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Evidence for increased behavioral control by punishment in children with attention-deficit hyperactivity disorder

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Background: The behavioral sensitivity of children with ADHD to punishment has received limited theoretical and experimental attention. This study evaluated the effects of punishment on the response allocation of children with ADHD and typically developing children. **Method:** Two hundred and ten children, 145 diagnosed with ADHD, completed an operant task in which they chose between playing two simultaneously available games. Reward was arranged symmetrically across the games under concurrent variable interval schedules. Asymmetric punishment schedules were superimposed; responses on one game were punished four times as often as responses on the other. **Results:** Both groups allocated more of their responses to the less frequently punished alternative. Response bias increased significantly in the ADHD group during later trials, resulting in missed reward trials and reduced earnings. **Conclusions:** Punishment exerted greater control over the response allocation of children with ADHD with increased time on task. Children with ADHD appear more sensitive to the cumulative effects of punishment than typically developing children. **Keywords:** Attention-deficit hyperactivity disorder; punishment; response allocation; matching law.

Introduction

Altered motivational processes are hypothesized to account for symptoms of attention-deficit hyperactivity disorder (ADHD). In general, these explanations emphasize altered sensitivity to positive reinforcement (see Luman, Tripp, & Scheres, 2010). Behavioral evidence supports these hypotheses, children with ADHD consistently show a stronger preference for immediate over delayed reward (see Sonuga-Barke, Sergeant, Nigg, & Willcutt, 2008) and there is some evidence for differential enhancement of task performance under reward conditions (see Luman, Oosterlaan, & Sergeant, 2005) and normalization of performance under continuous reinforcement (e.g., Douglas & Parry, 1994).

Both positive and negative outcomes affect behavior and behavior management programs for ADHD employ reward and punishment (typically response cost). Despite this, the responsiveness of children with ADHD to punishment has received limited theoretical attention and experimental findings are mixed. Wender (1974) hypothesized anomalies in the biological processing of reinforcement in children with ADHD resulting in diminished responsivity to both reward and punishment. Quay (1997) later proposed that the impulsive behavior of children with ADHD results from a deficient behavioral inhibition system leading to reduced responsiveness to cues that predict punishment or non-reward, but not to unconditioned punishment. Aside from these general ideas, there are no detailed theories regarding altered sensitivity to punishment in ADHD, or its contribution to the disorder's symptoms.

Experimentally, mild punishment (response cost) has been shown to enhance the performance of children with ADHD across a range cognitive tasks. In about a third of these studies, improved performance was seen in the children with ADHD only (Carlson, Mann, & Alexander, 2000; Carlson & Tamm, 2000; Iaboni, Douglas, & Baker, 1995; Slusarek, Velling, Bunk, & Eggers, 2001), possibly due to ceiling effects among controls. In the remaining studies, the influence of punishment was similar for children with and without ADHD (Crone, Jennings, & Van Der Molen, 2003; Cunningham & Knights, 1978; Drechsler, Rizzo, & Steinhausen, 2010; Firestone & Douglas, 1975; Groen, Tucha, Wijers, & Althaus, 2013; Solanto, 1990; Van Meel, Oosterlaan, Heslenfeld, & Sergeant, 2005a).

Gambling tasks with a penalty component provide further information about punishment sensitivity in ADHD. In a recent review, Groen, Gaastra, Lewis-Evans, and Tucha (2013) identified four, out of 12, studies reporting increased risky choices in children and adolescents with ADHD compared to controls. Two further studies reported greater risk-taking in those with ADHD and comorbid Oppositional Defiant Disorder (ODD) or Conduct Disorder. Increased engagement in behavior with high risk of penalty could be considered evidence of reduced sensitivity to punishment in children with ADHD. In these studies, however, such decisions are often accompanied by larger immediate rewards, and so might be explained by altered sensitivity to reward or deficits

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in response inhibition. Two of the studies reviewed also reported less frequent response switches following penalties in those with ADHD, while one study reported no group differences in subsequent behavior (see Groen, Gaastra, et al., 2013).

A series of Event-Related Potential (ERP) studies have evaluated sensitivity to punishment at the neural level. van Meel, Oosterlaan, Heslenfeld, and Sergeant (2005b) reported enhanced sensitivity to monetary losses in their ADHD group during a guessing game. They reported the opposite result with a time production task (van Meel, Heslenfeld, Oosterlaan, Luman, & Sergeant, 2011). With a selective attention task, Groen, Tucha, et al. (2013) identified enhanced responses to both reward and punishment in their ADHD group. Gong et al. (2014) reported children with inattentive type ADHD failed to show differential responses to small versus large penalties during a gambling task compared to the combined type ADHD and control groups.

Overall, the evidence for differential sensitivity to punishment in children with ADHD is limited, and mixed with respect to direction. The strongest support comes from studies using gambling paradigms where differences might be due to motivational and/or executive factors. In this study, we use an operant procedure that allows more direct measurement of contingency effects on behavior (Bull, Tippett, & Addis, 2015). Earlier studies have used single schedules demonstrating the effectiveness of mild punishment in reducing off-task or maintaining on-task behavior in children with ADHD (Rapport, Murphy, & Bailey, 1982; Rosén, O'Leary, Joyce, Conway, & Pfiffner, 1984; Worland, 1976). The current study uses concurrent schedules to assess the extent to which punishment influences response allocation in children with and without ADHD.

The generalized matching law provides a framework to evaluate the effects of contingencies on behavior when organisms can choose between more than one activity (Baum, 1974). It stipulates that animals and humans allocate behavior in proportion to the rates of reinforcement available (Kollins, Newland, & Critchfield, 1997). When reinforcements are arranged symmetrically across two alternatives, behavior should be distributed evenly. Superimposing asymmetric schedules of punishment on these symmetrical reinforcement schedules biases responding toward the less punished alternative (Critchfield, Paletz, MacAleese, & Newland, 2003; Rasmussen & Newland, 2008). This shift in response allocation provides a quantitative measure for examining the behavioral control exerted by punishment. More pronounced punishment effects would appear as a larger bias toward the less punished alternative.

Children with ADHD and typically developing controls completed a computer task in which they chose between playing two simultaneously available games (response alternatives). The two games arranged equal rates of reward using concurrent variable interval (VI/VI) schedules, over which punishment schedules were superimposed such that responses on one game were punished four times as often as responses on the other. We expected control group children to allocate more of their responses to the less frequently punished alternative. If children with ADHD differ from typically developing children in their sensitivity to punishment, this should be seen in their response allocation across the two games. Relative to controls, increased sensitivity to punishment would appear as a larger bias toward the less frequently punished alternative, reduced sensitivity as a smaller bias.

Method

Ethical approval for the study was obtained from the Lower South Health and Disability Committee (New Zealand) and the OIST Graduate University Human Subjects Research Review Committee (Japan). Participating parents, teachers and children were volunteers and provided written consent.

Participants

This study includes data from 210 children, 145 meeting DSM-IV diagnostic criteria for ADHD (71.7% boys) and 65 typically developing children (64.6% boys). Within the ADHD group, 77 children were diagnosed with inattentive and 68 with combined type ADHD. Data from six children with hyperactive/impulsive type ADHD were excluded due to the sample size. Thirty-six children had at least one comorbid disorder, including 21 with ODD, 31 were prescribed stimulant medication for symptom management (see Table 1 for details).

Inclusion criteria were an estimated IQ of at least 70, normal or corrected vision, no past or current head injury, neurological disorder or psychosis, no medication use for these conditions, and English as a first language. Children in the ADHD group were recruited through two University ADHD Research Centers, where they completed multimethod, multiinformant diagnostic assessments. Data from the semistructured diagnostic interviews (K-SADS-PL, Disruptive Behavior Disorder section; Kaufman et al., 1997), parent and teacher completed rating scales for ADHD symptoms (DBD/SNAP; Molina, Pelham, Blumenthal, & Galiszewski, 1998; Swanson, 1995) and observations of the child's behavior were used to make a clinical diagnosis of ADHD. Parent and teacher completed broadband rating scales (CBCL/TRF; Achenbach & Rescorla, 2001) and background questionnaires screened for other behavioral and emotional problems, neurological and medical conditions. Cognitive functioning was assessed with the WISC-IV (Wechsler, 2003).

Children in the ADHD group were required to display six or more symptoms of inattention and/or hyperactivity/impulsivity in at least one setting, evidence of symptoms in a second setting, and functional impairment from symptoms. Symptoms were not summed across informants. Assessments were carried out by a licensed clinical psychologist or a supervised intern. All diagnostic decisions were reviewed by at least two PhD clinical psychologists experienced in the assessment of children with ADHD (GT, EF, PS, with GT supervising all cases at both Centers). Children prescribed stimulant medication discontinued its use for at least 24 hrs prior to study participation.

Children in the control group were recruited through invitation letters sent home to parents through schools in Dunedin, New Zealand. Children completed an abbreviated IQ assessment (WISC-IV, Vocabulary/Matrix Reasoning). Their parents and teachers completed the behavior rating scales, which were used to rule out the presence of ADHD or other

Table 1 Participant characteristics for the control and ADHD groups and ADHD subtypes

	Control (n = 65)			ADHD (n = 145)			*Inattentive (n = 77)*			*Combined (n = 68)*		
	M	*SD*	Range	*M*	*SD*	Range	*M*	*SD*	Range	*M*	*SD*	Range
Age (months)	99.75	16.74	69–140	108.03	19.51	62–154	*114.22*	*19.14*	*62–154*	*101.03*	*17.58*	*65–141*
Estimated IQ	101.78	11.71	77–129	103.38	13.31	71–138	*103.65*	*12.00*	*77–129*	*103.07*	*14.73*	*71–138*
Attention Problems CBCL *T*-score[a]	51.37	2.19	50–64	70.31	9.85	53–97	*69.52*	*10.09*	*55–97*	*71.22*	*9.56*	*53–96*
Attention Problems TRF *T*-score[a]	50.05	0.29	50–52	64.98	8.61	50–92	*63.27*	*7.65*	*50–92*	*67.26*	*9.34*	*50–87*
Boys n (%)	42 (64.6)			104 (71.7)			*48 (62.3)*			*56 (82.4)*		
Medication n (%)	–			31 (21.4)			*9 (11.7)*			*22 (32.4)*		
ODD n (%)	–			21 (14.5)			*5 (6.5)*			*16 (23.5)*		
ASD/Anxiety n (%)	–			2/4 (1.4/2.8)			*0/2 (0/2.6)*			*2/2 (2.9/2.9)*		
Learning Problems/Other n (%)	–			29/4 (13.1/2.8)			*13/0 (16.9/0)*			*16/4 (23.5/5.9)*		

[a]Based on n = 60 for CBCL and n = 59 for TRF in the control, n = 136 for CBCL and n = 128 for TRF in the ADHD group. These scales were missing for some participants.

behavioral or emotional disorders. Those demonstrating fewer than four symptoms of ADHD (as reported by a single informant) were included in the control group. For three children, the responses of a parent yielded a score in the clinical range on one of the problem behavior scales of the CBCL (not the Attention Problems scale). Because these elevations were not confirmed by teacher ratings (TRF) the children's data were retained.[1] Parental questionnaire reports of past and current illness, disability, and medication use were reviewed for other inclusion criteria.

Table 1 presents the sample characteristics of the ADHD and control groups (see Supporting Information for additional demographic information). Independent t-tests compared the characteristics of the ADHD and control group. No significant differences were identified for estimated IQ scores. The mean age of the ADHD group was significantly higher than that of the control group ($t(208) = 2.97$, $p < .01$). The Attention Problems scale T-scores were significantly higher for the ADHD group than the control group (CBCL $t(162.36) = 21.26$, $p < .001$; TRF $t(127.62) = 19.59$, $p < .001$).

Experimental task

The children sat approximately 400 mm from a flat-screen monitor with a mouse. The task began with the computer presenting written instructions on the screen. The experimenter read the instructions aloud and provided clarification as necessary. Two 2 × 2 grids of cartoon characters were presented on the screen, one on the left (Game 1) and one on the right (Game 2), together with a center window to display accumulated points. All children began with a positive balance of 20 points. They played one game at a time. They were told they could switch between the two games as often as they liked and they should win lots of points to get a prize after the task ended. A mouse click on a button below each grid made the characters in the selected game spin for approximately 3,000 ms. Whenever the four characters matched (reward trial), 10 points were added to their total, a randomly selected, without replacement, animated cartoon was displayed for 2,500 to 3,000 ms, and a congratulatory 'tada!' sound played. Whenever four sad-faced characters appeared together (punishment trial), 5 points were taken away from the child's total and a laughing sound 'ha ha ha!' played for 5,000 ms. A mismatch of characters had no associated outcome (nonconsequential trial). Once a choice was made, the response buttons were disabled until the trial was complete, including the outcome delivery. The task continued until the child accumulated 400 points or completed 300 trials, whichever occurred first. If a child had not earned 400 points after 300 trials, 'bonus' points were given so that the child could exchange their points for a small prize. Sessions typically lasted 30–35 min.

Reinforcements became available every 10 s on average arranged equally across the two games (VI/VI) with the following constraints. For each successive block of 12 reinforcements, each game delivered 6 reinforcements, randomized within each block. This ensured that each child obtained the same arranged distribution of reinforcers in earlier and later trials, and discouraged playing on one game exclusively. Reinforcements were never delivered on the first trial after switching from one game to the other to avoid adventitious reinforcement of switching behavior (Stubbs & Pliskoff, 1969).

Punishments were arranged asymmetrically across the two games, superimposed over the reinforcement schedules. Each response on Game 1 had a 16% chance of being punished, while on Game 2 the probability was 4%. The rates of reinforcement and punishment were chosen such that the children should, overall, win more points than they lose.

Data collection and analyses

On each trial, the computer recorded the game chosen, the outcome (win, loss or no outcome) and response time (recorded from the time the response buttons became available, after outcome presentation, until a response).

Response bias (log b) was calculated by the following equation:

$$\log b = \log 10 \frac{\text{responses to Game 2 (less punished)}}{\text{responses to Game 1 (more punished)}}.$$

Scores above zero indicate a systematic preference for the less frequently punished response alternative.

Response bias, number of each outcome type, and median response times were calculated for the first and second blocks of 100 trials for all participants ($N = 210$). The fewest trials completed were 226 for the ADHD and 241 for the control group. For participants who completed 300 trials before earning 400 points ($n = 180$; ADHD = 84.8%, control = 87.7%), the same measures were also calculated for the third block of 100 trials, together with the total accumulated points. The ADHD and control group means were compared for the first and second blocks for all participants; the analyses were repeated for all three blocks for participants who completed 300 trials.

Instances of playing the same game for two consecutive trials (stays) were counted across all trials completed for each participant. The proportion 'stays' (number stay trials/total trials) were calculated separately for Game 1 and Game 2.

These proportions were subjected to Logit transformations, that is, log10 (proportion/(1−proportion)). The ADHD versus control group means of the logit-transformed values were compared across the two games.

Counts were also made for stays following each trial type and converted to proportions for reward, punishment and nonconsequential trials (stay trials of one trial type/total trials of that type). Group means were obtained for the logit-transformed values of these proportions.[2] The ADHD and control groups were compared for punishments versus no outcomes. The proportion of stays after rewards was examined separately. The first response after switching games was followed by either a punishment or no outcome. After these trials, staying was adaptive since reward always followed at least two consecutive trials played on the same game. This task parameter increased the expected proportion of stays after nonrewarded trials, compared to rewarded trials, hence separate analyses of these trial types.

Finally, median response times following each trial type were calculated for each participant and the group means compared across the three trial types.

Results

Preliminary analyses indicated no significant differences on any of the performance measures for children with inattentive and combined type ADHD; therefore, their data were combined into a single ADHD group. Excluding comorbid ODD participants did not alter the results; therefore, their data were retained. Age was included as a covariate in all the analyses due to the significant group difference and the small, but significant, correlation between age and bias (r ranging from −.15 to −.17, $p < .05$ for all blocks). Table 2 presents mean scores for the performance measures for each block of 100 trials. The data were analyzed with Mixed ANOVA using SPSS GLM (IBM SPSS Statistics for Macintosh, Version 23.0, IBM Corp., Armonk, NY) unless otherwise specified.

Wins, losses and no outcomes

The number of wins, losses and no outcomes experienced were compared across the ADHD and control groups. There was a main effect of Group for the number of wins ($F(1, 207) = 4.13$, $p < .05$), losses ($F(1, 207) = 6.68$, $p < .01$) and no outcomes ($F(1, 207) = 8.31$, $p < .01$) over the two blocks of 100 trials. Control group children experienced more wins and more losses than children with ADHD, while the ADHD group children experienced more no-outcome trials than controls. Similarly for the three blocks of 100 trials there was a significant Group effect for the number of wins ($F(1, 177) = 11.15$, $p < .001$), losses ($F(1, 177) = 10.84$, $p < .001$) and no outcomes ($F(1, 177) = 16.02$, $p < .001$). Among the participants who did not reach 400 points, between-subject ANOVA indicated the total accumulated points were higher for the control than the ADHD group ($F(1, 177) = 6.53$, $p < .05$).

Response bias toward the less frequently punished game

Over the first and second blocks, there was a significant Block x Group interaction effect ($F(1, 207) = 6.83$, $p < .01$, Figure 1). Mean bias scores were similar for both groups during the first 100 trials; one-sample t-tests indicated the control ($t(64) = 5.83$, $p < .001$) and ADHD ($t(144) = 6.38$, $p < .001$) groups developed a significant bias toward the less punished alternative. During the second block, the ADHD group demonstrated a larger bias than the control group. There was also a significant Block x Group interaction ($F(1.7, 305.2) = 3.26$, $p < .05$, Greenhouse-Geisser correction) for the

Table 2 Means and standard errors for response bias toward the less punished game, number of each outcome type, points accumulated and median response time for each block of 100 trials for the control and ADHD groups

Group/Trial Block	First (Trial 1–100)	Second (Trial 101–200)	Third (Trial 201–300)
	(ADHD n = 145, Control n = 65)		(ADHD n = 123, Control n = 57)
	M (SE)		
Bias for less punished (log b)			
Control	0.13 (0.02)	0.13 (0.03)	0.13 (0.03)
ADHD	0.11 (0.02)	0.21 (0.02)	0.24 (0.04)
Response Time (ms)			
Control	1,775 (79)	1,304 (60)	1,226 (68)
ADHD	1,608 (47)	1,225 (39)	1,300 (153)
Wins (counts)			
Control	13.95 (0.55)	13.28 (0.57)	12.95 (0.48)
ADHD	13.11 (0.37)	11.88 (0.41)	10.95 (0.40)
Losses (counts)			
Control	8.98 (0.34)	8.29 (0.39)	8.42 (0.39)
ADHD	8.28 (0.25)	7.61 (0.22)	7.33 (0.26)
No outcome (counts)			
Control	77.06 (0.64)	78.43 (0.74)	78.63 (0.69)
ADHD	78.61 (0.46)	80.52 (0.48)	81.72 (0.55)
Points earned (=wins*10 − losses*5)			
Control	94.62 (5.74)	91.31 (5.78)	87.37 (4.77)
ADHD	89.72 (3.82)	80.72 (4.17)	72.97 (3.74)

Means presented are not adjusted for age.

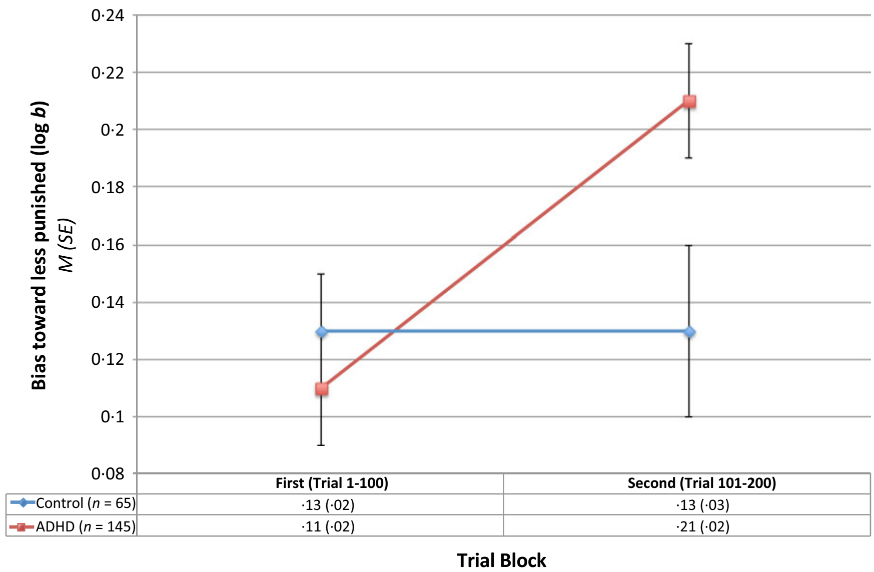

Figure 1 Mean response bias scores and standard errors for the control and ADHD groups during the first and second blocks of 100 trials. [Colour figure can be viewed at wileyonlinelibrary.com]

three-block analysis. The bias of the control group remained constant, whereas the bias of the ADHD group increased from the first to the second block, remaining high during the third block.

Response speed

Median response time declined significantly over the first two blocks for both groups, indicated by a main effect of Block ($F(1, 207) = 28.22$, $p < .001$). Both groups of children responded more quickly with increased exposure to the task. This effect was no longer significant when the analysis was repeated over the three blocks. The decrease in the response time over the first two blocks was followed by a further small decrease for the control group and an increase for the ADHD group during the third block. There was no significant Group or interaction effect.

Frequency of stays on the two alternatives

Analysis of the logit-transformed values of the proportion of stays on Game 1 (more punished) versus Game 2 (less punished) yielded main effects for Game ($F(1, 207) = 22.36$, $p < .001$) and Group ($F(1, 207) = 13.22$, $p < .001$). Both groups of children were more likely to play the same game for two consecutive trials on the less punished alternative. Irrespective of the alternative, the ADHD group showed a higher proportion of stays than the control group.

Influence of outcome on subsequent response allocation

Main effects for Outcome ($F(1, 207) = 7.67$, $p < .01$) and Group ($F(1, 207) = 14.05$, $p < .001$) were identified for the logit-transformed proportion of stays following punishment versus nonconsequential trials (Figure 2). Both groups of children played the same game less often following a loss than following no outcome. Children with ADHD were more likely than controls to stay on the same game following both trial types. One-way ANOVA indicated no group difference on the logit-transformed proportion of stays following a reward trial.

Influence of outcome on response speed

Response times after each trial type were examined, yielding a significant Outcome x Group interaction ($F(1.94, 400.76) = 14.51$, $p < .001$, Greenhouse-Geisser correction, Figure 3). Both groups of children responded more quickly after a nonconsequential trial than following a rewarded or punished trial. Children in the control group responded faster than the ADHD group children after reward and punishment trials.

Supplemental analyses

The analyses were repeated with the New Zealand data only (ADHD $n = 31$, control $n = 65$). The direction of results was unchanged, although not all differences remained statistically significant reflecting the smaller ADHD sample and possibly demographic and subtype differences between this subsample and the larger ADHD group (see details in Supporting Information).

Discussion

This study addresses the question of whether the behavior of children with ADHD is differentially influenced by punishment compared with that of typically developing children. Using a concurrent operant procedure, we assessed the effect of unequal

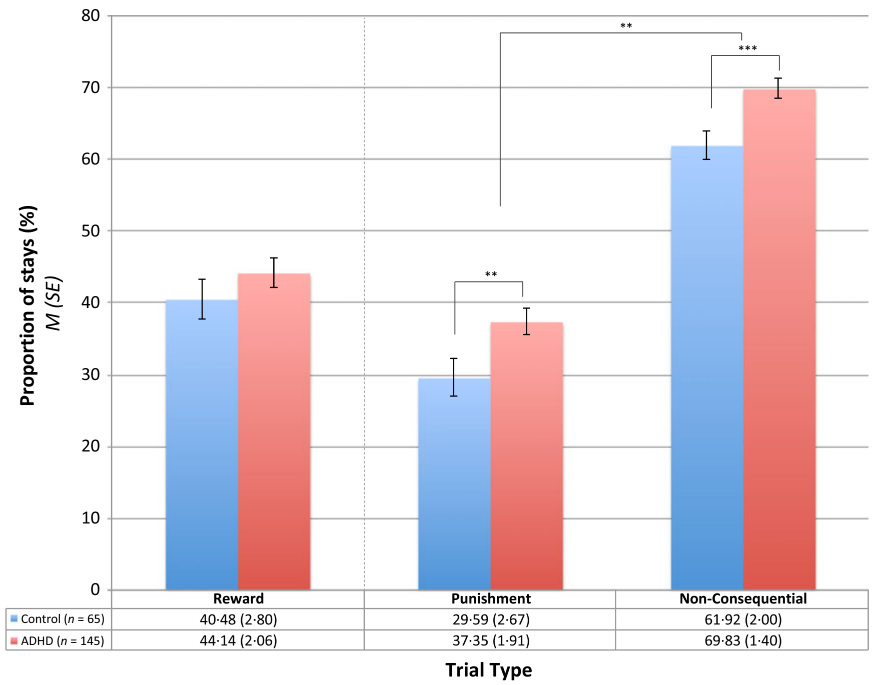

Figure 2 Means and standard errors for proportions of stays following each trial type for the control and ADHD groups. **p < .01, ***p < .001. [Colour figure can be viewed at wileyonlinelibrary.com]

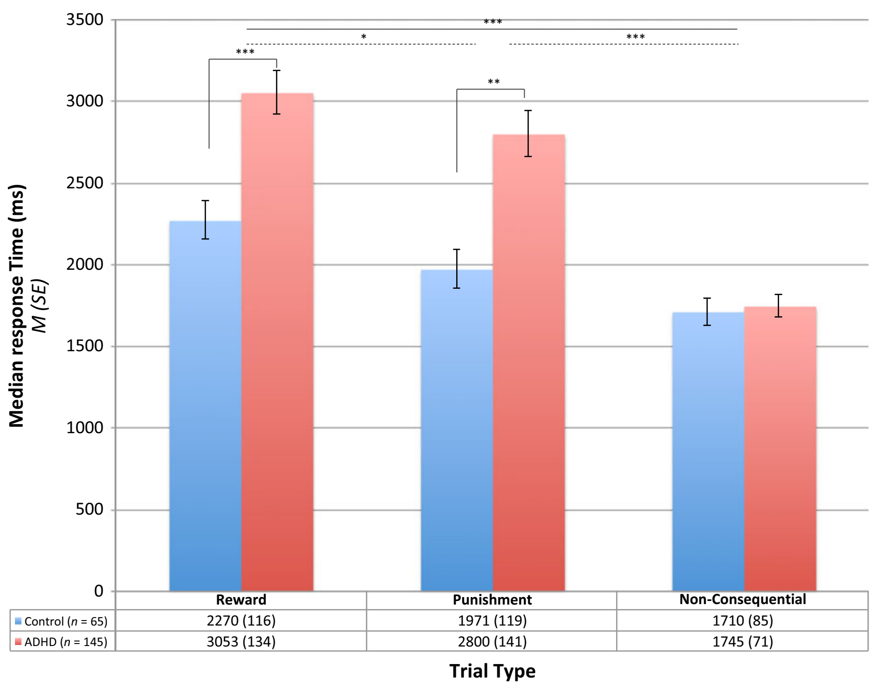

Figure 3 Means and standard errors for median response times following each trial type for the control and ADHD groups. *p < .05, **p < .01, ***p < .001. [Colour figure can be viewed at wileyonlinelibrary.com]

frequency of punishment on the children's behavioral allocation. Both groups of children demonstrated a preference for playing the game associated with less frequent punishment. This finding is consistent with the existing literature showing the behavior of children with and without ADHD is sensitive to, and influenced by, unfavorable outcomes.

With increased exposure to the contingencies, children in the ADHD group allocated significantly more of their responses to the less punished alternative than controls. Over time, the asymmetric distribution of punishment exerted more control over the behavior of children with ADHD than controls, relative to the moderating effects of reinforcement. These data suggest children with ADHD experienced punishment as more aversive. This effect was common to children with inattentive and combined type ADHD and not explained by the presence of comorbid ODD.

Greater avoidance of the more punished alternative emerged in the ADHD group despite it being associated with poorer overall outcomes. In allocating more of their responses to the less punished alternative, children with ADHD lost fewer points but also won fewer points given the symmetric reward distribution. Furthermore, this response pattern resulted in the ADHD group experiencing more trials with no outcomes. The responses of the control group were distributed more evenly across the two alternatives resulting in them experiencing more wins and more losses.

Both groups of children were more likely to play the same game on two consecutive trials on the less punished than the more punished alternative. However, the overall proportion of stays was higher for children with ADHD, resulting from a greater proportion of stays following nonrewarded trials. While playing the same game was adaptive in some instances (i.e., no rewards were delivered on switch trials), staying for too many consecutive trials reduced opportunities to win points. Children with ADHD may have a more conservative response style than controls, contributing to, or possibly arising from, their avoidance of punishment.

The response speed data offer further evidence that children with ADHD differ from controls in their reaction to punishment. Mean response times following no-outcome trials did not differentiate the groups, suggesting similar levels of attention to task. However, children in the ADHD group responded more slowly than controls after punished and rewarded trials. Such motivationally significant outcomes may be more distracting or emotionally arousing for children with ADHD, slowing their response times. In the case of reward, Douglas and Parry (1994) previously reported on its distracting/arousing effects in children with ADHD. Groen, Tucha, et al. (2013) reported ERP signals indicating children with ADHD attach more affective value to positive and negative feedback. Children with ADHD may also require more time to process motivationally relevant information.

Despite the stronger overall preference of the ADHD group for the less punished alternative and the response time data suggesting heightened sensitivity to motivationally significant outcomes, the two groups show a similar pattern of response allocation following individual instances of reward or punishment. Both groups of children were more likely to change games following a punished than a no-outcome trial. The proportion of stays following a win did not differ between the groups. These data suggest similar immediate effects of punishment and reward on response choices in children with and without ADHD; punishment inhibited and reward increased immediate repetition of behavior. Differences in the behavior allocation of the two groups appear driven more by the cumulative effects of the contingencies than their individual effects.

Altered sensitivity to reinforcement may also be contributing to the findings. Reduced behavioral control by reward in those with ADHD would magnify the behavioral effects of punishment. Barkley (1989) hypothesized a decline in the effectiveness of reward over time in children with ADHD. Although previous research using reward only in a related choice procedure found no decline in reward effectiveness over the task (Tripp & Alsop, 1999), additional research might evaluate if the increased bias observed in the ADHD group reflects increased sensitivity to punishment only, or if it includes reduced control by reward in the presence of punishment. Such research might focus on changes in sensitivity to asymmetric arrangements of reward only or punishment only in similar concurrent operant tasks (although maintaining children's motivation on any task that provided *only* punishment would be challenging).

Overall, the current findings indicate differential responding to punishment in children with ADHD. Children in the ADHD group allocated more of their responses to the less punished alternative, suggesting they find punishment more, rather than less, aversive than typically developing children. This result differs from the findings of gambling studies reporting either no group differences or reduced sensitivity to penalties in children with ADHD (Groen, Gaastra, et al., 2013). Paradigm differences most likely give rise to these discrepancies. In this study, the availability and magnitude of reward was consistent across response alternatives, the probability of punishment was the only difference between games. The children were not required to make complex cognitive choices involving a trade-off between the likelihood, magnitude or delay of reward and punishment. The contingency arrangements in our paradigm allowed a more direct examination of the behavioral effects of punishment.

Other important aspects of this paradigm include the absence of a skill component and the use of positive punishment. We wished to avoid task difficulty confounding the findings through ceiling effects, or differentially affecting motivation. The study included positive punishment (laughing sounds) as well as response cost, whereas most previous studies include response cost only. Anecdotal reports indicate the children found the laughter punishing, although the extent this contributed to the current findings is not clear. Future research should systematically examine how the form and level of negative (e.g., response cost) and positive (e.g., laughter) punishment impacts behavior change.

While making an important contribution toward understanding the behavioral sensitivity of children with ADHD to punishment, the study has limitations. Children in the ADHD group were recruited in two different countries, those in the control group from one country only, introducing a possible confound to the data. However, the same diagnostic and inclusion criteria were applied at both sites and all assessments supervised by the same senior author. Furthermore, repeating the analyses including only participants recruited in New Zealand did not change the findings. The proportion of children with inattentive type ADHD and the number prescribed medication for symptom management, suggests a sample of moderate severity. The number prescribed medication also reflects that for many children this was their first detailed assessment for ADHD. Generalization of the findings to those with more severe clinical presentation may require caution. However, all children in the ADHD group demonstrated sufficient symptoms and functional impairment to meet DSM-IV diagnostic criteria. The children in the ADHD group were older than the controls on average. Age was correlated with a smaller bias toward the less punished alternative, suggesting a possible developmental trajectory in punishment sensitivity. Interestingly, the behavior of children with ADHD was controlled more by punishment despite their older average age. Future studies might examine whether punishment sensitivity normalizes with development in children with ADHD.

The study also has a number of strengths that increase our confidence in the findings. Diagnoses of ADHD were made according to best practice guidelines and behavioral and emotional difficulties were ruled out in the control group. The number of children prescribed medication was relatively low and all were medication free for the study. Final sample sizes are adequate, IQ estimates are similar across groups, and rates of comorbid disorders in the ADHD group are low. The latter is important in attributing group differences to ADHD. In addition, the paradigm has some ecological validity in offering the children competing response alternatives operating under different contingencies, a common occurrence in daily life, for example, persisting with a frustrating math problem versus playing with the ponytail of the girl sitting in front, listening to the teacher versus chatting to a classmate, or rushing to complete work versus taking time to respond carefully. While some caution is warranted in generalizing findings from the laboratory to everyday situations (Borrero et al., 2010), especially with a new task, concurrent schedules and the generalized matching law have a long history in the assessment of response allocation in animals and humans (e.g., Baum, 1975, 1979). In future studies, operant procedures might be adapted to examine the effects of punishment on subsequent behaviors in more naturalistic settings.

Clinical implications

Avoidance of punishment increased over time in the children with ADHD, resulting in missed opportunities for reward and overall poorer 'outcomes'. These findings may help explain lack of persistence in children with ADHD for tasks that are annoying, frustrating or aversive. Our data predict that children with ADHD are more likely to avoid, or escape from, such tasks. With increased exposure, these activities may be more 'punishing' for children with ADHD than for typically developing children.

The current findings also argue against increased use of punishment in children with ADHD in managing or shaping their behavior. They may focus more on avoiding punishment, distracting them from, or reducing their engagement in, desirable behavior that would lead to better outcomes. Worland (1976) reported negative consequences reduced off-task behavior, but also task accuracy, in hyperactive boys. Punishment may reduce undesirable behaviors in the short-term; however, its long-term use may have unanticipated and unwanted side effects in children with ADHD.

While the use of positive reinforcement is emphasized in behavior modification programs, it is unlikely that punishment is completely eliminated from discipline practices. Researchers and clinicians need to establish best practices guidelines for use of negative consequences with children with ADHD. This is especially important given children with ADHD are more likely to engage in behaviors judged inappropriate by others, increasing the likelihood that punishment will be applied. While acknowledging the preliminary nature of our findings, we make the following suggestions. Efforts should be made to reduce the extended use of punishment as much as possible. To this end, caregivers and teachers need be encouraged to make rules and consequences explicit for children with ADHD (Alsop et al., 2016), with nonpunitive calmly presented reminders, as necessary. Immediate and frequent reinforcement of appropriate behavior is urged to help prevent, or replace, undesirable behavior. When punishment is necessary to reduce unacceptable behavior quickly, its behavioral and emotional effects require careful monitoring, with redirection to, and positive reinforcement of, alternative behaviors provided. Tasks or activities that arrange rewards for correct responses and costs for incorrect responses need to maintain sufficient levels of reinforcement to ensure children do not abandon these activities. The selection of everyday and academic tasks appropriate to the child's ability level is important to create opportunities for success. Positive consequences for effortful and frustrating tasks need to be highly salient. These recommendations are not specific to children with ADHD. However, children with ADHD may benefit more than typically developing children from the carefully balanced use of reward and punishment.

Conclusions

Under conditions of equal reward availability, unequal probability of punishment biases responding toward the less frequently punished response alternative. With increased exposure to the contingences, punishment exerts greater control over the behavior of children with ADHD than controls. Individual instances of punishment appear to have greater emotional and attentional consequences for children with ADHD. This study provides evidence that the behavior of children with ADHD is more, rather than less, sensitive to the effects of punishment than typically developing children. These findings argue for further investigation of the behavioral and emotional effects of punishment in children with ADHD.

Supporting information

Additional Supporting Information may be found in the online version of this article:

Table S1. Characteristics of ADHD participants recruited in New Zealand and Japan.

Table S2. Means and standard errors for response bias toward the less punished game, response times, and points won and lost for ADHD participants in New Zealand and Japan.

Table S3. Means and standard errors for proportion of stays and response times following each trial type for ADHD participants in New Zealand and Japan.

Appendix S1. Supplemental method and results.

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Key points

- The behavioral sensitivity of children with ADHD to punishment is poorly understood.
- Using a choice task, we demonstrate punishment exerts greater control over response allocation in children with ADHD compared with controls.
- Children with ADHD are more, not less, sensitive to the cumulative effects of punishment than typically developing children.
- In acting to avoid punishment, children with ADHD miss opportunities to engage in rewarding behavior.
- Long-term use of punishment in children with ADHD may be detrimental.

Notes

1. Results were unchanged when data from these three children were excluded from the analyses.
2. A correction factor was applied to the data when a participant never stayed after a particular outcome type. A value of 0.5 was added to instances of zero. Four participants (ADHD = 3) never stayed after a win and 8 (ADHD = 5) never stayed after a loss. The results remain unchanged if these data are treated as missing.

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