International Journal of Psychophysiology 72 (2009) 283–288

Contents lists available at ScienceDirect

International Journal of Psychophysiology

journal homepage: www.elsevier.com/locate/ijpsycho

Decision-making patterns and sensitivity to reward and punishment in children with attention-deficit hyperactivity disorder

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ARTICLE INFO

Article history:
Received 16 June 2008
Received in revised form 22 December 2008
Accepted 19 January 2009
Available online 3 February 2009

Keywords:
ADHD
Iowa gambling task
Sensitivity to rewards and punishments
Decision-making strategies
T-patterns

ABSTRACT

Earlier studies have demonstrated that attention-deficit hyperactivity disorder (ADHD) is associated with aberrant sensitivity to rewards and punishments. Although some studies have focused on real-life decision making in children with ADHD using the Iowa gambling task, the number of good deck choices, a frequently used index of decision-making ability in the gambling task, is insufficient for investigating the complex decision-making strategies in subjects. In the present study, we investigated decision-making strategies in ADHD children, analyzing T-patterns with rewards, with punishments, and without rewards and punishments during the gambling task, and examined the relationship between decision-making strategies and skin conductance responses (SCRs) to rewards and punishments. We hypothesized that ADHD children and normal children would employ different decision-making strategies depending on their sensitivity to rewards and punishments in the gambling task. Our results revealed that ADHD children had fewer T-patterns with punishments and exhibited a significant tendency to have many T-patterns with rewards, thus supporting our hypothesis. Moreover, in contrast to normal children, ADHD children failed to demonstrate differences between reward and punishment SCRs, supporting the idea that they had an aberrant sensitivity to rewards and punishments. Therefore, we concluded that ADHD children would be impaired in decision-making strategies depending on their aberrant sensitivity to rewards and punishments. However, we were unable to specify whether large reward SCRs or small punishment SCRs is generated in ADHD children.

1. Introduction

Attention-deficit hyperactivity disorder (ADHD) is one of the most prevalent psychiatric disorders in children and adolescents, characterized by inattentive, hyperactive, and impulsive behaviors (American Psychiatric Association, 1994).

Earlier studies have attempted to investigate the decision-making ability of children with ADHD using the Iowa gambling task, which simulates real-life decisions in the manner it factors uncertainty of rewards and punishments (Ernst et al., 2003a,b; Garon et al., 2006; Geurts et al., 2006; Toplak et al., 2005). The gambling task was specifically designed to detect the decision-making deficit in patients with ventromedial prefrontal damage, who generally demonstrate a strong preference for immediate prospects combined with reduced sensitivity to future consequences, positive or negative (Bechara et al., 1994, 1996, 1997, 2000). Although differences have been noted between ADHD patients and normal controls in performing the gambling task, some studies have failed to show a clear difference in the number of good deck choices, which is an index of decision-making ability in the task (Ernst et al., 2003b; Geurts et al., 2006).

On the other hand, Geurts et al. (2006) suggested that ADHD children may not change their decision-making strategies in response to losses in the same manner as normal individuals, although their result showed only a marginally significant difference. Therefore, children with ADHD and normal children may demonstrate different decision-making strategies or choice patterns derived from such strategies, which are hardly detectable by the number of good deck choices. Moreover, because several theories have proposed that ADHD is associated with an aberrant sensitivity to reinforcement (Luman et al., 2005), the differences in decision-making strategies may result from different sensitivity to rewards and punishments. However, to my knowledge, the study by Geurts et al. (2006) is the only study to examine decision-making strategies depending on rewards and punishments, and they only examined whether such feedbacks influence decision-making that occurs immediately afterward. There are no studies to examine whether feedbacks influence decision-making after several trials on the gambling task.

In order to detect such patterns between temporally distant events and elucidate the differences in decision-making strategies between ADHD and normal children more precisely, we employed the heuristic bottom-up pattern detection method developed by Magnusson (1996, 2000). This method can detect a complex time pattern called a T-pattern

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doi:10.1016/j.ijpsycho.2009.01.007

in a bottom-up manner while considering the time interval between events. If pairs of events recur in the same order (and/or concurrently) with a significantly similar time interval between them even if their interval is distant, they are regarded as components of a T-pattern. Moreover, the bottom-up manner allows to detect not only simple patterns which consist of only two events but also more complex and complete patterns. Because of focusing on patterns relevant to rewards and punishments, the detected T-patterns were categorized into those with rewards, with punishments, and without rewards and punishments.

Moreover, in order to examine their sensitivity to rewards and punishments, we measured skin conductance responses (SCRs). We analyzed not only SCRs to rewards and punishments but also anticipatory SCRs, which normal subjects generate before choosing from a bad deck in the gambling task, because choosing from good decks is a correlate of the development of anticipatory SCRs (Bechara et al., 1996, 1997, 1999; Crone et al., 2004).

Our primary hypothesis for the present study was that ADHD and normal children use different decision-making strategies depending on their sensitivity to rewards and punishments in the gambling task. Based on theories of reinforcement contingencies, it is possible to establish four hypotheses regarding the differences in T-patterns and sensitivity to rewards and punishments between ADHD and normal children. First, as explained by many theories (Douglas, 1989, 1999; Douglas and Parry, 1994; Sagvolden et al., 1998, 2005; Sonuga-Barke, 2002, 2003), if ADHD children have high sensitivity to rewards or immediate rewards, they would pay more attention to rewards. As a result, they would demonstrate large reward SCRs and many T-patterns depending on rewards (i.e., T-patterns with rewards). Second, as explained by Quay (1988a,b,c), if ADHD children have low sensitivity to punishments, they would pay less attention to punishments. As a result, they would demonstrate small punishment SCRs and few T-patterns depending on punishments (i.e., T-patterns with punishments). Third, as explained by Haenlein and Caul (1987), if ADHD children have an elevated reward threshold, they would have low sensitivity to rewards. As a result, they would demonstrate small reward SCRs and few T-patterns with rewards. Fourth, according to the cognitive-energetic model (CEM) of Sergeant (2005) and Sergeant et al. (1999), ADHD children have a deficit in the effort pool which is related to motivation. Since effort pool is activated by a system which monitors rewards and punishments, the dysfunction of the pool seems to cause low sensitivity to both rewards and punishments. That is why, based on the CEM, ADHD children would demonstrate small reward and punishment SCRs and few T-patterns with rewards and punishments.

2. Method

2.1. Participants

Participants consisted of 14 children (1 girl, 13 boys) referred by a pediatrician, in whom the diagnosis of ADHD was confirmed using a semi-structured interview based on DSM-IV (American Psychiatric Association, 1994) criteria for ADHD, and 11 normal children (5 girls, 6 boys) between the ages of 7 and 14 years. The children with ADHD, comprising 13 children with a combined type diagnosis and 1 with the inattentive type of the disorder, had a full-scale IQ score of 85 or higher (WISC-III or WISC-R). Mean ages and IQs of the children with ADHD and the normal children are summarized in Table 1. Methylphenidate administration was stopped in ADHD children for more than 24 h prior to participating in this experiment. Prior to the experiment, all participants and parents were informed of the experimental design and signed informed consents to participate in the study. The normal and ADHD children were not gender matched because the normal children were limited to those who could visit our laboratory accompanied by their parents and have never participated in our preliminary experiment including the behavioral task only. The sample size of each gender in the normal children was too small to make statistical comparisons, and the Wilcoxon rank sum test did not demonstrate gender differences in the number of good deck choices, the T-patterns (patterns with rewards, with punishments, and without rewards and punishments), and SCRs (reward, punishment, and anticipatory) in the normal children ($p>.10$); consequently, boys and girls among the normal children were treated as one group to enhance the statistical power.

Table 1
Demographic and characteristics of the sample.

Measure	Children with ADHD	Normal children
N of boys/girls	13/1	6/5
Age (mean (SD))	11.5 (2.2)	11.7 (1.7)
WISC-III (mean (SD))		
FSIQ	102.2 (12.2)	
VIQ	105.8 (11.6)	
PIQ	97.4 (14.1)	

Note: The FSIQ, VIQ, and PIQ scores (mean and SD) represent the scores of 13 children with ADHD except for 1 who was evaluated with WISC-R with FSIQ, VIQ, and PIQ of 133, 141, and 118, respectively.
FSIQ, full-scale IQ; VIQ, verbal IQ; PIQ, performance IQ.

Table 2
Comparison of decks in the gambling task.

Labels of good/bad decks (Hiragana)	Bad deck		Good deck	
	い	ろ	は	に
Reward per card	+100	+100	+50	+50
Average punishment per card	−125	−125	−25	−25

2.2. Task and procedure

The children with ADHD were tested in the same manner as those without ADHD, except that the former were tested at a hospital and the latter were tested at our laboratory. All children were individually tested for approximately 30 min.

2.2.1. Gambling task

The gambling task presented on a computer screen required the children to make 100 total card choices from four decks labeled by different Japanese Hiragana characters. The children selected a card by clicking a mouse button once at a time from any of the four decks (the total number of card selections was unknown to the children). The computer tracked the sequence of the cards selected from the various decks. Every time the children clicked on a deck to pick a card, a Japanese message was displayed on the screen indicating the amount of points the children had won or lost, and the score bar on the top of the screen changed according to the increase and decrease of the total score. The children were given a score of 2000 points before beginning; the goal was to achieve as high a score as possible. After turning each card, the children received only a reward. After turning some cards, the children received a reward and a punishment. Table 2 summarizes the contingencies associated with each of the four decks used in this task. Turning any card from the two decks to the left in Table 2 yielded a large reward (100 points), but at unpredictable points, a large punishment was also issued (125 points per card), so that in the long run, these decks decreased the total score. These decks are equivalent in terms of overall net loss over the trials. The difference is that in the deck "い," the punishment was more frequent, but of smaller magnitude, whereas in the deck "ろ," the punishment was less frequent, but of higher magnitude. Turning any card from the two decks to the right in Table 2 yielded a smaller reward (50 points), but the unpredictable punishments were also small (25 points per card), so that in the long run, these decks increased the total score. These decks were also equivalent in terms of overall net loss. In the