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Does reward frequency or magnitude drive reinforcement-learning in attention-deficit/hyperactivity disorder?

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ABSTRACT

Children with attention-deficit/hyperactivity disorder (ADHD) show an impaired ability to use feedback in the context of learning. A stimulus-response learning task was used to investigate whether (1) children with ADHD displayed flatter learning curves, (2) reinforcement-learning in ADHD was sensitive to either reward frequency, magnitude, or both, and (3) altered sensitivity to reward was specific to ADHD or would co-occur in a group of children with autism spectrum disorder (ASD). Performance of 23 boys with ADHD was compared with that of 30 normal controls (NCs) and 21 boys with ASD, all aged 8–12. Rewards were delivered contingent on performance and varied both in frequency (low, high) and magnitude (small, large). The findings showed that, although learning rates were comparable across groups, both clinical groups committed more errors than NCs. In contrast to the NC boys, boys with ADHD were unaffected by frequency and magnitude of reward. The NC group and, to some extent, the ASD group showed improved performance, when rewards were delivered infrequently versus frequently. Children with ADHD as well as children with ASD displayed difficulties in stimulus–response coupling that were independent of motivational modulations. Possibly, these deficits are related to abnormal reinforcement expectancy.

1. Introduction

In children with attention-deficit/hyperactivity disorder (ADHD), there is evidence of impaired ability to use feedback in the context of learning. This is observed in an impaired ability in ADHD to detect errors as indicated by decreased electrophysiological brain potentials associated with error processing in response-inhibition tasks (Liotti et al., 2005; Van Meel et al., 2007). In addition, children with ADHD have been found to show an inability to adjust behaviour following errors as indicated by reduced post-error response time slowing (Sergeant and Van der Meere, 1988; Wiersema et al., 2005). Further, children with ADHD show an impaired feedback monitoring as indicated by decreased heart rate responses following performance feedback (Luman et al., 2007). All these reports, however, measured behaviour in tasks where the appropriate response was well established. Studies on the acquisition of new behaviour in children with ADHD remain scarce.

In the process of learning, reinforcement plays a significant role, since contingencies such as reward and punishment that follow behavioural responses increase or decrease the chance of repetition of that behaviour (Schultz, 2000; Wise, 2004). Physiologically, this reinforcement-learning is mediated by dopamine, which facilitates learning by 'stamping in' stimulus–response associations (Wise, 2004). Children with ADHD compared with normal controls (NCs) show an abnormal sensitivity to reinforcement, as demonstrated by an intensified response to recently received rewards, while being less responsive to more distant rewards (Sonuga-Barke et al., 1992; Tripp and Alsop, 1999). A review of the impact of reinforcement on cognitive task performance in ADHD revealed some evidence that appropriate motivational stimulation (such as reward or response cost) may improve cognitive functioning to a larger extent in children with ADHD than in controls (Luman et al., 2005). The studies in that review, however, all assessed the impact of reinforcement on established responses. Learning of new behaviour using reinforcement contingencies is likely to be impeded in children with ADHD, due to their abnormal response to reinforcement.

According to Sagvolden and colleagues (2005), the behaviour that characterizes ADHD can be explained by hypo-dopaminergic functioning in the fronto-striatal pathway. As a consequence, children with ADHD compared with healthy controls should show a faster decay of reward that influences reinforcement-learning through an inefficient stimulus–response coupling, specifically when reinforcement is delivered infrequently (Johansen et al., 2002; Sagvolden et al.,

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2005). Indeed, in ADHD children frequent compared with infrequent rewards decreased the variability of responding (Aase and Sagvolden, 2006), increased response speed in a Figure Matching task (Douglas and Parry, 1994), and improved decision-making abilities in the face of reinforcement (Toplak et al., 2005). Other studies, however, have failed to replicate a detrimental effect of infrequent reinforcement in ADHD (Barber et al., 1996; Pelham et al., 1986; Tripp and Alsop, 1999). An issue in the studies on reinforcement frequency and ADHD is that most studies did not distinguish whether reward frequency or reward magnitude modulated the behaviour of children with ADHD, since frequent rewards are necessarily associated with a larger amount of reward. It has been shown that increasing the magnitude of reinforcement (penalty) significantly ameliorated inhibitory deficits in ADHD in a Stop Task paradigm (Slusarek et al., 2001). Together, these studies show some support for the view that performance in ADHD is affected by the intensity of reinforcement rather than the time interval between stimulus and reward, as suggested by Sagvolden et al. (2005). The need for intense reinforcement concurs with the suggestion of Haenlein and Caul (1987) that children with ADHD suffer from a decreased sensitivity to reinforcement as a result of an elevated reward threshold. This elevated reward threshold would explain why children with ADHD need either immediate or larger, or more frequent rewards in order to profit from reinforcement in a similar way to controls.

Consequently, the goal of the current study was three-fold. Firstly, the present study investigated whether children with ADHD demonstrate reinforcement-learning problems as reflected by slower acquisition rates during a stimulus–response learning task. Secondly, this study independently assessed the impact of frequency and magnitude of reinforcement on stimulus–response learning, testing the model of Sagvolden et al. (2005) and of Haenlein and Caul (1987). Third, the specificity of reinforcement-learning problems in children with ADHD was examined by comparing the performance of the ADHD group with the performance of a clinical control group: A group of children with a primary clinical diagnosis of autism spectrum disorder (ASD). Unlike children with ADHD, children with ASD are characterized by problems in communication as well as stereotypical patterns of behaviours and interests (American Psychiatric Association; APA, 2000). An ASD group is included since there may be overlap in the occurrence of ADHD and ASD (APA, 2000) and the brain areas that are suggested to be involved in motivational problems in ADHD (the fronto-striatal circuit, see Sagvolden et al., 2005) are exactly those that are suggested to be associated with ASD (e.g., Bachevalier and Loveland, 2006; Mundy, 2003). In addition, both groups show problems with cognitive control that are as severe or even more severe in ASD than ADHD (Geurts et al., 2004; Happé et al., 2006). Motivational abnormalities in children with ASD have been reported: children with ASD showed less efficient learning of contingencies compared with healthy controls in a decision-making paradigm (Johnson et al., 2006) and performed more similarly to healthy controls, when performance in a sustained attention task was coupled to tangible reinforcers (Garretson et al., 1990). In contrast, Antrop et al. (2006) demonstrated that, when children had to choose between a small immediate reward and a large delayed reward, children with ASD (unlike children with ADHD) did not differ from healthy control children in their choice behaviour. Thus, there is some evidence for motivational problems in children with ASD.

Reinforcement-learning was investigated by examining the accuracy and speed of response acquisition. Children with ADHD were expected to show impaired response acquisition reflected by flatter learning curves. If children with ADHD are dependent on frequent reinforcement in order to perform accurately, one would expect an effect of reinforcement frequency. Conversely, if children with ADHD require more intense reinforcement than controls, they would be expected to perform optimally under intense reinforcement, showing an effect of reinforcement magnitude. To check whether children were aware of the reinforcement manipulations, children completed a visual analogue scale following each condition, registering children's subjective experience of their gain. If children in the ASD group suffer from motivational problems like those of children with ADHD, no group difference in impact of reward on reinforcement-learning would be expected.

2. Method

2.1. Participants and selection procedure

Seventy-four boys between the ages of 8 to 12 participated in this study: 23 boys with ADHD, 21 with ASD and 30 normal controls (NCs) (see Table 1 for background information). Children in the ADHD and ASD groups were recruited from special educational services, through

Table 1
Age, IQ, rating scale scores and pairwise group comparisons.

Measure	Group ADHD (n=23) M	ADHD S.D.	ASD (n=21) M	ASD S.D.	NC (n=30) M	NC S.D.	F (2,71)	Group contrasts
Age in years	9.9	1.5	10.0	1.6	9.4	1.0	1.1	
IQ score	98.1	12.7	102.1	15.6	103.4	14.3	0.9	
Children on stimulant medication in %	78%		14%		0%		–	
DBD parents								
Inattention	16.8	6.7	15.2	5.8	2.3	2.7	62.9**	ADHD, ASD>NC
Hyperactivity/impulsivity	16.5	5.2	13.0	7.3	2.9	2.9	43.3**	ADHD>ASD>NC
ODD	8.7	5.0	7.2	5.2	1.8	2.5	8.9**	ADHD, ASD>NC
CD	2.2	2.5	1.6	2.4	0.3	0.7	6.1*	ADHD, ASD>NC
DBD teacher[1]								
Inattention	11.7	6.9	10.9	6.0	2.1	3.6	23.9**	ADHD, ASD>NC
Hyperactivity/impulsivity	11.0	7.3	8.8	7.6	1.6	2.5	18.1**	ADHD, ASD>NC
ODD	5.9	5.7	5.0	5.2	0.6	1.7	11.7**	
CD	1.7	2.2	1.5	2.9	0.3	1.7	2.6	
CSBQ total score[2]	33.1	11.4	47.8	16.3	9.9	10.1	49.0**	ASD>ADHD>NC

Note. ADHD = attention-deficit/hyperactivity disorder; ASD = autism spectrum disorder; CSBQ = Children's Social Behavior Questionnaire; CD = conduct disorder; DBD = Disruptive Behavior Disorder Rating Scale; NC = normal controls, ODD = oppositional defiant disorder.
[1]DBD teacher ratings of 4 children were missing (1 ADHD, 1 NC, 2 ASD); [2]CBSQ ratings of 8 children were missing (2 ADHD, 6 NC).
*$P<0.01$, **$P<0.001$.