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

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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.

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

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 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.

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 deck "は," the punishment was more frequent and of smaller magnitude, whereas in the deck "に," the punishment was less frequent but of higher magnitude. Thus, the decks on the left side were bad decks, whereas those on the right side were good decks. Considering the uncertain punishments and anticipating the future consequences are indispensable to choosing many cards from good decks in the gambling task.

2.2.2. SCR data collection

SCRs were measured using a PowerLab/8sp system (ADInstruments Japan, Nagoya, Japan), an ADInstruments Model ML116 GSR Amp, and two Ag/AgCl electrodes (ADInstruments Model MLT117F) attached to the medial phalanx surfaces of the index and middle fingers of the nondominant hand. SCRs were sampled at 100 Hz.

2.3. Analysis

2.3.1. Number of good deck choices

To quantify the performance of the children in the Iowa gambling task, the 100 choices were divided into five blocks of 20 cards each, and for each block, we calculated the total number of good deck choices. Although calculating the number of good deck choices or a similar method is the most frequently used index of decision-making ability in the gambling task, it was insufficient to analyze the more complex patterns such as deck selection after several trials of an appearance of punishments from a deck.

2.3.2. T-patterns

We used the Theme2000b software developed by Magnusson (2000) to detect the T-patterns in the gambling task. Figure 1, reproduced from Magnusson (2005), illustrates an example of a complex pattern hidden in an event series. The letters on each axis correspond to an event. The upper axis and its letter pattern is a copy of the lower axis, but with a few instances of "k" added. In the Theme software, such complex patterns can be detected by the bottom-up approach: event pairs such as "a" and "b," and "c" and "d" are tested to determine whether or not they represent a T-pattern, and then the pattern pairs ("a" and "b") and ("c" and "d") are tested to ascertain whether or not they represent a T-pattern. If pairs of already detected patterns or event types recur in the same order with a significantly similar time interval between them, they are regarded as components of a T-pattern (the time intervals need not be consecutive). The following 12 events were defined for detecting the T-patterns in the current study: the children select one of the four decks, only a reward appears in one of the four decks, and both a reward and a punishment appear in one of the four decks.

We calculated the percentages of the patterns with rewards, with punishments, and without rewards and punishments in all T-patterns detected by the Theme software. An example of a T-pattern with punishments was the following pattern consisting of four events: (1) the punishment appears in "い," which is a bad deck; (2) the child selects "は," which is a good deck; (3) the punishment appears in “ろ,” which is a bad deck; and (4) the child selects “ろ,” which is a bad deck. A minimum of three repeated pattern occurrences during the gambling task and a 0.05 significance level were specified as the criteria to determine the T-patterns using the Theme software.

2.3.3. SCRs

The SCRs generated during the gambling task were divided into three categories in accordance with Bechara et al. (1999) as follows: (1) reward SCRs, which are generated after turning cards for which there is a reward and no punishment; (2) punishment SCRs, which are generated after turning a card for which there is a reward and a punishment; and (3) anticipatory SCRs, which are generated prior to turning a card from any given deck, i.e., during the time period the child thinks from which deck to choose. The time window for reward and punishment SCRs was the 5 s immediately following the click of a card. SCRs generated during the end of the reward/punishment window and before the next click of a card were considered anticipatory SCRs. Within each time window, the amplitude of the largest SCR having onset within the window was measured and recorded (the criterion for smallest scorable SCR was set at 0.05 μ s). In accordance with Tranel et al. (1985), compound responses were considered separate responses if the first response peaked (i.e., the tangent to the curve reached at least a horizontal orientation) before the second one began; if this criterion was not met, the response was considered a single response and measured as such.

The differences between the groups and within each group were examined by the Wilcoxon rank sum test and the Wilcoxon signed rank test, respectively, with the significance level set at $p < 0.05$. Effect sizes for these differences were calculated as Cohen’s *r* (*r* = 0.10, small; 0.30, medium; 0.50, large; Cohen, 1988). Power values for these differences were calculated for an alpha level of 0.05.

3. Results

3.1. Number of good deck choices

To examine whether the children with ADHD differed from the normal children in decision-making ability, the number of good deck choices for each block of 20 cards was compared between the two groups using the Wilcoxon rank sum test. The result indicated no differences between the groups in all blocks, but small effect sizes were found in the first three blocks (the first block, Cohen's $r = 0.11$, power value = 0.08; the second block, Cohen's $r = 0.14$, power value = 0.10; the third block, Cohen's $r = 0.17$, power value = 0.12). No effect sizes were found in the last two blocks (the fourth block, Cohen's $r = 0.08$, power value = 0.06; the fifth block, Cohen's $r = 0.02$, power value = 0.05). Figure 2 shows the number of good deck choices for each group.

3.2. T-patterns

The data obtained from the gambling task revealed that there were many T-patterns in both groups of children. Figure 3 represents an example of a T-pattern with punishments detected by the Theme software. The T-pattern was composed of five events: (1) a subject selects "は," which is a good deck; (2) a subject selects "い," which is a bad deck; (3) the punishment appears in "い," which is a bad deck; (4) a subject selects "ろ," which is a bad deck; and (5) a subject selects "に," which is a good deck.

The Wilcoxon rank sum test demonstrated that the ADHD children had a significantly lower percentage of T-patterns with punishments compared to the normal children with a medium effect size ($p < 0.05$, Cohen's $r = 0.45$, power value = 0.62), whereas the ADHD children exhibited a tendency of having a significantly higher percentage of T-patterns with rewards compared to the normal children with a medium effect size ($p < 0.10$, Cohen's $r = 0.38$, power value = 0.46). The percentage of T-patterns without rewards and punishments did not differ between the groups, but a small effect size was found (Cohen's $r = 0.27$, power value = 0.25). The results are shown in Fig. 4.

3.3. SCRs

Reward, punishment, and anticipatory SCRs in good and bad decks were compared between the two groups using the Wilcoxon rank sum test. The result indicated no differences between the groups, but some small effect sizes were found (reward SCRs for bad decks, Cohen's r = 0.15, power value = 0.10; punishment SCRs for good decks, Cohen's $r = 0.10$, power value = 0.07; punishment SCRs for bad decks, Cohen's $r = 0.28$, power value = 0.26; anticipatory SCRs for bad decks, Cohen's $r = 0.15$, power value = 0.10). The others had no effect sizes (reward SCRs for good decks, Cohen's $r = 0.01$, power value = 0.05; anticipatory SCRs for good decks, Cohen's $r = 0.03$, power value = 0.05).

Within each group, we examined whether reward, punishment, and anticipatory SCRs for good decks differed from those for bad decks using the Wilcoxon signed rank test. The normal children had a significantly higher punishment and anticipatory SCRs for bad decks than for good decks with large effect sizes (punishment SCRs, $p < 0.01$, Cohen's $r = 0.93$, power value = 1.00; anticipatory SCRs, $p < 0.01$, Cohen's $r = 0.78$, power value = 0.84). Reward SCRs of the normal children tended to be significantly higher for bad decks than for good decks with large effect size ($p < 0.10$, Cohen's $r = 0.55$, power value = 0.41). Figure 5 represents SCRs of the normal children. The ADHD children had a significantly higher reward and anticipatory SCRs for bad decks than for good decks with large effect sizes (reward SCRs, $p < 0.01$, Cohen's r =

0.86, power value = 0.99; anticipatory SCRs, $p < 0.01$, Cohen's $r = 0.75$, power value = 0.90). In contrast to the normal children, the ADHD children did not show differences in punishment SCRs between good and bad decks, but a medium effect size was found (Cohen's $r = 0.43$, power value = 0.33). Figure 6 shows SCRs of the ADHD children.

Within each group, reward and punishment SCRs were compared for each deck using the Wilcoxon signed rank test. In the bad decks, the normal children generated significantly higher punishment SCRs than reward SCRs with a large effect size ($p < 0.01$, Cohen's $r = 0.93$, power value = 1.00), whereas the children with ADHD did not generate such differences (Cohen's $r = 0.05$, power value = 0.04). In the good decks, the normal children did not generate the differences between reward and punishment SCRs (Cohen's $r = 0.04$, power value = 0.04). The children with ADHD also did not generate such differences, but a medium effect size was found (Cohen's $r = 0.30$, power value = 0.16).

4. Discussion

In order to examine whether the children with ADHD and the normal children use different decision-making strategies depending on their sensitivity to rewards and punishments in the gambling task, we analyzed T-patterns with rewards, with punishments, and without rewards and punishments, and SCRs for rewards, punishments, and anticipation in both groups. The ADHD children had fewer T-patterns with punishments, which indicated that they paid less attention to punishments. Moreover, they showed a significant tendency to have many T-patterns with rewards with a medium effect size, which indicated that they paid more attention to rewards. The results of SCRs might be consistent with those of T-patteens. The normal children had higher punishment SCRs than reward SCRs in the bad decks, whereas the ADHD children failed to demonstrate differences between reward and punishment SCRs. This result is consistent with the findings of Crone et al. (2003) and Iaboni et al. (1997), which found smaller differences between responses to rewards and punishments in ADHD children. Therefore, in comparing reward and punishment SCRs, one option is to assume that the ADHD children have relatively high reward SCRs. Another option is to assume that they have relatively low punishment SCRs. These results support two of four hypotheses of the present study. First, the ADHD children would demonstrate large reward SCRs and many T-patterns with rewards, supporting the probability that they have high sensitivity to rewards or immediate rewards (Douglas, 1989, 1999; Douglas and Parry, 1994; Sagvolden et al., 1998, 2005; Sonuga-Barke, 2002, 2003) rather than the hypothesis of Haenlein and Caul (1987) which ADHD children have an elevated reward threshold. Second, the ADHD children would demonstrate small punishment SCRs and fewer T-patterns with punishments, supporting the theory of Quay (1988a, b, c) that these children have low sensitivity to punishments. Garon et al. (2006) revealed that sensitivity to punishments influences the performance of ADHD children in a child version of the gambling task. In the study, the ADHD children with and without anxiety/depression were compared to normal children. The result indicated that the ADHD children with anxiety/depression chose as more from good decks as normal children, whereas the ADHD-alone children demonstrated impaired performance. The findings suggest that a higher functioning behavior inhibition sysytem (Quay, 1988a, b, c) facilitates paying attention to punishments and leads to better performance for ADHD children in the gambling task. On the other hand, low sensitivity to punishments appears to influence impaired decision-making of ADHD. Although unfortunately we did not divide our ADHD children into the children with and without anxiety/depression, if these ADHD subgroups are analyzed using T-patterns and SCR, they may demonstrate different T-patterns and SCR patterns. For example, ADHD with anxiety/depression may have more T-patterns with punishments and large punishment SCRs, whereas ADHD-alone children may have few T-patterns with punishments and small punishments SCRs. Based on the CEM (Sergeant, 2005; Sergeant et al., 1999), we suggested the hypotheses of both rewards and punishments: ADHD children would demonstrate small reward and punishment SCRs and few T-patterns with rewards and with punishments. Our results were consistent with the predictions of CEM regarding punishments, but might have opposite results regarding rewards. Therefore, we support some theories which suggest that ADHD children have high sensitivity to rewards or low sensitivity to punishments rather than they have lower sensitivity to both rewards and punishments. Although we could not specify whether ADHD children have high sensitivity to rewards or low sensitivity to punishments in the present study, it was concluded that the ADHD and normal children used different decision-making strategies depending on the aberrant sensitivity to rewards and punishments in the gambling task.

The present study has several limitations. The first limitation is that the statistical power was limited due to our small sample size, which made it difficult to draw conclusions regarding some results. Small, but insignificant, effect sizes were found in the first three blocks when comparing the numbers of good deck choices between the ADHD and normal children. Although some studies reported such differences between these groups (Ernst et al., 2003a; Toplak et al., 2005), we were unable to detect such differences due to our small sample size. The normal children generated differences in punishment SCRs between good and bad decks, whereas the ADHD children did not generate such differences (Figs. 5 and 6). However, we could not clarify whether or not the aspects of SCRs between these groups were different when comparing punishment SCRs in good and bad decks, because the result for the ADHD children showed a medium effect size and a low power value. Crone et al. (2004) demonstrated that normal subjects ranging between the age of 18 and 31 years generated differences in punishment SCRs between good and bad decks regardless of their performance. Therefore, it is important to clarify whether or not children with ADHD have aberrant SCRs when comparing punishment SCRs in good and bad decks. Small effect sizes were observed when comparing some SCRs (e.g., anticipatory SCRs) between the ADHD and normal children. Bechara et al. (1999) demonstrated that patients with damage to the amygdala who cannot generate reward and punishment SCRs exhibited impaired decision-making on the gambling task and did not generate anticipatory SCRs. Therefore, it is important to clarify how anticipatory SCRs are influenced by aberrant sensitivity to rewards and punishments in ADHD children. The second limitation relates to measurement of only SCR as the index of sensitivity to rewards and punishments. Heart rate is more suited for examining sensitivity to rewards than SCR (Iaboni et al, 1997; Tranel, 1983). Therefore, aberrant sensitivity to rewards and punishments in the ADHD children may be elucidated more precisely by using both heart rate and SCR. The third limitation is that the children from both the groups were not gender matched, although the difference did not influence the results of the present study.

In conclusion, children with ADHD have impaired decision-making strategies resulting from their aberrant sensitivity to rewards and punishments. This feedback information is indispensable for the planning process, which allows an individual to make an appropriate decision by generating and switching strategies. Although many previous studies have investigated the planning process in the ADHD children, further research on T-patterns of problem solving using the Theme software would lead to greater understanding of planning and decision-making in ADHD children.

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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

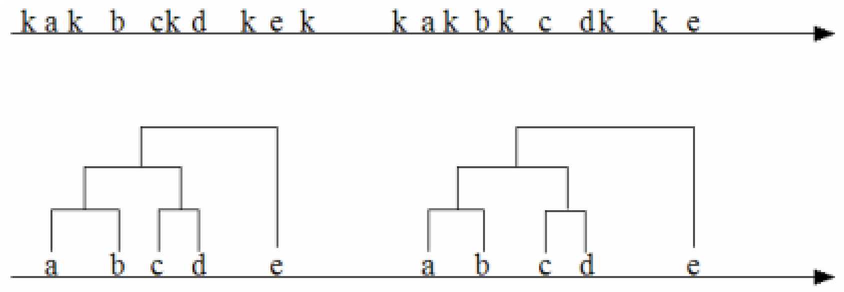

Fig. 1. A reproduced illustration from Magnusson (2005).

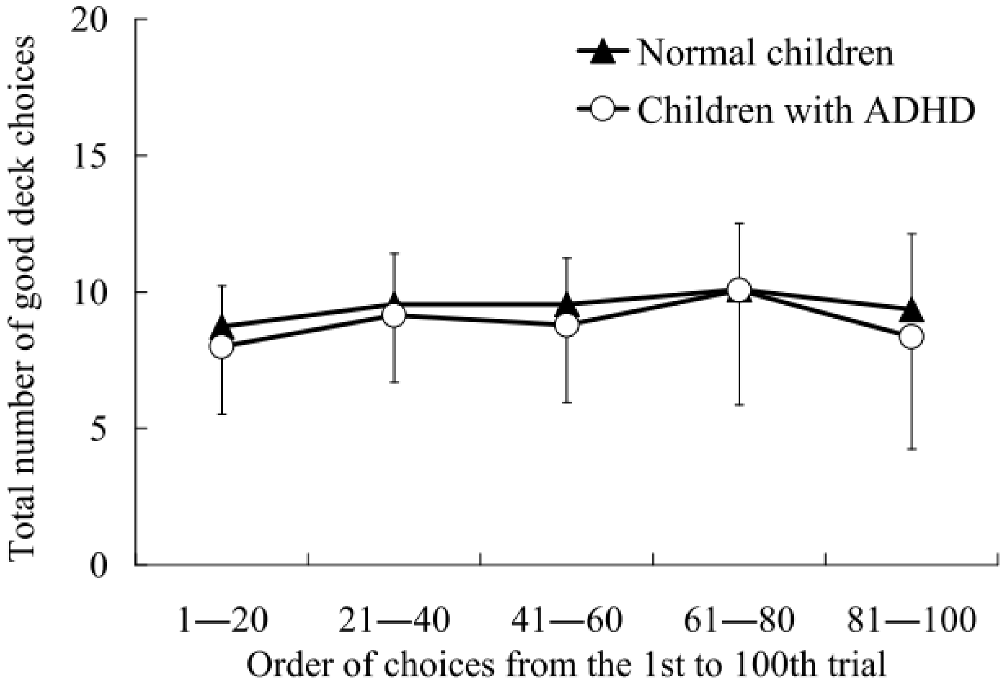

Fig. 2. Means ± SD of total number of good deck choices in each block of 20 cards, which were made by normal children and children with ADHD. Scores higher than 10 reflect more good than bad deck choices. Scores lower than 10 reflect more bad than good deck choices.

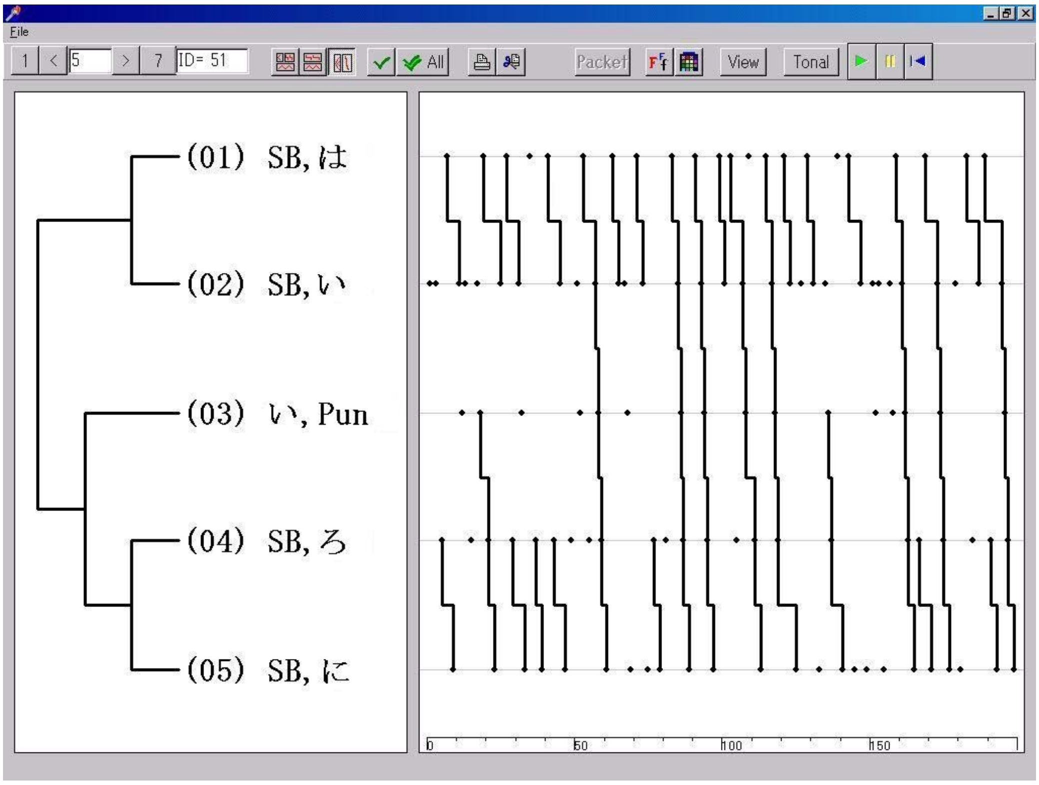

Fig. 3. Example of a T-pattern with punishments detected by the Theme software. The T-pattern was composed of five events. “SB, は” means a subject selected “は,” which is a good deck; “SB, い” means a subject selected “い,” which is a bad deck; “い, Pun” means a punishment appeared in “い,” which is a bad deck; “SB, ろ” means a subject selected “ろ,” which is a bad deck; and “SB, に” means a subject selected “に,” which is a good deck. Vertical lines in the right-hand box showed when the T-pattern in the left-hand box appeared. The T-pattern was repeated eight times in this example.

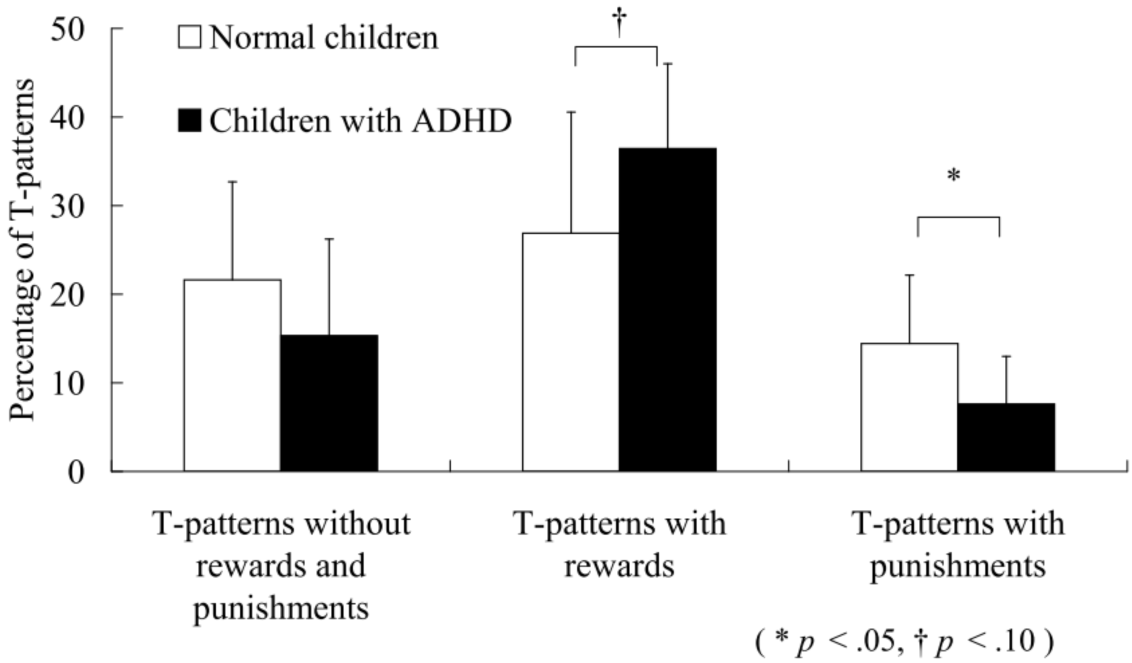

Fig. 4. Means ± SD of T-patterns without rewards and punishments, with rewards, and with punishments in normal children and children with ADHD.

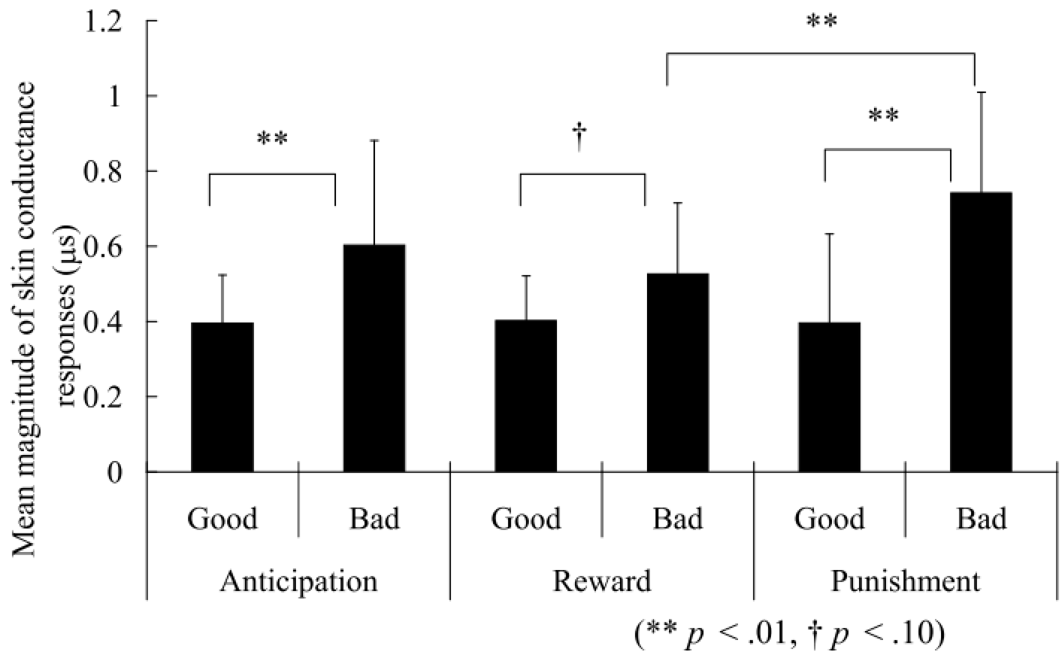

Fig. 5. Means ± SD of anticipatory, reward, and punishment SCRs generated by normal children in association with good or bad decks.

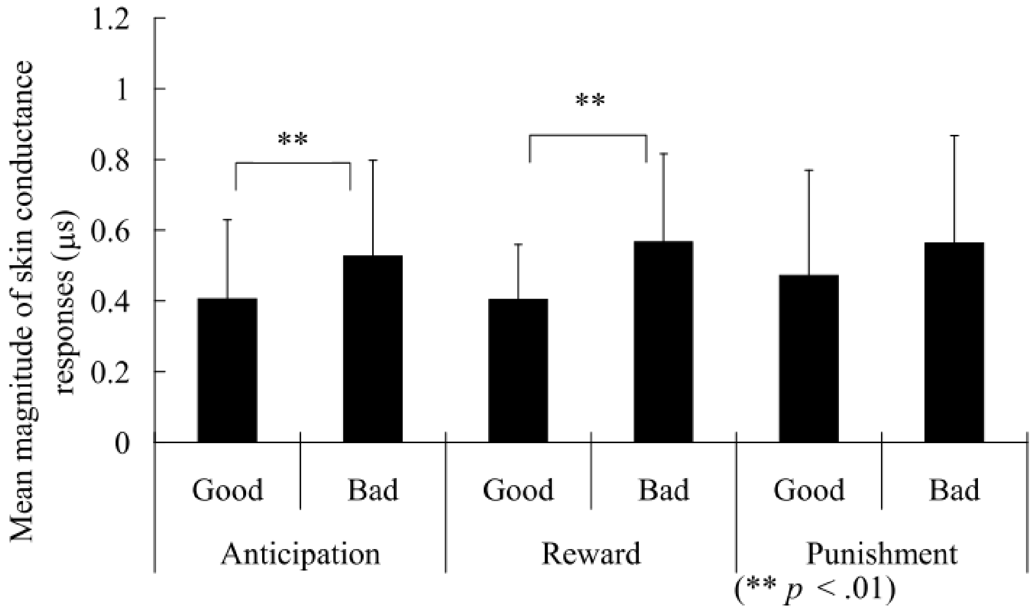

Fig. 6. Means ± SD of anticipatory, reward, and punishment SCRs generated by children with ADHD in association with good or bad decks.