agricultural Department (Préfecture du Bas-Rhin).

Subjects

The subjects were maintained at the Primatology Center of the Strasbourg University. Their age and sex are presented on Table 2. We tested eight tufted capuchins (*Cebus apella*) belonging to a group of 18 individuals housed in an indoor-outdoor enclosure composed of several compartments totaling 78 m^2. Four Tonkean macaques (*Macaca tonkeana*) belonged to a group of seven individuals housed in an indoor-outdoor enclosure composed of several compartments totaling 35 m^2. Two other Tonkean macaques belonged to a group of 16 individuals raised in a 1-acre wooded area including a shelter and a 40-m^2 wire-mesh fenced enclosure used for experiments. Three long-tailed macaques (*Macaca fascicularis*) were housed together in an enclosure of 10 m^2 composed of several compartments and located in an indoor room. Four other long-tailed macaques were individually housed in the same room in cages of 125×80×80 cm. Animals were fed with commercial monkey diet. They were never deprived of food.

Testing Procedure

Subjects had been trained to exchange food items with humans prior to experiments [8], [59]. Most subjects had been

Table 2. Subjects participating in the study.

Subjects	Age (yrs)	Sex	Rearing conditions
Tufted capuchins			
Kin	16	female	group-living, indoor-outdoor
Ali	9	female	group-living, indoor-outdoor
Pao	7	female	group-living, indoor-outdoor
Arn	10	male	group-living, indoor-outdoor
Pis	7	male	group-living, indoor-outdoor
Pop	7	male	group-living, indoor-outdoor
Rav	6	male	group-living, indoor-outdoor
Sam	5	male	group-living, indoor-outdoor
Tonkean macaques			
Syb	5	female	group-living, indoor-outdoor
Rim	6	male	group-living, indoor-outdoor
She	5	male	group-living, indoor-outdoor
Sim	5	male	group-living, indoor-outdoor
Lad	11	female	group-living, semifree-ranging
Sha	5	male	group-living, semifree-ranging
Long-tailed macaques			
Lou	11	male	group-living, indoor
Ram	16	male	group-living, indoor
Sad	12	male	group-living, indoor
Cas	12	male	separated, indoor
Don	16	male	separated, indoor
Jac	15	male	separated, indoor
Joe	11	male	separated, indoor

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involved in a delay-of-gratification task where they had to keep a piece of biscuit in their hand for a given amount of time before returning it for a better or larger reward. All subjects succeeded in waiting for more than 10 seconds in this task. The present study, by comparison, was based on an immediate exchange and imposed a lower need for self-control in all subjects. They were also involved in daily training sessions over a 3-month period where they had to give several Zante raisins to obtain twice the number of raisins. Another experiment gave subjects some background in discriminating between values of 6 and 18 food items [60].

Group-living subjects were temporarily separated from their mates into individual compartments and later released back into their group. The experimenter sat in front of the wire mesh and laid four cups containing four potential rewards on the ground in full view of the subject. The number of potential rewards shown depended on the quality of the experimenter running the trial. A test started when the experimenter showed to the subject four raisins on a teaspoon for 2 s. Then she gave them to the subject. After 3 s, the experimenter held out a hand, palm open, in front of the subject requesting them back. When the subject gave one or more raisins, the experimenter rewarded the subject by supplying him/her with a corresponding, larger, number of raisins from one of the four potential cups (Figure 3). If the subject did not give raisins, the trial ended. We waited for 2 min after the end of food consumption before starting another trial.

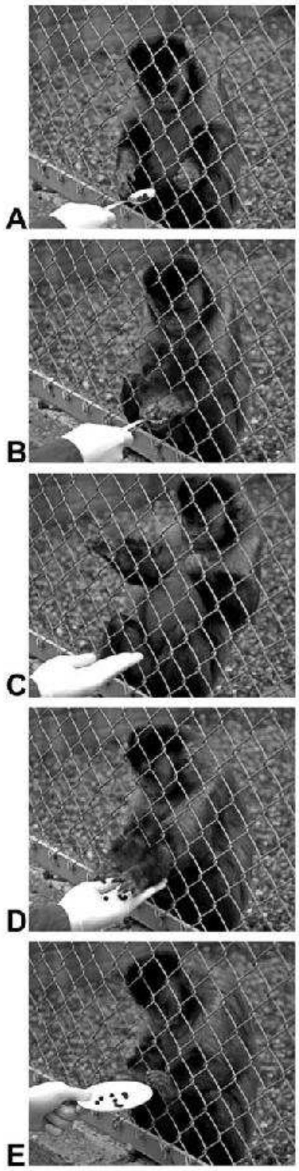

Figure 3. Exchange sequence between capuchin monkey and experimenter. (A) The experimenter presents four raisins on a spoon, (B) The subject is allowed to take the raisins, (C) The subject is requested to return the raisins, (D) The subject drops the raisins in the hand of the experimenter, (E) The subject receives eight raisins in a cup.
doi:10.1371/journal.pone.0017801.g003

Experimental Design

Two different experimenters familiar to the subjects were involved in the testing phase. A first one, the doubling partner, always returned a number of raisins twice those given by the subjects. Therefore, potential rewards consisted in cups presenting either two, four, six or eight raisins. The second experimenter, the fixed partner, always returned eight raisins, regardless of the number of raisins given by subjects (one to four). Thus, potential reward consisted in one cup among four, each cup presenting eight raisins. The subjects' net income, i.e. the amount of raisins non-invested by the subject plus those received, could vary depending on which partner they interacted with (Table 1).

For training, a first 2 day-period was run where subjects were trained to give several raisins. Subjects were submitted to one daily session of six trials. A different experimenter from the two partners described above initially provided the subject with either one or four raisins and requested subjects to give them all to obtain eight raisins. Three trials were run in a random order for each condition. We did not require learning criteria for this step. In a second 2-day training period, subjects were familiarized to the doubling and fixed partners. They were exposed once (in a single trial) to the doubling partner and once to the fixed. In order for them to experience the difference in the reward amount, subjects had to give at least one raisin to each partner. If they failed, a second trial was run. Subjects needed between 2 and 4 trials to reach this criterion.

With regard to the testing phase, we first tested subjects in successive sets of two sessions (one session per partner) in a random order. There was no more than one session of six trials per half-day. The subjects' net income could vary within one session from 24 to 48 raisins with the doubling partner, and from 24 to 66 with the fixed partner. The partners' role differed and was counterbalanced across subjects; the doubling partner for 11 subjects was the fixed one for the remaining ten.

Because subjects failed to adapt their strategies according to the quality of the partner they were tested with, we ran them in a second phase involving the fixed partner only. We aimed to detect whether subjects could maximize their gain in a simplified version of the task. Phase 2 was run to counterbalance the tendency of subjects to return all 4 raisins in Phase 1. Indeed, during the training phase, all subjects had learned to return a maximum of raisins, which was the main behavior observed in Phase 1. In Phase 2 the goal was therefore to reinforce any subject who would start "giving less". When subjects did choose the best strategy in the second phase (giving only one raisin to obtain eight ones), we tested them in a third phase, which replicated the procedure of Phase 1. Phase 3 was then run with the knowledge that the seven subjects involved had all been capable of both responses, giving either a maximum (Phase 1) or a minimum number of raisins (Phase 2). A single subject (Sha) directly passed from Phase 1 to Phase 3 because of success in Phase 1. Each phase involved different experimenters.

Whenever the strategy adopted by subjects was not stable at the end of each phase, and to ascertain that no learning trend was occurring, we added testing sessions until the performances' curve flattened. In Phase 1, subjects were tested in 21 sets of two sessions with the doubling and fixed partners; the first set was a learning period. One subject (Sha) was tested in 24 sets of two sessions. Phase 2 was composed of 20 sessions with the single fixed partner. Four subjects (Pao, Kin, Pis, Rav) were tested in 40 sessions. In Phase 3, subjects were tested in 20 sets of two sessions with both partners' qualities. We conducted 25 sets with Rav and 24 sets with Sha. Trials when subjects did not return any raisins (2.1% of trials) were discarded from data processing.

To test whether subjects responded differently to the fixed and doubling partners, we compared their performances at the individual or at the group level in the last part of each testing phase, i.e. the last 10 sets of sessions, using a Wilcoxon matched-pairs test (exact procedure, [61]) with SPSS software version 16 (SPSS Inc., Chicago IL, U.S.A.).

Supporting Information

Figure S1 Number of raisins returned by 13 subjects in Phases 1 and 2. In Phase 1, each set is composed of one session with the doubling partner and another with the fixed one. In Phase 2, subjects were tested with the fixed partner only. They did not modify their strategy in this phase. Each plot represents the mean number of raisins returned in one session of six trials. Errors bars represent standard errors of the mean for each session. The subject Pao was tested for a larger number of sessions than others to ascertain that no learning trend occurred in its performances.
(PDF)

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Author Contributions

Conceived and designed the experiments: BT SS VD. Performed the experiments: SS. Analyzed the data: SS. Wrote the paper: SS BT VD MHB.

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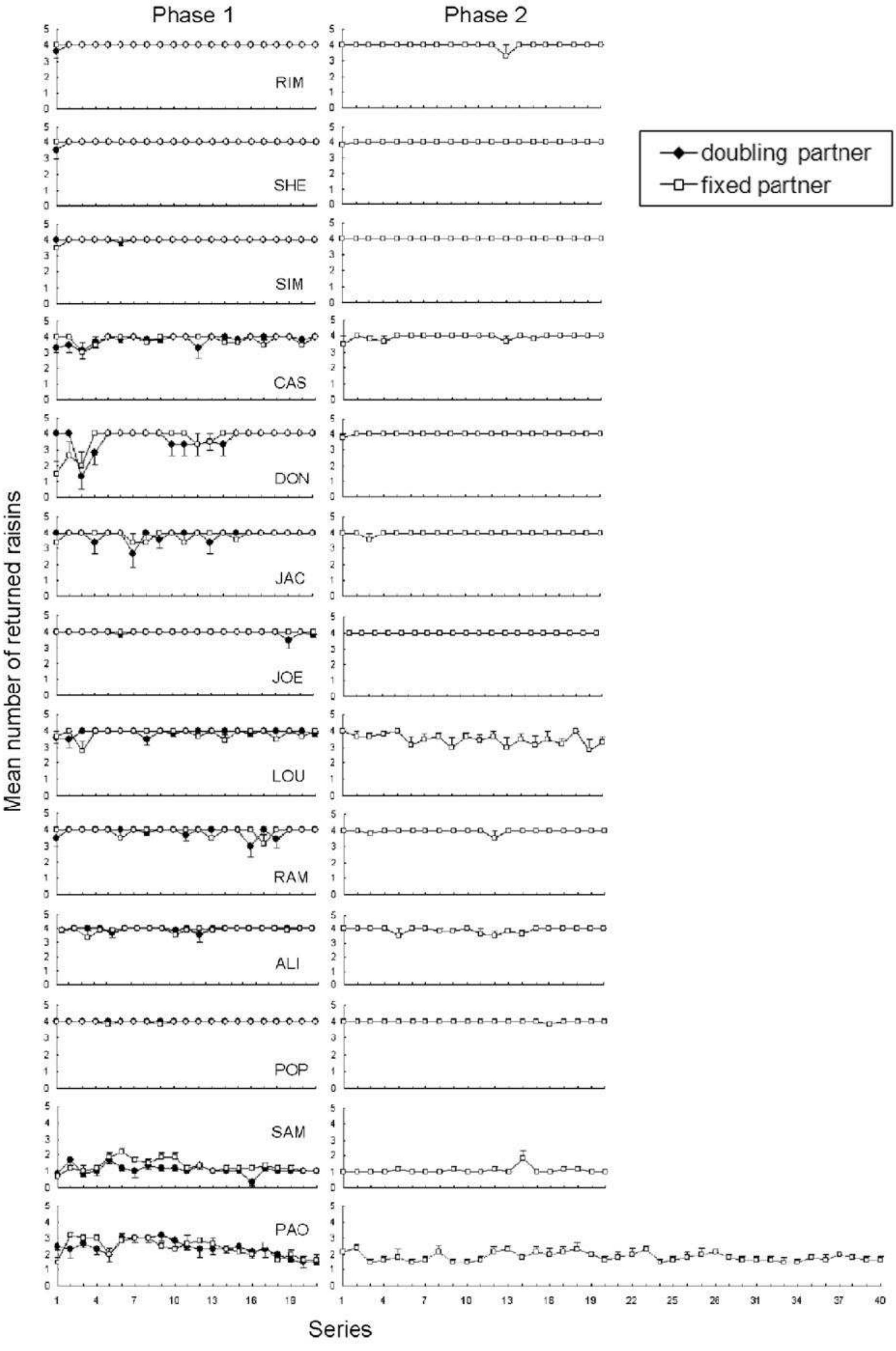
Figure S1. Number of raisins returned by 13 subjects in Phases 1 and 2.



ARTICLE 6

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Les primates non humains sont-ils sensibles à la régularité des bénéfices ?

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Are Monkeys Sensitive to the Regularity of Pay-off?

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Animals commonly face fluctuations in their environment and resources. To maximize their benefits, they need to integrate the risks attached to potential pay-offs. We do not know, however, to what extent individuals account for irregularity in the latter. We tested the sensitivity of monkeys (*Cebus apella, Macaca tonkeana, M. fascicularis*) to the irregularity of pay-offs in two different tasks. In a first experiment, the subjects were given an exchange task where the reward probability varied between different conditions, but yielded the same average pay-off. There was no evidence of subjects favoring either condition, meaning that they behaved in accordance with the predictions of the classical decision theory (Expected Utility Theory). In a second experiment, we offered to subjects a choice between two options involving different pay-off regularity. In this case, a wide range of inter-individual variation was found in the choices of individuals. Whereas monkeys accepted irregular pay-off in a rational way, there were individual biases in their preferences. These results indicate that the preferences of animals in a risky situation were not unequivocally shaped by the environment in which species have evolved.

Individuals commonly face fluctuations in their environment and resources. As assumed by behavioral ecology theory, natural selection should favor decision mechanisms producing optimal strategies, that is, maximizing the net rate of energy intake while minimizing time investment (Schoener, 1971). In the foraging context, two main variables influence decision-making, namely the expected amount of food and the time needed to obtain it. Regarding delay, animals prefer the variable delay to the fixed delay when choosing between two options; however, they prefer a fixed amount of food to a variable amount (Kacelnik & Bateson, 1996).

In the context of the Expected Utility Theory (EUT), Von Neumann and Morgenstern (1944) argue that risky choices can be specified both in terms of outcomes and probabilities of these outcomes, and that how individuals pick one option rather than another is based on maximizing expected utility. This behavior is referred to rationality in classical economic decision-making. Thereafter, any rational, risk-neutral individual should be indifferent when faced with two options having identical expected outcomes. For example, in animals facing variable and fixed delays with identical expected delay for the two options, risk neutrality would prevail if animals do not exhibit preference for either option. In other words, as subjects prefer the variable option to the fixed one, they are risk-prone regarding delays and risk-averse regarding food amounts. These results are very interesting according to the EUT, because it is precisely because animals are risk-averse for food amounts that they care about risk when seeking food resources.

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A number of experimental studies have, however, demonstrated that human decision-making is not consistent with EUT predictions (Plott & Smith, 2008; Tversky & Kahneman, 1981). Among the well-observed deviations from rationality, it appears that individuals feel more pain from losses than satisfaction from equivalent gains; this behaviour is called loss-aversion. Moreover, risk-aversion in humans is different for upside and downside risk (Camerer, Issacharoff, Lowenstein, & O'Donoghue, 2003; Tversky & Kahneman, 1981). In other words, individuals are risk-averse in the domain of gains whereas they are generally risk-prone in the domain of losses. It has been shown that chimpanzees (*Pan troglodytes*) and tufted capuchin monkeys (*C. apella*) display similar loss aversion when having to give or receive the same goods (Brosnan et al., 2007; Chen, Lakshminaryanan, & Santos, 2006; Lakshminaryanan, Chen, & Santos, 2008). It is therefore interesting to study non-human primate behaviour when certain outcomes involve a loss. In the following study, we will avoid labeling individuals' attitudes as risk-sensitive if individuals can obtain a gain which is either equal to zero or superior to the initial investment, the focus will be put on the impact of the pay-off regularity.

To study economic decision in animals, subjects are typically offered a choice between two options, a first option with delay or food quantity which remains constant from one trial to another and a second option with delay or food quantity which varies from one trial to the next. The reward to be gained is not predictable at a given trial in the variable option, but as the two options are equivalent over the experiments, individuals can learn the general pattern of reward delivery (Bateson & Kacelnik, 1997; Hayden & Platt, 2007). In a visual gambling task, two rhesus macaques (*Macaca mulatta*) were seen to choose the less regular options but their preference declined with increasing delay between choices (Hayden & Platt, 2007; McCoy & Platt, 2005). In a foraging choice task, Heilbronner, Rosati, Stevens, Hare, and Hauser (2008) found that chimpanzees preferred an irregular option, whereas bonobos (*Pan paniscus*) favored the regular one; the authors therefore assumed that the level of uncertainty of the ecological environment surrounding a species shapes the economic preferences of individuals.

The ability of animals to compare costs and benefits may be also examined using a food-exchange task. Non-human primates can readily engage in exchanges of goods with humans. They attribute values to non-edible tokens and give them back for food (Brosnan & de Waal, 2004; Hyatt & Hopkins, 1998; Westergaard, Liv, Rocca, Cleveland, & Suomi, 2004). They exchange food to receive a quantitatively or qualitatively more desirable one (Drapier, Chauvin, Dufour, Uhlrich, & Thierry, 2005; Lefebvre & Hewitt, 1986; Steelandt, Dufour, Broihanne, & Thierry, 2011) and can wait significant periods of time in order to maximize pay-off (Dufour, Pelé, Sterck, & Thierry, 2007; Pelé, Dufour, Micheletta, & Thierry, 2009; Ramseyer, Pelé, Dufour, Chauvin, & Thierry, 2006).

We studied tufted capuchin monkeys (*Cebus apella*) and macaques (*Macaca tonkeana, Macaca fascicularis*) to assess whether they account for the regularity of pay-off. In a first experiment, subjects were tested in an exchange task where the reward probability and the reward rule varied between different conditions, albeit yielding the same average pay-off. If monkeys were rational decision makers, they were expected to accept exchanging at the same rate in any condition; otherwise, they should behave differently according to conditions. In a second experiment, the subjects were tested in a choice task where they had to choose between two options for which the regularity of pay-off differed. If the sensitivity of animals to reward regularity is shaped by the ecological environment in which species have evolved, each group of individuals should display the same patterns of response; otherwise, inter-individual variations should be observed within groups.

Method

Subjects and Living Conditions

Subjects were maintained at the Primatology Center of the Strasbourg University (Table 1). Nine tufted capuchins belonged to a group of 18 individuals housed in a 78 m^2 indoor-outdoor enclosure composed of several compartments. Four Tonkean macaques belonged to a group of seven individuals housed in a 35 m^2 indoor-outdoor enclosure composed of several compartments. Two other Tonkean macaques belonged to a group of 16 individuals raised in a 1 acre wooded area including a shelter and a 40 m^2 wire-mesh fenced enclosure used for experiments. Three long-tailed macaques were housed together in an enclosure of 10 m^2 composed of several compartments and located in an indoor room. Three other long-tailed macaques were socially housed in individual cages of 125 x 80 x 80 cm allowing visual and physical contacts with others. Commercial monkey diet and water were available *ad libitum* and subjects were never deprived of food. For testing, group-living subjects were temporarily separated from their mates and placed in individual compartments using positive reinforcement. All research complied with animal care regulations, ASP Principles for the Ethical Treatment of Non-Human Primates and national laws.

Experiment 1

Testing procedure. Subjects had been already involved in food exchange tasks with human experimenters during previous studies (Pelé et al., 2009; Pelé, Micheletta, Uhlrich, Thierry, & Dufour, 2011). We used Corinthian raisins for training and testing. The experimenter sat in front of the wire mesh and laid three cups containing three potential rewards on the ground in full view of the subject. The number of potential rewards shown depended on the experimenter running the trial. A test started when the experimenter showed the subject three raisins on a teaspoon for 2 s. She then gave them to the subject. After 3 s, the experimenter held out a hand, palm open, in front of the subject requesting them back. When the subject gave one or more raisins, the experimenter could reward the subject by supplying him/her with raisins taken from one of the three cups. If the subject did not return raisins, the trial ended. The experimenter waited 1 min after food consumption before starting another trial.

Experimental design. Subjects were submitted to three different testing conditions. The subjects could recognize these conditions from different cues. First, the cups containing potential rewards were laid in full view of subjects. Second, a different experimenter conducted the tests in each condition. The three experimenters rewarded subjects with different degrees of regularity, the probability to be rewarded differing between experimenters. A first experimenter regularly gave back double the number of raisins returned by subjects in every trial; potential rewards in the cups numbered two, four or six. A second experimenter gave back three rewards for each returned raisin but only in two trials out of three; in this irregular condition, the subjects did not receive anything in one test out of three. Potential rewards in the cups numbered three, six or nine. A third experimenter gave back six rewards for each returned raisin but only in one trial out of three; in this very irregular condition the subjects did not receive anything in two tests out of three. Potential rewards in the cups numbered six, 12, or 18 raisins.

Table 1
Information about subjects.

Subjects	Age (yrs)	Sex	Rearing conditions
Tufted capuchins			
Ass*	19	female	group-living, indoor-outdoor
Kin	17	female	group-living, indoor-outdoor
Ali	10	female	group-living, indoor-outdoor
Pao	8	female	group-living, indoor-outdoor
Am	11	male	group-living, indoor-outdoor
Pis	8	male	group-living, indoor-outdoor
Pop	8	male	group-living, indoor-outdoor
Rav	7	male	group-living, indoor-outdoor
Sam	6	male	group-living, indoor-outdoor
Tonkean macaques			
Syb	6	female	group-living, indoor-outdoor
Rim	7	male	group-living, indoor-outdoor
She	6	male	group-living, indoor-outdoor
Sim	6	male	group-living, indoor-outdoor
Lad*	12	female	group-living, semifree-ranging
Sha	6	male	group-living, semifree-ranging
Longtailed macaques			
Lou	12	male	group-living, indoor
Ram	17	male	group-living, indoor
Sad	13	male	group-living, indoor
Cas	13	male	separated, indoor
Jac	16	male	separated, indoor
Joe	12	male	separated, indoor

* For reasons irrelevant to the study, Ass (died) and Lad (gave birth) were not tested in Experiment 2. All other subjects were tested both in Experiments 1 and 2.

Training phase. Prior to testing, subjects were run in several training periods carried out by an experimenter different from the three experimenters involved in testing. In a first training period, the experimenter gave two raisins and requested the subjects to return them both to obtain six raisins. Sessions of twelve trials were run until subjects succeeded in at least 80% of trials; they needed between one and four sessions to reach this criterion. They were then run in two sessions of twelve trials in which the experimenter gave three raisins and requested the subjects to return them all to obtain six raisins. We required subjects to succeed in at least 80% of trials in two consecutive sessions; they needed between three and eight sessions to reach this criterion. In another 2 day training period, subjects were submitted to one daily session of nine trials. The experimenter gave one, two or three raisins and requested subjects to return them to obtain twice the returned number, i.e., two, four or six raisins. Three trials were run in a random order in each condition. The aim was to show subjects that they could receive a reward amount proportional to the returned number of raisins; no learning criterion was required. In a further 2 day training period, subjects were habituated to the three testing experimenters. Subjects were exposed in a single trial to each of the three experimenters. Subjects had to give back at least one raisin to each experimenter. If they failed, a second trial was run; subjects needed between two and seven trials to succeed with all experimenters. In the last training period, subjects were run in daily sessions of nine trials. There were four successive sets of three sessions with each session corresponding to one of the three experimental conditions selected in a random order. This training aimed to lead subjects to learn that the three experimental conditions were rewarded in different ways. An examination of individual results showed that several subjects followed a learning curve during these first sets of sessions, but that all displayed stable performances during the testing phase (Fig. 1).

Testing phase. The testing phase was the continuation of the last training phase in which subjects were run in daily sessions of nine trials. They were tested in four other successive sets of three sessions with each session corresponding to one of the three experimental conditions selected in a random order. The experimenter's offers in each session were the same in the three conditions, i.e., between 0 and 54 rewards depending of the number of raisins returned by subjects. The subjects could get the same final number of raisins, i.e., between 27 and 54 raisins depending of the number of raisins returned. The order of trials was randomized in each session for irregular and very irregular conditions. The role of experimenters was also counterbalanced across subjects; each experimenter intervened regularly, irregularly or very irregularly with two or three subjects in each species.

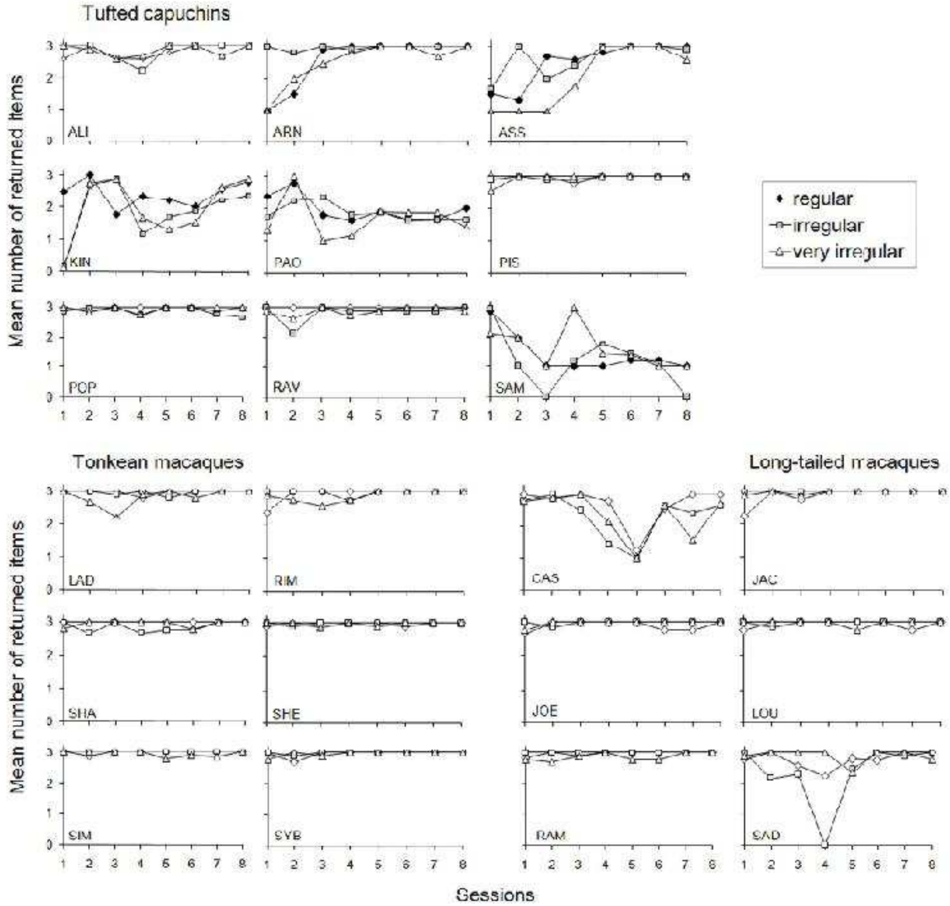

Figure 1. Number of raisins returned by monkeys. Each plot represents the mean number of raisins returned in one session of nine trials, along with standard errors. Several subjects followed a learning curve during the first sets of sessions. All subjects displayed quite stable performances during the testing phase (sessions 5 to 8).

Experiment 2

Apparatus. Subjects faced the experimenter through a wire mesh. Food rewards were placed on a plastic support (55 cm x 38 cm). Rewards could be obscured by plastic bowls of different colors and shapes (red bowl: diameter 12 cm, height 8 cm; grey bowl: diameter 12 cm, height 6 cm; white bowl: diameter 9 cm, height 9 cm). We used an occluder (height 10 cm, length 40 cm) to cover the bowls during baiting and prevent subjects seeing how many items were available beneath the bowls. During sessions, the experimenter placed the options on the support hold-off individuals so that they could be slid forward within the subject's reach.

Testing procedure. The experimenter sat in front of the wire mesh and laid two bowls and two cups on the support. The occluder prevented the subjects from seeing how many items were loaded on the cups beneath the bowls. The experimenter loaded the cups with the appropriate number of raisins and covered each side with the corresponding colored bowl. She always loaded the cups from left to right, in case subjects attempted to infer amounts from body placement. Then, the occluder was lifted and the experimenter pushed the two bowls forward to allow the subject to make a choice. The subject then had 10 s to make a choice by touching or jabbing in the direction of one of the two bowls. The experimenter then moved back the two bowls, uncovered the food amount, and rewarded the subject with the cup of raisins beneath the chosen bowl. The experimenter waited for 1 min after the end of food consumption before starting another trial.

Experimental design. There were three options for reward. The first option was regular; it always yielded six raisins. The second was irregular as it yielded nine raisins in two trials out of three. The third was very irregular as it yielded 18 raisins in one trial out of three. Subjects were submitted to binary choices between options: regular vs. very irregular, regular vs. irregular, irregular vs. very irregular. They could choose between a less regular option and a more regular option based on the shape and color of the bowl since each bowl was associated with a given option for each subject. The assignment of bowl color to each option was counterbalanced across subjects. The side assignments for the options were counterbalanced within sessions. For the two irregular options, rewarded trials were randomized within each session.

Training phase. Prior to testing, subjects completed two training periods. A first period aimed at teaching subjects to jab in the direction of one of the bowls. We performed two sessions of nine trials where we placed four raisins beneath one bowl and 1 raisin beneath the other bowl. The side assignments for the options were counterbalanced within sessions. There was no learning criterion for this period. The second period aimed to train subjects to discriminate between options. The procedure was the same as in testing except that the occluder was not used. Subjects saw the actual reward quantities for 4 s before the experimenter covered them with the appropriate bowls in full view of the subject. We performed four daily sessions of nine trials with each choice. For each training session, subjects were required to succeed in at least 80% of trials. Subjects needed between four and eight sessions to succeed.

Testing phase. In the testing phase, we run subjects in one set of four sessions of nine trials for each binary choice. There was no more than one session per half-day. The order of sets of sessions was counterbalanced across subjects. Each set of sessions was run straight after the four sessions of the corresponding second training period. The subjects' total pay-off could vary as follows within one session: from 18 to 90 raisins in the regular/very irregular choice, from 36 to 72 in the regular/irregular choice, and from 27 to 81 in the irregular/very irregular choice. Note that each option provided an average pay-off of 54 raisins in each session regardless of the option.

If a subject did not make a choice (i.e., did not jab in the direction of one bowl or did not touch one of the two bowls) within 10 s of being given access the two bowls, the trial was considered aborted. If a subject failed to consume all the food, the trial was aborted. If three trials were aborted in one session, the entire session was ended and the data discarded. Only two sessions were aborted in this way. Moreover, to eliminate side-biased data, if a subject chose a single side eight or more times out of nine trials, the data from that session were discarded and the session repeated. Based on this criterion, 19 sessions were consequently deemed biased.

Statistical Analysis

Data were analyzed using non-parametric statistics with SPSS 17.0 (SPSS Inc., Chicago, IL, U.S.A.). The significance level was fixed at 0.05.

Table 2
Experiment 1: comparison of the number of raisins returned by subjects in exchanges differing by the regularity of pay-off (mean number ± SD).

Subjects	Conditions			p*
	regular	irregular	very irregular	
Tufted capuchins				
Ali	2.94 ± 0.04	2.33 ± 0.21	2.47 ± 0.19	0.09
Am	2.92 ± 0.08	2.92 ± 0.08	2.92 ± 0.06	0.72
Ass	2.94 ± 0.06	2.81 ± 0.12	2.33 ± 0.20	0.80
Kin	2.39 ± 0.15	1.89 ± 0.16	1.81 ± 0.19	0.12
Pao	1.81 ± 0.08	1.56 ± 0.12	1.61 ± 0.12	0.27
Pis	3.00 ± 0	3.00 ± 0	3.00 ± 0	1
Pop	2.97 ± 0.03	2.78 ± 0.11	2.92 ± 0.08	0.10
Rav	3.00 ± 0	2.92 ± 0.05	2.94 ± 0.04	0.25
Sam	0.92 ± 0.09	1.08 ± 0.14	1.31 ± 0.15	0.10
Tonkean macaques				
Lad	3.00 ± 0	2.86 ± 0.09	2.86 ± 0.10	0.25
Rim	2.92 ± 0.08	2.83 ± 0.12	2.83 ± 0.12	0.78
Sha	2.50 ± 0.19	2.56± 0.17	1.67 ± 0.24	0.60
She	2.97 ± 0.03	3.00 ± 0	2.97 ± 0.03	0.61
Sim	3.00 ± 0	2.92 ± 0.08	2.39 ± 0.19	0.10
Syb	3.00 ± 0	3.00 ± 0	3.00 ± 0	1
Long-tailed macaques				
Cas	2.42 ± 0.16	2.11 ± 0.18	1.58 ± 0.22	0.10
Jac	3.00 ± 0	3.00 ± 0	3.00 ± 0	1
Joe	2.89 ± 0.07	2.92 ± 0.08	2.92 ± 0.08	0.61
Lou	2.86 ± 0.10	3.00 ± 0	2.94 ± 0.06	0.37
Ram	3.00 ± 0	3.00 ± 0	2.64 ± 0.16	0.20
Sad	2.11 ± 0.22	2.06 ± 0.22	2.11 ± 0.22	1

*Friedman test (N = 36)

Results

Experiment 1

We compared the number of returned rewards in the three experimental conditions for each subject. The Friedman test did not yield statistically significant differences between conditions for any subjects (Table 2). We then compared the mean performances of all subjects in the three experimental conditions. Although individuals tended to return a larger number of rewards in more regular conditions, the trend was not statistically significant (regular mean ± standard deviation = 2.69 ± 0.07, irregular 2.60 ± 0.09, very irregular 2.49 ± 0.12; Friedman test: $p = 0.064$, N = 21).

Experiment 2

For every subject we compared the number of options chosen in each binary choice using binomial tests (Table 3). Eight subjects displayed a significant preference in the regular/very irregular choice, three favoring the regular option and five the very irregular. Seven subjects displayed a significant preference in the regular/irregular choice, five favoring the regular option and two the irregular. Ten subjects displayed a significant preference in the irregular/very irregular choice, two favoring the very irregular option and eight the irregular. It must be stressed that only four subjects were consistent in their choices, two always favoring the more regular option and two the more irregular. Three other subjects were inconsistent, favoring either the more regular or the more irregular depending on choices. These various strategies were quite uniformly distributed among the three species studied. It may be noted however that long-tailed macaques generally tended to favor the less regular option (Table 3).

Table 3
Experiment 2: preferences of subjects in binary choices between options differing in the regularity of pay-off.

Subjects	Ratio of number of choices for more regular options by number of choices for less regular options		
	regular/ very irregular	regular/ irregular	irregular/ very irregular
Tufted capuchins			
Ali	0.83***	0.94***	0.36
Am	0.64	1.00***	0.00***
Kin	0.28*	0.83***	0.22***
Pao	0.69*	0.50	0.58
Pis	0.33	0.47	0.31*
Pop	0.44	0.39	0.19***
Rav	0.39	0.00***	0.67
Sam	0.53	0.50	0.92***
Tonkean macaques			
Rim	0.22***	1.00***	0.00***
Sha	0.75**	0.58	0.86***
She	0.61	0.56	0.58
Sim	0.64	0.53	0.33
Syb	0.64	0.86***	0.33
Long-tailed macaques			
Cas	0.47	0.47	0.06***
Jac	0.31*	0.56	0.17***
Joe	0.11***	0.19***	0.39
Lou	0.33	0.53	0.33
Ram	0.19***	0.47	0.36
Sad	0.42	0.44	0.31*

Values above 0.5 indicate a preference for the more regular option, values below 0.5 indicate a preference for the less regular option. Binomial test: N = 36, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

Discussion

In a first experiment we found no evidence that subjects were sensitive to the regularity of pay-off, whereas in a second experiment many of them displayed a preference, albeit in different directions, when they had to choose between two conditions differing by the regularity of pay-off.

In Experiment 1, individuals returned a similar number of raisins in three conditions differing by the probability and quantity of reward in each trial, but not by the average pay-off in a session. It could be argued that subjects failed to distinguish between conditions despite the different cues attached to them, i.e. cups and experimenters. This explanation appears unlikely, however, since there is ample evidence that macaques and capuchin monkeys can readily learn to discriminate cues and recognize experimenters (e.g., Kuroshima, Fujita, & Adachi, 2003; Mitchell & Anderson, 1997; Paukner, Anderson, Borelli, Visalberghi, & Ferrari, 2005). In particular, they can differentiate magnitudes and make "more" or "less" judgments about discrete quantities (Addessi, Crescimbene, & Visalberghi, 2007; Beran, Evans, Leighty, Harris, & Rice, 2008; Hauser, Carey, & Hauser, 2000; Wood, Glynn, Hauser, & Barner, 2008). In a study requiring monkeys to trade tokens for rewards with two different experimenters, tufted capuchins selected the one providing the higher pay-off (Chen et al., 2006). Besides it is possible that monkeys met difficulties distinguishing between the three different conditions; future research should check whether they would show the same responses when tested with two opposite conditions of pay-off regularity.

Previous works have shown that monkeys display loss aversion. In an exchange task with two experimenters, capuchin monkeys preferred trading with a first experimenter who presented and gave a reward rather than a second one who presented two rewards but gave only one (Chen et al., 2006; Lakshminaryanan et al., 2008). Yet when important gains are at stake, macaques and capuchin monkeys can significantly delay gratification; they are able to tolerate loss by giving back a piece of cookie and can then wait dozens of minutes to obtain a cookie 40 times larger (Pelé et al., 2009, 2011). The results of Experiment 1 were consistent with the prediction of the expected utility theory, which states that rational decision makers should be indifferent between options of same expected pay-off (Von Neumann & Morgenstern, 1944). The subjects' maximal expected satisfaction corresponded to the same utility function in the three conditions, making understandable that their performances did not differ in a significant way in the three conditions. The subjects of the three species studied optimized pay-off by investing comparable amounts in all conditions. It is noteworthy that they continued investing despite suffering a full loss in one or two trials out of three. Whereas the expected utility theory was built to account for the decisions of human beings, the present results show that it is also applicable to monkeys.

Whereas in Experiment 1 subjects could only accept an exchange or not, they had to choose between two options differing by the regularity of rewards in Experiment 2. A main finding of this second experiment is the large amount of variation observed between subjects. A majority of them displayed some significant preference, albeit in different directions. Several subjects exhibited inconsistent preferences, selecting either the more regular or the less regular option depending on proposed options. Moreover, two individuals consistently selected the more regular option while two others consistently selected the less regular one. Although long-tailed macaques tended to favor the less regular option, the results showed that there was no single decision-making pattern among subjects. Such individual biases contrast with the experiment of Heilbronner et al. (2008) who found that five bonobos favored the regular option, whereas five chimpanzees favored the irregular option, leading the authors to suggest that the preferences displayed by individuals depended on fluctuations typical of the environment in which the species evolved. On the other hand, it is worth noting that large individual differences remain a major finding from economic experiments in humans, e.g. in the trust game, the ultimatum game and the dictator game (Scheres & Sanfey, 2006). The absence of specific patterns in monkeys indicates that individual sensitivity to the regularity of pay-offs cannot simply be related to the habitat in which a species has evolved.

Inter-individual variations in patterns of decision-making in risky situations may be related to the differences in temperament arising from the influence of factors such as sex, age and rearing history (Clarke & Boinski, 1995; Coleman, Anntully, & McMillan, 2005; Suomi, 1991). Considering the limited sample size and the fact that study groups were not balanced for these factors, their possible significance could not be assessed here. So far, few studies have experimentally addressed how risks affect economical choices in animals. Future research should investigate the factors underlying decision-making, and in particular how chance and the amount of expected losses or gains can shape the strategies of individuals under various conditions of food income.

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Sophie STEELANDT

LE DEVELOPPEMENT DES COMPETENCES ECONOMIQUES CHEZ L'ENFANT

Résumé

Malgré l'importance des interactions économiques dans les sociétés humaines, l'étude de la prise de décision dans le contexte économique chez les enfants reste rare. Dans ce travail, j'ai testé 802 enfants âgés de 14 mois à 10 ans dans des situations expérimentales faisant intervenir une tâche d'échange afin (1) de déterminer l'âge auquel les enfants comprennent l'utilisation du don et de l'échange comme des outils permettant de maximiser leur gain, (2) de tester s'ils intègrent le coût temporel associé à un échange, (3) de rechercher s'ils sont capables d'ajuster leur investissement au comportement du ou des partenaires d'échange, et (4) d'évaluer leur aptitude à prendre en compte le risque inhérent à la situation d'échange. Pour chacune de ces questions, j'ai cherché à identifier d'éventuels parallèles entre l'efficacité des décisions économiques chez l'enfant et les stades connus du développement cognitif. Les résultats montrent un changement majeur entre 18 et 22 mois dans la capacité à donner et échanger. Les enfants sont capables d'ajuster leur temps d'attente à la quantité de récompense offerte à partir de trois ans. Enfin, on constate que les enfants de plus de cinq ans peuvent adapter leur choix d'investissement selon le comportement des partenaires et le risque de perte associé à un échange. Il apparaît que les compétences des enfants correspondent à ce que l'on connaît des stades de développement dans les facultés de calcul numérique, de jugement temporel et de compréhension des états mentaux d'autrui. Ce travail devra se poursuivre chez d'autres sociétés aux normes économiques différentes de manière à évaluer la généralité des résultats obtenus dans cette thèse.

Mots-clés : enfant, économie, prise de décision, cognition, don, échange, attente, investissement, risque.

Résumé en anglais

Given the importance of economic interactions in European societies, we have relatively little knowledge about children's decision-making in an economic context. In this work, I tested 802 children aged from 14 months to 10 years in experimental situations based on an exchange task in order (1) to determine the age from which children understand that they can use gifts and exchanges as means to maximize their gain, (2) to test whether they understand the temporal cost associated with an exchange, (3) to study whether they are able to adjust their investment according to the exchange partner(s), and (4) to evaluate their capacity to take a risk during an exchange. For each question, I aimed at identifying potential parallels between the efficiency of economic decisions and the stages of cognitive development already known in children. Results revealed a major shift between 18 and 22 months in the ability to give and exchange. Children were able to adjust their waiting time to the quantity of reward being offered from the age of 3. Finally, I found that children aged over 5 could adapt their investment according to the behavior of partners and the risk of losing related to an exchange. It appears that children's competencies match what is known of the stages of development in numeric competency, temporal judgment and understanding of others' mental states. This work should be conducted in other societies with different cultural and economic norms in order to assess the generality of the results found in this thesis.

Keywords: children, economics, decision-making, cognition, gift, exchange, waiting, investment, risk.