ARCHIVAL REPORT

Impaired Decision Making in Oppositional Defiant Disorder Related to Altered Psychophysiological Responses to Reinforcement

Marjolein Luman, Joseph A. Sergeant, Dirk L. Knol, and Jaap Oosterlaan

Background: When making decisions, children with oppositional defiant disorder (ODD) are thought to focus on reward and ignore penalty. This is suggested to be associated with a state of low psychophysiological arousal.

Methods: This study investigates decision making in 18 children with oppositional defiant disorder and 24 typically developing control subjects. Children were required to choose between three alternatives that carried either frequent small rewards and occasional small penalties (advantageous), frequent large rewards and increasing penalties (seductive), or frequent small rewards and increasing penalties (disadvantageous). Penalties in the seductive and disadvantageous alternatives increased either in frequency or magnitude in two conditions. Heart rate (HR) and skin conductance responses to reinforcement were obtained.

Results: In the magnitude condition, children with ODD showed an increased preference for the seductive alternative (carrying large rewards); this was not observed in the frequency condition. Children with ODD, compared with typically developing children, displayed greater HR reactivity to reward (more HR deceleration) and smaller HR reactivity to penalty. Correlation analyses showed that decreased HR responses to penalty were related to an increased preference for large rewards. No group differences were observed in skin conductance responses to reward or penalty.

Conclusions: The findings suggest that an increased preference for large rewards in children with ODD is related to a reduced cardiac reactivity to aversive stimuli. This confirms notions of impaired decision making and altered reinforcement sensitivity in children with ODD and adds to the literature linking altered autonomic control to antisocial behavior.

Key Words: Arousal, decision making, heart rate, ODD, penalty, reinforcement, reward, skin conductance

Oppositional defiant disorder (ODD) in children is defined by a pattern of negativistic and rule-breaking behavior (1), often accompanied by emotional, familial, and social problems, including heightened anger, frequent family arguments, and problems with peers. The disorder frequently co-occurs with attention-deficit/hyperactivity disorder (ADHD) with comorbidity rates of 30% to 90% (2,3) and is a predictor for antisocial behavior such as conduct disorder (CD) in adolescents (4).

It is believed that poor self-regulation, specifically in the face of cues for reward and punishment, adds to the development of ODD (5). Individuals with ODD are thought to focus on reward, while ignoring signals of punishment, which is explained in terms of impaired emotional reactivity and reduced autonomic nervous system (ANS) functioning (5–7). Newman and Wallace (5) incorporated the work of Gray (8) by suggesting that antisocial behavior is related to a predominant behavioral activation system that initiates "approach" toward reward cues and an underactive behavioral inhibition system that impairs "avoidance" of aversive cues. Similarly, Raine (6) proposed that lack of fear and low autonomic arousal in antisocial behavior decrease the attention to threat-related stimuli, such as punishment. A slightly different approach by Zuckerman (7,9) suggests that antisocial individuals show sensation-seeking behavior to boost low psychophysiological arousal. Experimental findings with a task in which the rate of winning decreased and rate of losing increased confirmed that children with ODD keep responding for reward, irrespective of increasing punishment (10,11).

Studies that have investigated ANS activity in ODD show mixed results. Children with ODD display lower baseline heart rate (HR) and skin conductance (SC) levels (10,12–15) than typical developing (TD) children (although see [16]). Studies of autonomic responses in ODD to penalty are absent, but there is evidence that ODD is related to reduced cortisol reactivity to aversive events such as stress (13,15). In addition, ODD is related to reduced HR reactivity to positive events such as rewards (12). Moreover, there is some evidence of reduced ANS activity in ODD that may explain poor self-regulation in the face of reinforcement (10,11).

Sensitivity to reinforcement and ANS functioning are thought to influence decision-making abilities. One possibility is that decisions are guided by psychophysiological markers that develop through the coupling of a positive or negative affective experience with a given response option (17). These markers serve as indicators of the value of what is represented and are suggested to be mediated by the orbitofrontal cortex and amygdala (17), as supported by the research with the Iowa Gambling Task (18). In this task, players are instructed to choose between four decks of cards. Turning a card results in immediate reward, which is either high (deck A or B) or low (deck C or D). In addition to reward, there is an unpredictable penalty, which is larger in decks A and B compared with decks C and D. In the long run, playing from decks A and B is disadvantageous, while playing from decks C and D is advantageous. Healthy subjects exhibited anticipatory SC responses during the course of the task before selecting a card from the disadvantageous decks and they chose more cards from the advantageous decks (18). Recent

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data, however, suggest that anticipatory SC may reflect variance in the gains and losses that are offered (being larger in decks A and B), rather than final outcome (19), and that SC reactivity rather than anticipation may be important for regulating task behavior (20).

The current study investigates decision making in children with ODD using an adapted Iowa Gambling Task (21). Participants were asked to choose from three response options (A, B, and C). Option A was advantageous, carrying frequent small rewards and infrequent small penalties, option B was seductive, carrying frequent large rewards and infrequent large penalties, while option C was disadvantageous, carrying frequent small rewards and infrequent large penalties. Two independent conditions were used to investigate whether choice behavior was altered. In these two conditions, penalties in options B and C increased over the course of the task either in magnitude or in frequency. Children with ODD compared with TD children were expected to show an increased preference for large rewards (seductive option) and therefore a smaller preference for the advantageous option (5,6). This effect was expected to be largest when penalty allocation remained infrequent (magnitude condition), since humans are found to attach less weight to infrequent occurrences, even if these are negative (22). If children with ODD were underaroused (7,9), risky choice behavior was expected to be associated with low basal HR and SC level (10,12–15), as well as reduced autonomic responses to reward and penalty (12).

Methods and Materials

Participants and Selection Procedure

Eighteen children with ODD (12 boys) and 24 TD children (13 boys), aged 7 to 12, were included in this study. Children with ODD were included if they met the following criteria: 1) a clinical diagnosis of ODD or clinically referred for behavioral/disruptive problems; 2) no psychiatric diagnosis other than ODD or ADHD; 3) IQ score >70; 4) absence of any neurological disorder, learning disability such as dyslexia, or sensory or motor impairment; and 5) not taking medication, except for methylphenidate, that was discontinued at least 24 hours before testing.

Children were recruited through the parent association for children with developmental disorders and through a university-affiliated outpatient clinic for disruptive behavior problems. The assessment procedure consisted of two stages. First, parents were administered the Dutch version of the disruptive behavior disorder section of the Diagnostic Interview Scale for Children (23) to confirm the diagnosis of ODD. According to the Diagnostic Interview Scale for Children, 16 children met criteria for ADHD; none met criteria for CD. Second, to ensure symptom pervasiveness, the Disruptive Behavior Disorder Rating Scale (24) was administered to both parent(s) and the teacher of the child. Children had to score above the clinical cutoff (>90th percentile) on both the parent- and teacher-rated ODD. Typical developing children were recruited through local elementary schools and were included when they were free of any psychiatric or neurological disorder and when they scored in the normal range (<90th percentile) on all scales of the parent and teacher Disruptive Behavior Disorder Rating Scale.

The IQ score of each child was estimated by four subtests (picture arrangement, arithmetic, block design, vocabulary) of the Wechsler Intelligence Scale for Children. These four subtests correlate between .93 and .95 with full-scale IQ (25). Children with ODD scored significantly lower on estimated IQ than the TD group (Table 1). Correlation analysis revealed no significant relation between IQ and the preference for any of the alternatives (in neither of the six trial bins, see below), all p values > .5, and no significant relation between IQ and ODD symptoms was observed, all p values > .5.

Table 1. Group Characteristics[b]

	Group				
	ODD (n = 18)		TD (n = 24)		Group Comparison
Measure	M	SD	M	SD	F(1, 40)
Number of Boys	12		13		.6[a]
Age in Months	122.9	15.4	120.0	15.3	.3
IQ	93.4	15.3	111.4	13.6	15.4[b]
DBD Parent					
ODD	13.3	4.2	1.3	1.8	146.5[b]
CD	3.6	2.6	.1	.3	49.5[b]
Inattention	17.4	4.4	1.7	2.0	221.7[b]
Hyperactivity/impulsivity	16.6	4.7	1.6	1.5	192.8[b]
DBD Teacher					
ODD	12.7	4.7	.9	2.1	118.8[b]
CD	2.3	2.2	< .1	.2	24.3[b]
Inattention	12.7	5.5	1.8	3.0	69.6[b]
Hyperactivity/impulsivity	12.9	5.2	.4	.8	137.4[b]

CD, conduct disorder; DBD, Disruptive Behavior Disorder rating scale; ODD, oppositional defiant disorder; TD, typically developing control subjects.

[a]Groups were compared using a chi-square test.

[b]$p < .01$.

Materials

Computerized Gambling Task. Children were shown three alternatives presented as jackpots (21). The advantageous alternative carried small rewards ($.01, $.02, or $.03) on every trial and small penalties (−$.02) on one third of the trials. The seductive alternative carried large rewards ($.03, $.04, or $.05) on every trial and large penalties (−$.08) on one third of trials. The disadvantageous alternative carried small rewards ($.01, $.02, or $.03) on every trial and large penalties (−$.08) on one third of trials. Children performed the task twice: in a magnitude condition, where penalty in the seductive and disadvantageous alternatives increased in magnitude, and a frequency condition, where penalty in the seductive and disadvantageous alternatives increased in frequency. Total increase in penalty was similar in both conditions ($.06 every nine trials) (see [21] for reward and penalty schedules). For all children, the magnitude condition was presented first to avoid interactions between group and the order in which the conditions were presented (21).

Children had to choose a jackpot (10 by 5 cm) by clicking on it (Figure 1). The position of the three alternatives on the screen (left, middle, right) was counterbalanced between subjects. A digital scale (range −100 to +100) monitored the amount of money obtained. Once a choice was made, 1000 msec later a reward appeared on the display of the chosen jackpot for 1000 msec, printed in green. After the reward was removed, if applicable, 1500 msec later a penalty appeared for 1000 msec printed in red (otherwise, the display remained white). The intertrial interval varied between 3500 and 5000 msec, to measure the relatively slow SC response (26). During this interval, pressing the mouse was ineffective and five "smiley's" disappeared one by one from the screen to indicate when the next choice could be made. Both conditions contained 180 trials.

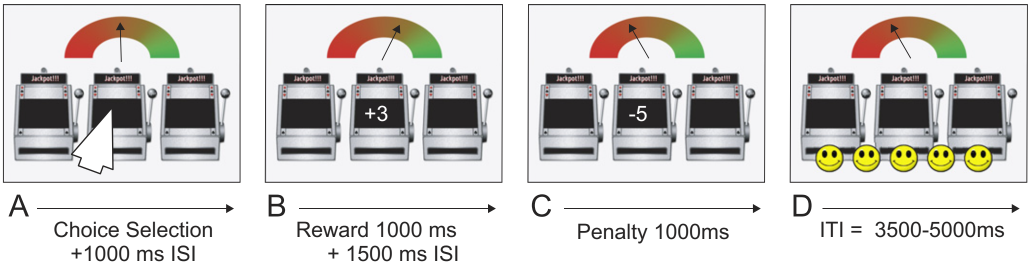

Figure 1. Time course of a jackpot trial. **(A)** Children had to press the mouse button to select one of three alternatives. One thousand milliseconds later, **(B)** reward feedback appeared in the window of the chosen jackpot for 1000 msec in green ink. Another 1500 msec later **(C),** when applicable, penalty feedback appeared in the similar window for 1000 msec in red ink; otherwise, the window remained blank. **(D)** During the intertrial interval (ITI) of 3500 to 5000 msec, five "smileys" disappeared one by one from the screen to indicate when the next trial started. ISI, interstimulus interval.

Autonomic Measures. The electrocardiogram was registered via two active 10 mm silver/silver chloride electrodes attached 1) between the collarbones over the jugular notch of the sternum and 2) under the left breast, 1.6 inch under the nipple between the ribs. One ground electrode was attached at the right lateral side between the lower two ribs. The continuous electrocardiogram signals were sampled at 500 Hz from which R-peak occurrences were detected. Contingent on the occurrence of reward, five interbeat intervals (IBIs) were extracted. Interbeat interval –1 represented the interval preceding reward; IBI0 represented the interval in which reward occurred; IBI+1, IBI+2, and IBI+3 followed the onset of reward. Interbeat interval –1 was used as reference for the other intervals. If penalty was presented, penalty followed reward with a stimulus-onset asynchrony of 1500 msec (Figure 1). As a result, IBI+2 and IBI+3 following reward contained penalty processing. Therefore, IBI−1, IBI0, and IBI+1 were analyzed. When applicable, a similar interval was analyzed contingent on the occurrence of penalty.

Skin conductance was measured by two 1 cm² silver/silver chloride electrodes that were attached with Velcro straps to the volar surfaces of the medial phalanges of the index and middle fingers of the left hand. A constant voltage of .5 V was used to register SC and the signals were amplified and sampled at 10 Hz. Electrolyte gel (.05 mol/L sodium chloride) was applied to the two electrodes. Skin conductance response amplitude and latency of the peak were calculated for each trial separately. Amplitudes were calculated by comparing SC at the onset of reward with the SC peak in the interval 4000 msec following reward (26). When applicable, a similar 4000-msec interval following penalty

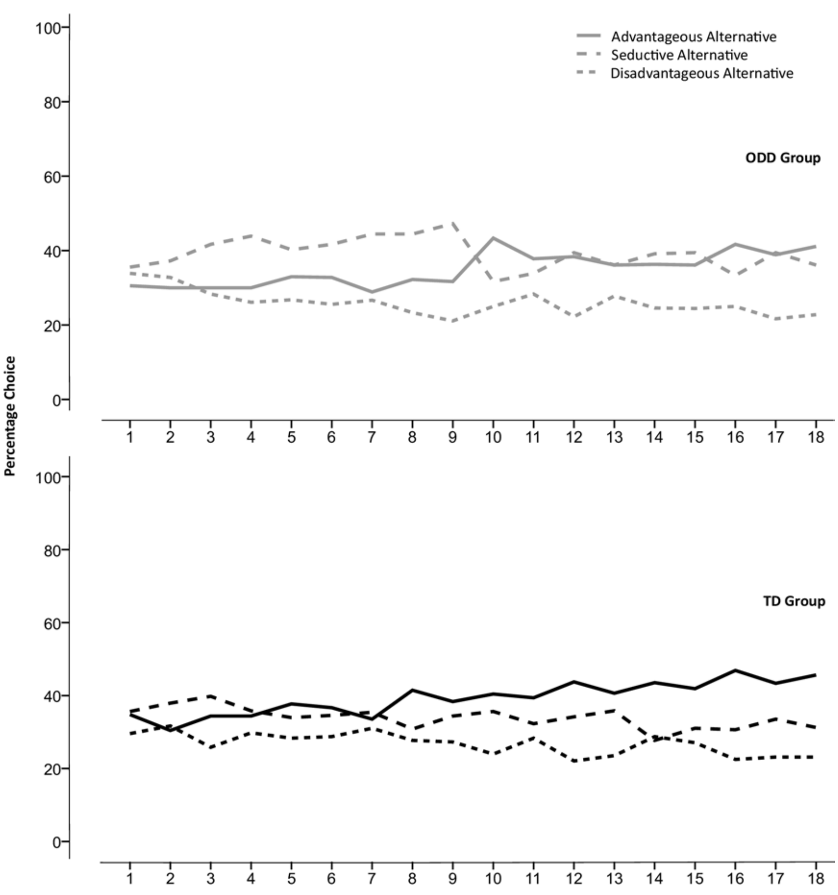

Figure 2. Choice probabilities over time (trials 1–180) in the magnitude condition for the advantageous alternative (small frequent reward, small infrequent penalty), the seductive alternative (large frequent reward, infrequent penalty increasing in magnitude), and the disadvantageous alternative (small frequent reward, infrequent penalty increasing in magnitude) for children with oppositional defiant disorder and typically developing children. Children with oppositional defiant disorder showed a smaller preference for the advantageous alternative than control subjects due to an increased preference for the seductive alternative and disadvantageous alternative. ODD, oppositional defiant disorder; TD, typically developing control subjects.

was used to determine the SC response to penalty. Only SC responses $>.04$ μS were included in the analyses (26).

Procedure

All parents completed a written informed consent before the study that was approved by the local ethical committee. Children came to the laboratory twice, separated by a week. The magnitude condition was administered during the first session, followed by the Wechsler Intelligence Scale for Children; the frequency condition was administered during the second session. Children were told that they were in a theme park in which they played "Jackpot." They had to win as much as possible by choosing between the alternatives. In both conditions, children were told that winning over $.50 was required to receive a gift. At the end of the task, all children received a small present worth $4 (€3), irrespective of their performance. See Supplement 1 for performance data according to the multilevel nominal regression model.

Statistical Analyses

To explore choice behavior over time (nominal data) in a task with three alternatives, an analysis of variance (ANOVA) could not be used, because the number of data points in each cell (choices for each alternative at different time points) greatly differs between alternatives when choice preferences change over time. Using multilevel nominal logistic regression (21), time functions of choice behavior (probabilities of alternatives A, B, and C) of the ODD and TD groups were created across the 180 trials. For both conditions, a multiple logistic model was used ([27]pp205–211) in which two logistic functions for both the seductive alternative $\log(\pi_{ib}/\pi_{ia})$ and disadvantageous alternative $\log(\pi_{ic}/\pi_{ia})$ were expressed using the advantageous alternative as a baseline category. The probability functions of the three alternatives (π_{ia}, π_{ib}, and π_{ic}) summed to 1 for each of the 180 time points. Dummy variables were created for group.

Multilevel models consist of two parts: a fixed part that describes the average time curve (referred to as slope) and a random part that describes the between-subject and within-subject variance (28). Here, the intercept, time, and group were used to describe the fixed part. The intercept refers to the initial level of the dependent variable, choice preference. Time was modeled either in a linear or quadratic parameter, the highest significant trend being most informative. The linear parameter describes the linear change in choice preference at each time point. The quadratic factor described the acceleration (or deceleration) of choice preference at each time point. The model was estimated using MLwiN 2.02 (Institute of Eduction, University of London, London, United Kingdom) (29).

Psychophysiological responses were analyzed across alternatives, separately for both conditions. Mean HR and mean SC level were calculated and compared between groups using an ANOVA. Heart rate responses to reward and penalty were each submitted to a repeated measure ANOVA with IBI (IBI−1, IBI0, and IBI+1) as within-subject factor and group as between-subject factor. The peak and latency of the SC responses to reward and penalty were each submitted to an ANOVA with group as between-subject factor. In the magnitude condition, psychophysiological data of two children in each group were missing due to noise in the communication between the task software and the psychophysiological device. Correlations were calculated between preference for the seductive and advantageous alternative, symptoms levels, and psychophyiological responses to reinforcement. Since choice preference changed over time, the task was divided into six bins of 30 trials, to ensure that each trial bin contained a sufficient number of observations (30). Trial bin 1 refers to trial 1–30, bin 2 refers to trial 31–60 etcetera.

Results

Performance

For both conditions, the model is presented. This is followed by group comparisons of the slopes of the model (intercept, linear, and quadratic parameters).

Decision Making in the Magnitude Condition. Since the quadratic trends for both logistic functions $\log(\pi_{ib}/\pi_{ia})$ and $\log(\pi_{ic}/\pi_{ia})$ were not significant (joint $\chi^2_4 = 7.7$, $p = .10$), they were omitted from the model. Choice behavior was best described by the linear trends (joint $\chi^2_4 = 75.0$, $p < .001$), demonstrating that children increased their preference for the advantageous alternative, while decreasing their preference for the seductive alternative and disadvantageous alternative (Figure 2, Table 2). There was no significant difference in the linear slope that described the decrease in preference for the seductive alternative, $\log(\pi_{ib}/\pi_{ia})$, and disadvantageous alternative, $\log(\pi_{ic}/\pi_{ia})$, joint $\chi^2_2 = 4.4$, $p > .05$.

Figure 2 illustrates that the preference for the advantageous alternative was smaller for the ODD than TD group, indicated by a significant difference in linear slopes, $\chi^2_1 = 11.3$, $p < .001$. Post hoc analyses showed that this was true for $\log(\pi_{ib}/\pi_{ia})$, $\chi^2_1 = 9.5$, $p < .01$, and to a smaller extent for $\log(\pi_{ic}/\pi_{ia})$, $\chi^2_1 = 4.6$, $p = .04$. Thus, compared with TD children, children with ODD showed a greater preference for the seductive and the disadvantageous alternative.

There was a significant correlation between preference for the seductive alternative and parent-rated ODD in trial bins 2, 3, and 5 (r = .47, .42, .33; $p < .01$, $p < .01$, $p < .05$, respectively). Additionally, a significant correlation was observed between the advantageous alternative and parent-rated ODD in trial bin 3 and teacher-rated ODD in trial bin 1 ($r = -.27, -.30$; p values $< .05$). Thus, in the magnitude condition, a greater severity of ODD symptoms was related to a greater preference for the seductive alternative and smaller preference for the advantageous alternative. Similar associations were obtained in some trial bins for ADHD and CD symptoms. Preference for the seductive alternative correlated with parent-rated ADHD in bin 3 ($r = .35$, $p < .05$) and with parent-rated CD in bins 2 and 3 (r = .35, .32, p values $< .05$).

Decision Making in the Frequency Condition. Since the

Table 2. Parameters of the Multilevel Nominal Logistic Regression Model

Group and Condition	Log	Intercept (SE)	Linear Trend (SE)
ODD Magnitude (n = 18)	(π_{ib}/π_{ia})	.329 (.153)	−.003 (.001)^a
	(π_{ic}/π_{ia})	−.015 (.148)	−.004 (.001)^a
ODD Frequency (n = 18)	(π_{ib}/π_{ia})	−.059 (.161)	−.010 (.001)^b
	(π_{ic}/π_{ia})	−.480 (.159)	−.009 (.001)^b
TD Magnitude (n = 24)	(π_{ib}/π_{ia})	−.277 (.124)	−.003 (.001)^a
	(π_{ic}/π_{ia})	−.428 (.121)	−.003 (.001)^a
TD Frequency (n = 24)	(π_{ib}/π_{ia})	.238 (.123)	−.012 (.001)^b
	(π_{ic}/π_{ia})	.002 (.122)	−.013 (.001)^b

Note. $\log(\pi_{ib}/\pi_{ia}) = \beta_{0b}$ (intercept) $+ \beta_{1b}$ time (linear trend) for the seductive alternative with the advantageous alternative as baseline; $\log(\pi_{ic}/\pi_{ia}) = \beta_{0c} + \beta_{1c}$ time for the disadvantageous alternative with the advantageous alternative as baseline; Time = trial 1 to trial 180.

ODD, oppositional defiant disorder; TD, typical developing control subjects.

$^a p < .05$.
$^b p < .01$.

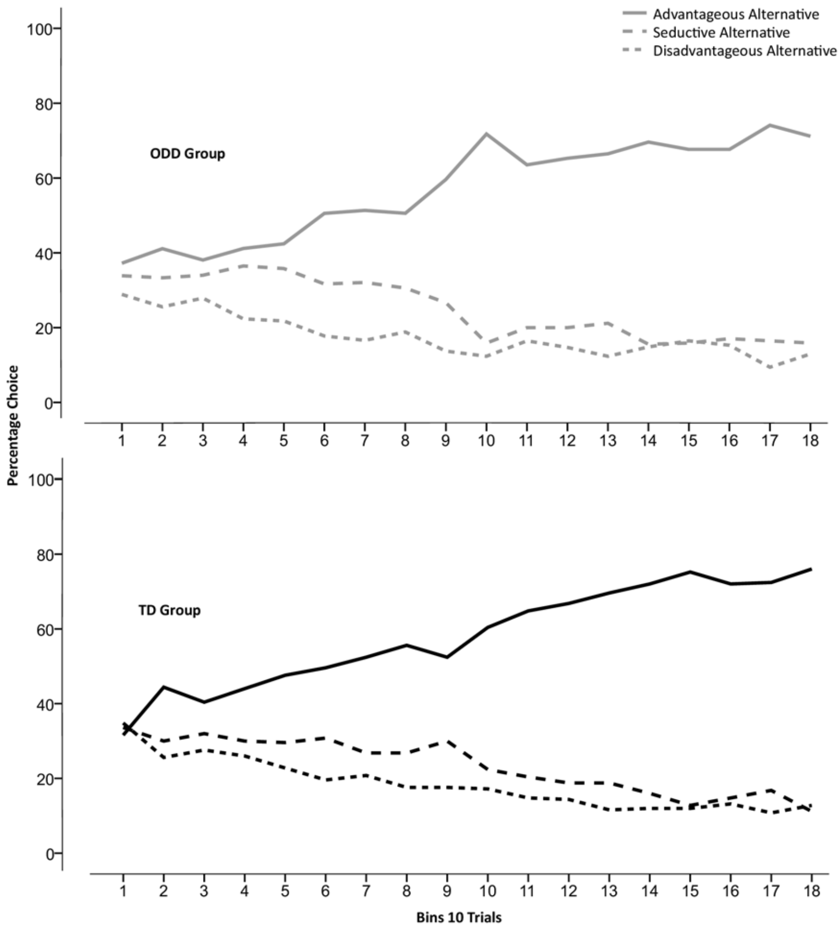

Figure 3. Choice probabilities over time (trials 1–180) in the frequency condition for the advantageous alternative (small frequent reward, small infrequent penalty), the seductive alternative (large frequent reward, small penalty increasing in frequency), and the disadvantageous alternative (small frequent reward, small frequent penalty increasing in frequency) for children with oppositional defiant disorder and typically developing children. In the first 10 trials, children with oppositional defiant disorder, compared with control subjects, showed a larger preference for the advantageous alternative and smaller preference for the disadvantageous alternative. ODD, oppositional defiant disorder; TD, typically developing control subjects.

quadratic trends were not significant (joint $\chi^4_4 = 8.3$, $p = .10$), they were omitted from the model. Choice behavior was best described by the linear trends (joint $\chi^2_4 = 119.6$, $p < .001$), demonstrating that children increased their preference for the advantageous alternative, while decreasing their preference for the seductive and disadvantageous alternatives (Figure 3, Table 2). There was a difference in the linear slope that describes the decrease in preference for the seductive alternative and the disadvantageous alternative, as the difference between $\log(\pi_{ib}/\pi_{ia})$ and $\log(\pi_{ic}/\pi_{ia})$ was significant, joint $\chi^2_2 = 6.9$, $p = .04$. Thus, the aversion was larger for the disadvantageous alternative than the seductive alternative. See Supplement 1 for performance data according to the multilevel nominal regression model.

Figure 3 illustrates that during the start of the task, the preference for the advantageous alternative was somewhat larger for ODD than for TD children, as indicated by a significant difference in slopes, $\chi^2_1 = 6.0$, $p = .02$. Post hoc analyses showed that this was true for $\log(\pi_{ic}/\pi_{ia})$, $\chi^2_1 = 5.7$, $p = .02$, but not for $\log(\pi_{ib}/\pi_{ia})$, $\chi^2_1 = 2.2$, $p > .05$. Thus, during the first 10 trials, children with ODD compared with TD children showed a greater preference for the advantageous alternative by choosing less often for the disadvantageous option. No significant correlations were observed between choice preference and symptom levels.

Heart Rate

In both conditions, mean HR was lower for children with ODD than TD, although the difference just escaped conventional levels of significance. In the magnitude condition, mean IBI was 740 msec (81 beats/min) for children with ODD and 680 msec (88 beats/min) for TD children, $F(1,36) = 3.5$, $p = .07$, $\eta_p^2 = .10$. In the frequency condition, mean IBI was 750 msec (80 beats/min) for children with ODD and 679 msec (88 beats/min) for TD children, $F(1,38) = 3.4$, $p = .07$, $\eta_p^2 = .09$.

HR Response to Reinforcement in the Magnitude Condition. A close to significant group by IBI interaction was found for HR responses to reward, $F(2,35) = 4.9$, $p = .05$, $\eta_p^2 = .15$. Figure 4 (left panel) illustrates that compared with TD children, HR of children with ODD decelerated in response to reward (larger IBI). A significant group by IBI effect was found for HR response to penalty, $F(2,35) = 5.5$, $p = .02$, $\eta_p^2 = .13$. Figure 4 (right panel) illustrates that HR of TD children decelerated in response to penalty (larger IBI), while children with ODD showed no HR deceleration.

Heart rate response to penalty was negatively related with the seductive alternative in trial bins 2 and 3 (for IBI0, $r = -.32$, $-.43$; for IBI+1, $r = -.34$, $-.38$; all p values $< .05$). Thus, reduced HR deceleration following penalty related to a greater preference for the seductive alternative. Heart rate response to penalty was negatively related to ODD symptoms at IBI0 and IBI+1, as rated by parents ($r = -.45$, $-.52$; p values $< .01$) and by teachers ($r = -.33$, $-.36$; p values $< .05$). Thus, reduced HR response to penalty related to more ADHD symptoms. Heart rate response to penalty also correlated significantly with parent-rated ADHD and CD at IBI0 ($r = -.41$, $-.37$; p values $< .05$) and IBI+1 ($r = -.37$, $-.45$; p values $< .05$).

HR Response to Reinforcement in the Frequency Condition. Figure 4 (left panel) illustrates that HR in response to reward decelerated in children with ODD (larger IBI), while TD children did not show any HR deceleration. This was confirmed by a significant group by IBI effect for HR response to reward, $F(2,37) = 4.9$, $p = .03$, $\eta_p2 = .15$. No significant group by IBI effect was revealed for HR responses to penalty ($p = .20$) (Figure 4, right panel). No significant correlations were observed between HR responses and choice preference. Heart rate response to reward related positively to parent-rated ODD at IBI0 ($r = .35$, $p = .05$).

Skin Conductance

There were no group differences in SC level ($p \geq .3$). In addition, there were no group, condition, or interaction effects for SC responses to reward or penalty (p values $> .5$), neither for latency nor amplitude. To validate the SC response measure, it was tested whether SC responses showed the expected increase over the course of the task (17). Skin conductance response amplitudes were compared between the first and second halves of the task. As expected, in both conditions, SC response to reward and penalty increased in the second half (p values $< .01$), but there were no differences between groups ($p > .2$).

Discussion

It was tested whether children with ODD focus on reward and ignore penalty (5–7,9), by using a decision-making task with risky choices that carry large rewards but also large penalties. The results demonstrate that, in the magnitude condition, children with ODD (with and without ADHD) displayed a smaller preference than control subjects for the advantageous alternative, resulting in a smaller final gain. This was caused by an increased preference for the seductive alternative and (to a smaller extent) by an increased preference for the disadvantageous alternative. Oppositional defiant disorder symptoms correlated positively with preference for the seductive alternative in three out of six trial bins, indicating that ODD is related to an increased "search" for rewards, despite aversive outcomes (10,11).

In the frequency condition, no group differences were detected in the preference for the seductive alternative. This suggests that children with ODD are as sensitive to reinforcement as TD children when penalty is presented frequently. Alternatively, children with ODD may have learned how to choose correctly when they played the task for the second time. A learning effect is noticeable in the first 10 trials of the frequency condition, where children with ODD showed a greater aversion toward the disadvantageous alternative than control subjects. This is probably caused by their greater experience with this alternative in the magnitude condition.

Mean HR levels during the task were somewhat lower for children with ODD than TD children, but unlike earlier studies (10,13,15), no group differences were detected in SC levels. Compared to the TD group, children with ODD displayed greater HR reactivity to reward (more HR deceleration) and smaller HR reactivity to penalty (less HR deceleration), although the latter difference was only observed in the magnitude condition. The correlational analyses suggest that impaired decision making in ODD is related to differences in autonomic reactivity to reinforcement, corroborating with Damasio (17). Compared to control subjects, children with ODD seem to have a different perception of the saliency of reinforcement, perceiving penalty as less salient and perceiving reward as more salient. Heart rate deceleration following feedback has been associated with feedback processing (31,32), and the degree of cardiac deceleration seems dependent on the saliency of the feedback (31). For example, HR deceleration is larger following negative than positive feedback (31) and larger when feedback is related to financial gain (33). This may suggest that an altered perception of the saliency of reinforcement influenced decision making.

No group differences were observed in SC responses to reward and penalty, a process that is mediated by sympathetic control. This is in line with earlier studies that showed normal SC responses in ODD to aversive stimuli such as stress (13,14), despite abnormal cortisol responses. In the current study, ODD was related to abnormal parasympathetic responses to reinforcement, reflected in altered stimulus-evoked HR changes. These

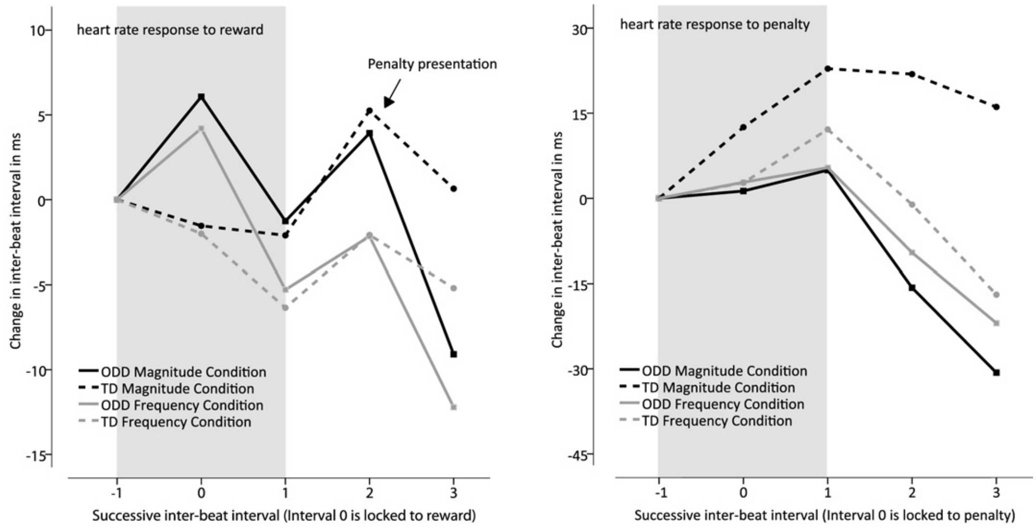

Figure 4. Heart rate (HR) response to reward (left panel) and penalty (right panel) in the magnitude and frequency condition. A repeated measures analysis of variance compared children with oppositional defiant disorder (ODD) and typically developing children on interbeat interval (IBI)−1, IBI0, and IBI+1 (gray area). The IBI+2 and IBI+3 were not included in this analysis because this interval also contained the HR response to penalty (left panel). During reward presentation, children with ODD displayed increased HR decelerated compared with control subjects in both conditions. During penalty presentation in the magnitude condition, children with ODD displayed reduced HR deceleration in contrast to control subjects. TD, typically developing control subjects.

findings add to the literature linking altered parasympathetic cardiac control to antisocial behavior (12,34).

Our findings are supported by a study with CD adolescents who selected more risky gambles than control subjects in a task where information on the probability of winning was explicit (35). In contrast, a decision-making study with two alternatives showed that ADHD, rather than ODD, was related to decision-making inability (36), but it was not investigated whether this was caused by an increased preference for large rewards. An earlier independent study of our group with the adapted version of the Iowa Gambling Task (21) demonstrated that children with ADHD kept choosing randomly from the three alternatives, which resulted in large losses. Thus, while both children with ODD and children with ADHD show maladaptive decision making, an increased preference for risky decisions seems more related to ODD than to ADHD. This is confirmed by clear correlations between the preference for the seductive alternative and ODD symptoms in trial bins 2, 3, and 5, while there was only one significant association between risky choice behavior and parent-rated ADHD. In the Luman *et al*. study (21), children with ADHD displayed increased HR responses to reward, like children with ODD, but did not show a decreased HR response to penalty.

The current study has some limitations that are worth noting. A larger sample size may have allowed counterbalancing of the order of conditions and excluding possible learning effects. Another issue is that a larger sample would have allowed a statistical comparison of IQ-matched groups. Finally, larger interstimulus intervals between reward and penalty presentation may have allowed independent inspection of the slow SC responses.

Conclusion

The behavioral findings support the suggestion that, compared with TD children, children with ODD focus on reward, while being less sensitive for signals of punishment (6,7,9). The psychophysiological findings suggest that this behavior is related to a reduced cardiac response to aversive outcomes and an increased cardiac response to reward. This argues against the proposal that children with ODD suffer from a general state of attenuated autonomic arousal (34), and this may dissociate children with ODD from children with CD (10,12–15,37,38). If replicated, the findings have important clinical implications for behavioral interventions. If children with ODD focus on reward while being less sensitive to (infrequent) penalty, using large and infrequent punishment to shape their behavior may be ineffective.

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Supplementary material cited in this article is available online.

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