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Decision-making on an explicit risk-taking task in preadolescents with attention-deficit/hyperactivity disorder

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Summary. Inappropriate risk-taking and disadvantageous decision-making have been described as major behavioural characteristics of patients with attention-deficit/hyperactivity disorder (ADHD). However these behaviours are difficult to measure in laboratory contexts and recent studies have yielded inconsistent results which might be related to task characteristics. The present study adopted the Game of Dice Task, a test procedure in which risks are made explicit and the load on working memory is minimal. As a result, preadolescents with ADHD ($N = 23$) made significantly more risky choices and suffered major losses of money compared to normal controls ($N = 24$) but only when they played the game a second time. Differences in risk-taking correlated significantly with hyperactivity as rated by parents and with inhibitory control, but not with working memory performance. The results are discussed in the context of current theories of ADHD.

Keywords: Attention-deficit/hyperactivity disorder (ADHD); risk-taking; decision-making; impulsivity; reward; gambling-task; probabilistic discounting

Introduction

Inappropriate decision-making and unnecessary risk-taking in everyday situations have been described as major characteristics of ADHD (Barkley 2006; Williams and Taylor 2006). It is controversial, however, whether this should be attributed to cognitive or to motivational/emotional causes. Recent theories have claimed that ADHD originates from multiple pathways: a motivational pathway with a predominant dysregulation of the reward system, and one or several cognitive pathways which cause impairments of executive functions, especially of working memory and self-regulatory abilities (Castellanos and Tannock 2002; Sonuga-Barke 2003, 2005; Castellanos et al. 2006). In addition, a motor pathway seems to contribute to deficits of inhibitory control, especially in younger children with ADHD (Moll et al. 2001; Yordanova et al. 2006).

In adolescents, risky decision-making has been linked to sociopathic tendencies (Blair et al. 2001), to substance abuse, externalizing behavioural disorder and conduct disorder (Ernst et al. 2003a; Crowley et al. 2006). Developmental studies on decision-making show a protracted developmental course until young adulthood (Hooper et al. 2004; Crone et al. 2005; Eshel et al. 2007) and some authors conclude that young children's decision-making resembles that of adult patients with orbitofrontal damage (Crone and van der Molen 2004). Normal adolescence is a period of life that is particularly characterized by inappropriate risk-taking and novelty seeking (Kelley et al. 2004) and by a vulnerability to gambling, which has been explained by a transitional increased cognitive impulsivity due to the immaturity of frontal cortical and subcortical monoaminergic systems (Chambers and Potenza 2003).

Only a limited number of objective procedures are available to assess motivational impairments. The best evaluated task for emotional decision-making is the Iowa Gambling Task (IGT) (Bechara et al. 1994, 2000). In the IGT, the participant draws cards from several decks connected with different probabilities of wins or losses, which are unknown to the participant at the beginning of play. Normal individuals learn quickly which deck to select from in order to maximize outcomes, whereas patients with damage to the orbitofrontal cortex continue to select cards from the decks connected with infrequent high gains and frequent

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high losses. It has been suggested that the Iowa Gambling Task can be divided into two stages which tap two different types of decision-making: a first stage of ambiguous choice, where the risk linked to the different options is still unknown, and a second stage of risky decision-making where the probability of outcome has been learned (Bechara et al. 1997, see Brand et al. 2007b). This latter type of decision-making seems to be connected to more affectively-loaded ''hot'' executive functions. According to a meta-analysis by Krain and Castellanos (2006), risky decision-making is associated with activity of the orbitofrontal cortex, while ambiguous decision-making seems to be associated with dorsolateral frontal activity. However, the extent to which emotional decision-making on the IGT is confounded by cognitive functioning, such as working memory, cognitive flexibility, or deductive reasoning, remains controversial. Several studies report impaired performance on the IGT in patients with working memory deficits or amnesia (Manes et al. 2002; Gutbrod et al. 2006).

Children and adults with ADHD have been found to be impaired on the IGT (Ernst et al. 2003b; Toplak et al. 2005; Garon et al. 2006), but results are inconsistent: according to the study of Garon et al. (2006), impaired decision-making in ADHD is confined to children without symptoms of depression. Ernst et al. (2003a) found group differences between participants with ADHD and controls, but only in a second test session, and Geurts et al. (2006) failed to find group differences at all.

In ADHD research, decision-making has also been addressed from a perspective of temporal or probabilistic discounting (e.g. Barkley et al. 2003; Scheres et al. 2006). In the latter, subjects have to make choices between small rewards delivered with high probability and large rewards delivered with small or variable probabilities. Scheres et al. (2006) failed to find differences between children with ADHD and controls on a probabilistic discounting task which, at least in part, was explained by characteristics of the procedure used in the study.

In order to control for cognitive functional overlap as far as possible, the Game of Dice Task (GDT), a risk-taking task with explicit rules developed by Brand et al. (2004), was selected for the current study. In the GDT, subjects carry out decisions on a computerized dice game, choosing between four possible outcomes: two of them are high risk choices, associated with high gains and a major probability to lose, and two are low risk choices, associated with small gains and a high probability to win (see the Material and methods section for a description). The GDT matches a familiar game and the probabilities for wins and losses remain stable all the time so that participants do not have to infer and memorize rules. Also no waiting time is involved. Different groups of patients seem differentially impaired on this task (Brand et al. 2004, 2005a, b, 2006, 2007b): individuals with pathological gambling start with a cautious response strategy and end up with an enhanced tendency for risky choices, which is interpreted as a loss of attraction of the safer alternatives during the game (Brand et al. 2006), due to a failure of the reward system. In contrast, Parkinson patients' increased tendency to make risky decisions is equally distributed over the game, which is interpreted as due to cognitive problems: They start with a disadvantageous strategy or no strategy at all and partly fail to learn the reward-alternative and punishment-alternative associations (see Brand et al. 2004). In patients with cognitive impairment, decision-making on the GDT correlates with performance on the Wisconsin Card Sorting Task, but not with working memory or control of interference. This suggests a relation to executive functioning, as far as strategy application is involved. In contrast to other probabilistic discounting tasks, however, no re-evaluation of chances is needed and the rules of the game remain stable. Once the rules are understood, the player can select his strategy as he wishes and does not have to take into account continuously changing probabilities. Therefore response tendencies during repetitive trials may show different trajectories than in other gambling tasks.

The aims of the present study are to investigate whether and to what extent young adolescents with ADHD can be distinguished from normal controls by their performance on an explicit risk-taking task, and whether a tendency towards risky choices is related to impaired cognitive performance or to clinical behavioural symptoms. As a general hypothesis, we expect adolescents with ADHD to differ from normal controls. Two competing predictions will be tested: 1. If children with ADHD shift from cautious towards more risky choice alternatives, such as observed in pathological gamblers, we would conclude that the affective valence of reward gradually changes during the course of the task. In this case we would expect decision-making to be increasingly influenced by impulsive components and correlated with deficits in inhibitory control. 2. If children with ADHD fail to choose a convenient strategy because of cognitive impairment – or eventually fail to understand the task at all – they would demonstrate a disadvantageous decision-making – strategy from the beginning with no or only slight improvement towards the end of the game. In this case we would expect a positive correlation with performance deficits in executive tasks related to planning and flexibility, and elevated scores in corresponding clinical scales.

Material and methods

Participants

Twenty three preadolescents with ADHD participated in the study, 2 girls and 21 boys (combined subtype $N = 16$, hyperactive/impulsive subtype $N = 2$, inattentive subtype $N = 5$; see Table 1 for a description of the sample). They were recruited from the Department of Child and Adolescent Psychiatry, University of Zurich. The Conners' Teacher Rating Scale – CTRS-R:L (Conners 1997, 2002) and the German version of the SNAP – Rating Scale (Swanson 1992) were used as initial selection instruments. HYPESCHEME, a computerized operational criteria checklist and diagnostic algorithm for DSM-IV and ICD-10 which includes a diagnostic interview (PACS: Taylor et al. 1986) was used to confirm the diagnosis (see Curran et al. 2000). For three participants, parents were not available for interviews. Diagnostic classification in these cases was based on clinical diagnoses from the child psychiatrist running the treatment program and from previous diagnostic information provided for referral. Adolescents with severe ODD/CD were excluded from the study after the initial screening. However, three children with ADHD who fulfilled the criteria of comorbid ODD according to the subsequent assessment remained in the group. Sixteen patients with ADHD were taking stimulant medication which they stopped at least 24 h prior to testing. Twenty-four normal developing children participated in the study as controls, 23 boys and 1 girl, who had been recruited from public schools in the Zurich area. Controls who scored above the clinical cut-off on the SNAP or on Conners' Teacher Rating Scale were excluded from the study. All participants were aged between 11 and 13 years. The participants gave informed consent and written consent was obtained from all parents. The study had been approved by the local ethical committee.

Table 1. *Descriptive data of preadolescents with ADHD and controls*

	ADHD ($N = 23$) Mean (SD)	Controls ($N = 24$) Mean (SD)	*T*	*p*
Age	12.2 (0.8)	11.9 (0.6)	−1.640	n.s.
IQ	101.3 (10.7)	108.5 (18.5)	1.543	n.s.
SNAP (raw scores)				
Hyperactivity	6.0 (3.8)	1.5 (2.0)	4.923	***
Impulsivity	5.7 (2.8)	1.5 (1.6)	6.205	***
Inattention	17.2 (5.1)	6.8 (6.0)	6.431	***
Oppositional-defiant	10.1 (5.4)	4.6 (4.3)	3.811	***
CBCL (T-scores)				
Withdrawn	58.7 (15.2)	53.7 (5.9)	1.459	n.s.
Somatic complaints	58.8 (10.4)	53.6 (6.0)	2.067	*
Anxious-depressed	62.6 (10.9)	54.9 (7.5)	2.781	**
Social problems	63.0 (11.3)	53.8 (5.0)	3.576	***
Thought problems	59.8 (10.1)	52.9 (7.3)	2.666	*
Attentional problems	67.3 (8.0)	54.9 (6.1)	5.870	***
Delinquent behaviour	67.8 (13.2)	53.4 (6.9)	4.595	***
Aggressive behaviour	67.2 (11.8)	54.1 (6.39)	4.665	***
BRIEF (raw scores)				
Inhibit	20.2 (4.8)	13.3 (3.4)	5.448	***
Shift	14.0 (3.2)	12.0 (5.4)	2.090	*
Emotional control	21.3 (4.4)	13.6 (4.5)	5.554	***
Initiate	16.6 (3.9)	10.9 (2.9)	5.485	***
Working memory	23.2 (4.7)	14.8 (4.1)	6.347	***
Plan/organize	27.4 (5.6)	17.4 (4.4)	6.617	***
Organization of material	14.3 (3.6)	9.2 (3.2)	5.061	***
Monitor	18.6 (2.9)	13.1 (3.8)	5.317	***

n.s. Non significant, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Game of Dice Task

In this computerized task, participants have to guess the outcome of a dice game in order to maximize their gains. They choose between different combinations of dice by clicking on the computer screen – on one die, or combinations of two, three or four dice – associated with different probabilities for gains and losses (see Fig. 1). If they choose a combination of four dice, the probability of an advantageous outcome is 4:6 and the possible gain or loss is 100 Euro. If they choose a combination of three dice (winning probability 3:6) they win or lose 200 Euro, if they choose two dice (winning probability 2:6) they may lose or win 500 Euro. If they choose the highest risk, one single die, the probability of a favourable outcome is 1:6 and the possible gain or loss is 1000 Euro. Participants begin the game with a fictive amount of 1000 Euro. In each round one single die is thrown: if the outcome is included in the chosen combination the player wins, otherwise he loses the corresponding amount (i.e. when he chooses the combination "1, 2, 3, 4" and the outcome of the first round is "3", the player wins 100 Euro, but

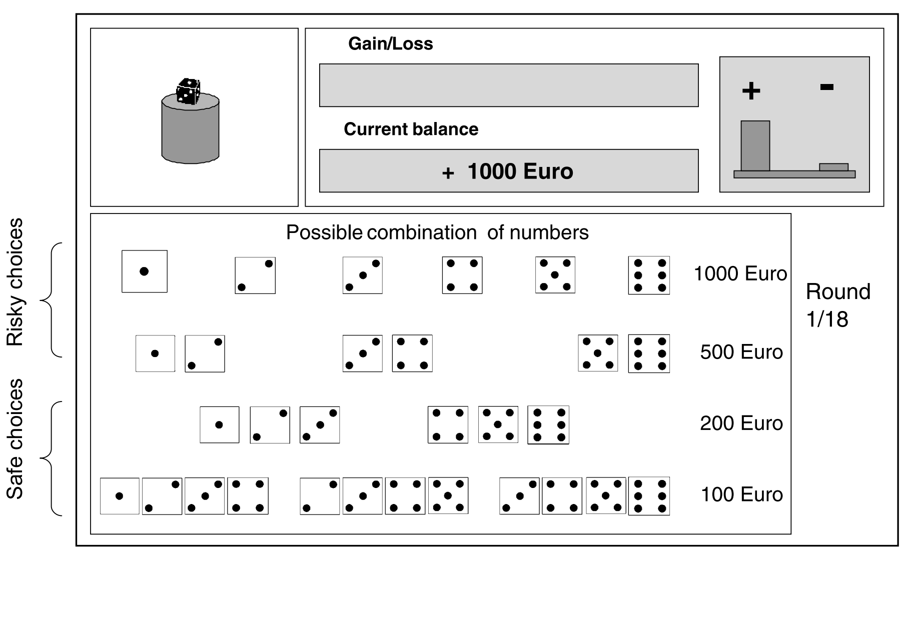

Fig. 1. The Game of Dice Task (from Brand et al. 2004, modified)

when the outcome is "5", he loses 100 Euro). Gains or losses are indicated on the screen and accompanied by pleasant or aversive sounds. The number of rounds and the current account are visible on the screen throughout the game.

Selections of one or two dice were classified as "risky" choices and selections of combinations of three or four dice as "safe" choices. Participants performed two games, a first game of 18 rounds followed immediately by a second game of 12 rounds. As the game is not preceded by training trials, it was hypothesized that the first 6 rounds of the GDT might be considered as a preliminary orienting phase, whereas rounds 7–18 can be considered as a stage of risky decision-making. For that reason, in the statistical analysis, rounds 7–18 of game 1 were compared to rounds 1 to 12 of game 2. Participants were informed that the second game would be shorter and the number of total rounds was visible throughout the games.

Cognitive tests

Participants performed a series of standardized neuropsychological test procedures. Working memory was assessed by "Digit span" (WISC III) and by a computerized 2-back-task, the subtest "Working Memory" from the Test for Attentional Performance (TAP) (Zimmermann and Fimm 2002). In this task, different numbers appear consecutively one by one on the screen. Participants have to press the response button as quickly as possible when the number currently seen on the screen is identical to the number that was presented two items before. To assess response inhibition, a computerized Go/Nogo task was performed (Subtest "Go/Nogo", TAP, Zimmermann and Fimm 2002). In this task participants are instructed to respond as quickly as possible when an "X" symbol is presented in the centre of the screen and to withhold responding when a plus-symbol ("+") appears. Complex executive functions (planning, response to feedback, mental flexibility, observation of rules) were assessed by a 64-item computerized version of the Wisconsin Card Sorting Task (WCST) (Heaton and Par 2000) and by the Tower of London (Culbertson and Zillmer 2001). A continuous performance task (CPT) was used to evaluate sustained attention (subtest "Vigilance", TAP, Zimmermann and Fimm 2002). In this version of the CPT, which has a duration of 10 min, participants have to press a response button when the appearance of the letter "E" in the centre of the computer screen is preceded by a high pitched tone or when the letter "*N*" is preceded by a low pitched tone. Finally, IQ was calculated based on a short form of the German version of the WISC III, including Arithmetic, Block Design, Vocabulary, and Picture Arrangement subtests (Schallberger 2005).

Behavioural scales

Parents rated behaviour on the Behaviour Rating Inventory of Executive Function (BRIEF) (Gioia et al. 2000), a German version of the Swanson, Nolan and Pelham (SNAP) rating scale (Swanson 1992) and the Child Behavior Checklist (CBCL) (Achenbach 1991) (Table 1).

Results

Game of Dice Task

In the first game adolescents with ADHD made as many risky choices as controls, i.e. they chose a single die or combinations of two dice with the same frequency as controls. The financial outcome did not differentiate between the groups (Table 2). A similar result was obtained when only rounds 7–18 of Game 1 were included, departing from the hypothesis that the first choices might be considered as a stage of preliminary orientation or ambiguous decision-making and therefore should not necessarily be entered in an analysis of deliberate risk-taking (Table 2). When the 18 rounds of the Game 1 were divided into three blocks of 6 trials, as suggested by Brand et al. (2006), and the results were entered into a repeated measures MANOVA, no effects of block ($F = 0.988$, $p = 0.381$) no group differences ($F = 0.095$, $p = 0.760$) and no interaction ($F = 1.200$, $p = 0.311$) were found, indicating that during the course of the first game no major changes of the decision-making strategy occurred.

Table 2. *Results of the Game of Dice Task*

	ADHD ($N = 23$) Mean (SD)	Controls ($N = 24$) Mean (SD)	T	*p*
Game 1, total (18 rounds)				
Number of risky choices	6.3 (4.3)	6.1 (3.7)	0.153	n.s.
Financial outcome	−1060 (2224)	−983 (3491)	−0.0991	n.s.
Game 1 (rounds 7–18)				
Number of risky choices	4.13 (3.27)	3.37 (2.49)	0.886	n.s.
Financial outcome	−430 (2131)	−162 (2007)	−0.443	n.s.
Game 2 (12 rounds)				
Number of risky choices	5.60 (3.7)	2.9 (2.8)	2.833	**
Financial outcome	−1734 (2866)	820 (1480)	−3.815	***

n.s. Non significant, ** $p < 0.01$, *** $p < 0.001$.

In the second game of 12 rounds, preadolescents with ADHD made significantly more risky decisions and ended up with a higher financial loss compared to normal controls (Table 2). When the results of Game 1 (trial 7–18) and Game 2 were entered into a repeated measures MANOVA (group × game × financial outcome, risky decisions), a main effect of group (Wilks' Lambda = 0.838, $F = 4.247$, $p = 0.021$) and of game by group (Wilks' Lambda = 0.831, $F = 4.472$, $p = 0.017$) emerged, whereas the effect for game was not significant. Post-hoc analyses showed that the interaction of game by group was significant for the number of risky choices ($F = 5.761$, $p = 0.021$) as well as for the financial outcome ($F = 7.627$, $p = 0.008$). To evaluate which of the two groups showed major changes from one game to the next, results of Game 1 (rounds 7–18) and Game 2 were compared separately for both groups using paired *t*-tests. For the adolescents with ADHD a significant increase in the number of risky choices between Games 1 and 2 ($p = 0.046$) was found, but only a trend for the decrease in the financial outcome ($p = 0.067$). In contrast, control participants showed a strong trend for an improvement in the financial outcome ($p = 0.056$) but the number of risky choices did not change from one game to the next ($p = 0.278$). The frequencies of choices for the four response alternatives were analyzed separately in a repeated measures MANOVA (group by game by choice alternatives) in order to investigate more fine-grained changes in the decision-making behaviour. Only a trend for an overall group-effect was found (Wilks' Lambda = 0.823, $F = 2.252$, $p = 0.080$), but the interaction of game by group was significant (Wilks' Lambda = 0.803, $F = 2.571$, $p = 0.052$). Post-hoc analyses revealed a significant effect for the most risky choice alternative ($F = 10.560$, $p = 0.002$): participants with ADHD chose the most risky alternative (one die) more frequently in Game 2 than in Game 1 (Fig. 2).

Relation between neuropsychological performance and risky decision-making

Differences between the groups on the neuropsychological tests were not very pronounced and confined to aspects of inhibitory control. Adolescents with ADHD made more errors on the Go/Nogo Task, produced more rule breaks on the Tower of London and made more commission errors on the CPT (Vigilance Task, TAP). No differences were found on the WCST, the Working Memory Task of TAP and Digit Span (Table 3).

Table 3. *Results of neuropsychological tests*

	ADHD ($N = 23$) Mean (SD)	Controls ($N = 24$) Mean (SD)	t/Z	p
Digit span (Hawik III)	9.17 (2.9)	9.3 (2.6)	-0.139^a	n.s.
Go/nogo (TAP) errors	6.0 (4.8)	3.0 (3.0)	-2.173^b	*
Working memory (TAP)				
Omissions	4.0 (2.9)	4.0 (2.8)	-0.312^b	n.s.
Correct responses	10.3 (2.8)	10.8 (2.7)	-0.538^a	n.s.
WCST				
Categories completed	3.2 (1.4)	2.9 (1.8)	-0.136^b	n.s.
Perseverative errors	8.0 (2.9)	8.5 (4.3)	-0.469^a	n.s.
Failure to maintain set	0.5 (0.7)	0.3 (0.5)	-0.413^b	n.s.
Tower of London				
Total moves	32.3 (11.2)	27.6 (8.7)	1.501^a	n.s.
Rule breaks	0.6 (1.0)	0.1 (0.4)	-1.972^b	*
CPT ("Vigilance", TAP)				
Omission errors	2.2 (3.1)	1.5 (2.6)	-0.195^b	n.s.
Commission errors	6.4 (5.8)	3.7 (3.9)	-2.161^b	*

n.s. Non significant, [a] t (*t*-test), [b] Z (Whitney-*U*-test), * $p < 0.05$.

When performances of participants with ADHD on the neuropsychological tests were correlated with the number of risky choices and financial outcomes (controlled for age), only one significant correlation emerged: the number of commission errors on the CPT was related to a low financial outcome in Game 2 ($r = -0.49$, $p = 0.026$). This was not the case for controls ($r = -0.105$, $p = 0.634$). In the control group, the correlations between omissions in the working memory task and risky choices in Game 1 ($r = -0.539$, $p = 0.008$) and Game 2 ($r = -0.718$, $p = 0.000$) were highly significant. For the ADHD group, no such relation was found (Game 1: $r = -0.331$, $p = 0.132$, Game 2: $r = -0.156$, $p = 0.488$).

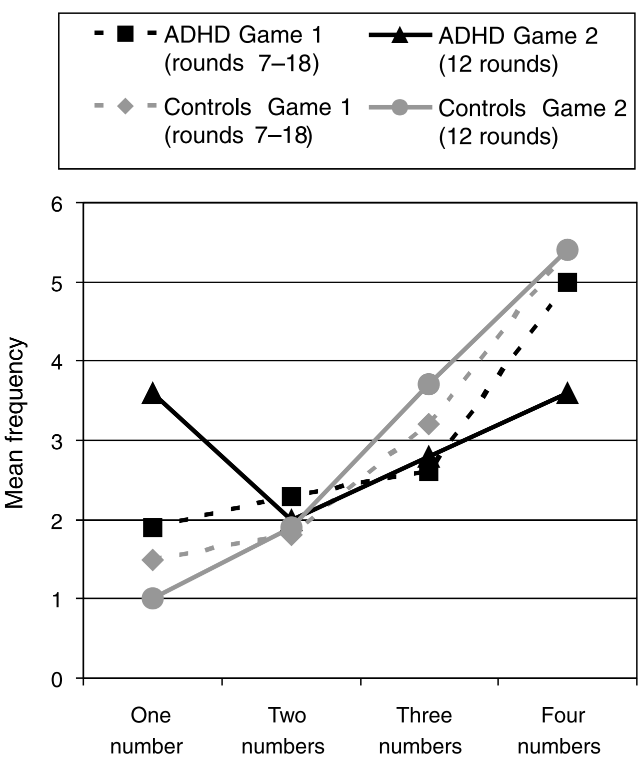

Fig. 2. Distribution of choice alternatives in Games 1 and 2 in young adolescents with ADHD and controls

Relation between risky decision-making and behavioural ratings

Subscales of behavioural ratings were correlated with the financial outcome and the number of risky decisions in Games 1 and 2, respectively (Table 4). In the ADHD group the risky decision-making of Game 1 was moderately correlated with the "Hyperactivity"-subscale of the SNAP, with "Attentional Problems" and "Aggressive Behavior" (CBCL), and the "Initiate"-subcale of the BRIEF. Risky decision-making of Game 2 was correlated with the "Hyperactivity"-subscale from the SNAP and "Attentional

Table 4. *Correlations between risky choices and clinical behavioural ratings in preadolescents with ADHD ($N=23$) and controls ($N=24$)*

Clinical subscale	Risky choices				Financial outcome			
	Game 1		Game 2		Game 1		Game 2	
	ADHD	Control	ADHD	Control	ADHD	Control	ADHD	Control
SNAP								
Hyperactive	0.43*	0.08	0.61**	0.29	–0.28	–0.10	–0.46*	0.10
Impulsive	0.06	0.03	0.28	0.00	–0.16	–0.11	–0.13	0.14
Inattentive	0.23	0.02	0.27	0.10	–0.12	–0.03	–0.26	0.43*
Oppositional-defiant	0.24	0.09	0.19	0.18	–0.24	–0.16	–0.16	0.37
CBCL								
Withdrawn	0.38	0.31	0.29	0.32	–0.24	–0.23	–0.35	–0.03
Somatic complaints	0.33	0.10	0.10	0.28	–0.11	–0.03	–0.25	0.27
Anxious-depressed	0.40	0.25	0.32	0.13	–0.11	–0.11	–0.54**	0.17
Social problems	0.13	0.18	–0.08	0.10	0.05	–0.19	–0.13	–0.16
Thought problems	0.13	0.46*	–0.09	0.55**	0.03	–0.32	0.09	0.10
Attentional problems	0.50*	0.07	0.48*	0.03	–0.41*	–0.16	–0.50*	0.09
Delinquent behaviour	0.30	–0.03	–0.08	–0.01	–0.29	–0.02	0.05	0.15
Aggressive behaviour	0.42*	0.01	0.13	0.01	–0.44*	–0.01	–0.16	0.29
BRIEF								
Inhibit	0.35	–0.19	0.39	–0.06	–0.24	0.01	–0.49*	0.37
Shift	0.28	–0.34	–0.16	–0.18	–0.26	0.27	0.07	0.34
Emotional control	0.33	–0.18	0.04	–0.16	–0.12	0.12	–0.01	0.38
Initiate	0.69**	–0.17	0.24	–0.15	–0.48*	0.14	–0.42	0.15
Working memory	0.15	–0.14	0.06	–0.12	–0.12	–0.01	–0.24	0.39
Plan/organize	0.18	–0.21	0.00	–0.23	–0.08	0.03	–0.24	0.39
Organization of material	0.34	–0.22	0.30	–0.20	–0.28	0.29	–0.41	0.30
Monitor	0.24	–0.38	0.10	–0.14	0.22	0.12	0.29	0.42*

* $p<0.05$, ** $p<0.001$.

Problems'' (CBCL). In the control group significant correlations between risky decision-making and behavioural measures were confined to ''Thought Problems'' (CBCL). In the ADHD group the financial outcome of Game 2 was negatively correlated with ''Hyperactivity'' (SNAP), ''Anxious-Depressed'' symptoms and ''Attentional Problems'' (CBCL), and the ''Inhibit''-subscale from the BRIEF, indicating that an elevated number of symptoms on these scales is related to a lower financial outcome. In the control group low financial outcome of Game 2 was associated with elevated symptoms of ''Inattention'' (SNAP) and deficits on the ''Monitor''-subscale from the BRIEF.

Discussion

In this study, young adolescents with ADHD made more risky choices and ended up with a higher financial loss in a decision-making task with explicit probabilities for gains and losses compared to controls. However, these differences only became apparent at the second game, a result which is surprising when compared to studies on impaired risky decision-making with the GDT in adult clinical groups (see Brand et al. 2006). It is possible that both groups of preadolescents go through a prolonged ambiguous stage of decision-making where they try out the different possibilities of the game without a clear-cut strategy. It might be more difficult for adolescents to fully understand the task or to change a strategy in the middle of the game, and they may need a fresh start in order to initiate a more goal-oriented strategy. Also, differences in response patterns of adolescents with ADHD compared to adult pathological gamblers could be indicative not of a maturational effect but of a less severe or a different underlying pathology. Ernst et al. (2003a) found group differences on the IGT between adolescents with and without ADHD only in a second test session, which may be interpreted as poor learning of risks in the ADHD group. Results of the current study, however, point towards another interpretation.

In Game 2 both groups of adolescents obviously adopted a new strategy, however according to different criteria: Normal young adolescents made more choices that were aimed at a minimization of losses, which is expressed by a significantly better financial outcome, although the ratio of high and low risk choices remained constant compared to Game 1. Their response style became more tactical, which, however, did not affect risk-taking tendencies. In contrast, the ADHD group opted for a significantly more risky decision-making strategy, resulting in even greater losses than at the first game. This latter change of strategy does not seem indicative of poor learning of rewards or of risks in the ADHD group – which would imply a decreased frequency of risky decisions in the control group at Game 2 – but rather suggests a gradual change of the affective value of feedback. When confronted with novelty, individuals with ADHD might be indistinguishable from normal controls in their responses to feedback, but when the task becomes familiar, differences in behaviour may emerge. This does not imply that the GDT was perceived as boring by the participants with ADHD: on the contrary, they seemed excited and often wished to play it again.

Risky choices in the ADHD group were unrelated to working memory problems or to other neuropsychological characteristics such as flexibility or planning. Similar results have been reported by Toplak et al. (2005) using the Iowa Gambling Task. However, monetary outcome of Game 2 was correlated with commission errors in the CPT, indicating an association between deficits in inhibitory control and inappropriate strategy selection. Control adolescents with low performance on a working memory task were characterized by a preference for low-risk choices; a finding which is in contrast to results on decision-making tasks in clinical groups reported previously (Manes et al. 2002; Brand et al. 2004). However it might be plausible that non-pathological individuals who have some difficulties in overseeing a complex situation might opt for a low-risk strategy. Poor cognitive abilities as rated by parents seemed to contribute to a poor financial outcome in control children, but they were not related to risk-taking or to financial losses in children with ADHD: Risky choices and the financial outcome of Game 2 were unrelated to symptoms of inattention in the ADHD group, but closely related to hyperactivity (SNAP) and inhibition (BRIEF). In the control group, in contrast, risky decision-making and low financial outcome of Game 2 were linked to some more cognitive behavioural scales, such as "Monitor" (BRIEF), "Thought problems" (CBCL) or "Inattention" (SNAP). In contrast to other studies, we did not find an inverse association between anxious-depressed symptoms and risky decision-making, as reported by Garon et al. (2006), nor an especially close association with oppositional defiant symptoms or aggressiveness (Blair et al. 2001; Ernst et al. 2003a). Elevated symptom scores on the "Aggressive Behaviour" scale (CBCL) were related to risky decision-making of Game 1 but not of Game 2. Therefore it seems rather unlikely that enhanced risk-taking in Game 2 may be reduced to symptoms of a comorbid behavioural disorder.

Taken all together, the results lend support to our first hypothesis which claimed an association between risky decision-making and impulsiveness. Adolescents with ADHD initially may select decision-making strategies based on "cold" cognitive processes just as their age-matched controls. But a gradual shift towards a more impulsive "hot" response style occurs when decisions become cognitively less demanding. In the Game of Dice Task, probabilities do not need to be cognitively re-evaluated at each choice, which progressively may lead to a more risky decision-making style. Possibly, these task characteristics partly account for differing outcomes of previous studies.

Our results are in line with explanatory models that link impulsive behaviour in ADHD to motivational impairments or to deficits in the interplay between the reward system and executive functions (Sonuga-Barke 2005; Castellanos et al. 2006). The exact nature of the motivational deficit remains still controversial (for a review see Luman et al. 2005) and the complex patterns of interaction between "hot" and "cold" processing pathways are currently subject of intense research (Haber 2003; Haber et al. 2006, see Kelly et al. 2007).

Several explanatory hypotheses may account for the present data: 1. The results of the study suggest a progressively growing insensitivity to negative reinforcement during the task. A deficit in the response to negative feedback has been described as characteristic for ADHD by several authors (e.g. Quay 1997). 2. Children with ADHD seem to present an increased sensitivity for the magnitude of rewards (see Scheres et al. 2006) and might be progressively drawn towards the largest gain. 3. The arousal associated with the higher risk could become more rewarding than the hypothetical reward itself, especially when possible gains or losses are purely fictitious: The increase of arousal associated with the "kick" of risk-taking could be placed over and above any eventual monetary gain and adolescents with ADHD may opt for the more exciting choice against better knowledge. Children with ADHD would be driven to the highest risk rather than to the largest gain. This explanation of "sensation-seeking" when the task has become habitual would be in accordance with the Cognitive Energetic Theory (Sergeant 2005) which links symptoms of ADHD to a deficient regulation of arousal and effort.

These explanations do not need to be mutually exclusive but may contribute differentially to the description of risk-taking in ADHD. Recent studies have shown that the value of reward and the estimation of risks are coded in distinct networks (Tobler et al. 2007), and one may assume that subcomponents of the reward system can be separately affected.

In conclusion, young adolescents with ADHD can be distinguished from normal controls on a risk-taking task, although these performance differences do not emerge immediately. Further research is needed in order to evaluate the impact of specific task characteristics on risky decision-making in ADHD and to improve the prediction of risk-taking in real life situations.

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