



The impact of reinforcement contingencies on AD/HD: A review and theoretical appraisal

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Abstract

One of the core deficits in attention deficit/hyperactivity disorder (AD/HD) is thought to be an aberrant sensitivity to reinforcement, such as reward and response cost. Twenty-two studies ($N=1181$ children) employing AD/HD and reinforcement contingencies are reviewed from vantage points: task performance, motivation, and psychophysiology. Results indicate that reinforcement contingencies have a positive impact on task performance and levels of motivation for both children with AD/HD and normal controls. There is evidence that the effect related to task performance is somewhat more prominent in AD/HD. There is some evidence that a high intensity of reinforcement is highly effective in AD/HD. Children with AD/HD prefer immediate over delayed reward. From a psychophysiological point of view, children with AD/HD seem less sensitive to reinforcement compared to controls. While comorbid disorders are suggested to be confounders of the dependent variables, many studies do not examine the effect of oppositional defiant disorder (ODD) and conduct disorder (CD). We discuss the implications of the findings for five theoretical frameworks, including the model by Haenlein and Caul (1987), Douglas (1999), the cognitive-energetic model (CEM) (Sergeant et al., 1999), the dual-pathway model (Sonuga-Barke, 2003) and the BIS/BAS model (Quay, 1988a,b,c). Results show a discrepancy between the theoretical models and the behavioural findings.

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1. Introduction

Attention deficit/hyperactivity disorder (AD/HD) is one of the most prevalent psychiatric disorders in children and adolescents, characterized by inattentive, hyperactive, and impulsive behavior ([American Psychiatric Association, 1994](#)). In several theoretical explanations, AD/HD is thought to be associated with an aberrant sensitivity to reinforcement, including reward, punishment, and reinforcement schedules (e.g., manipulation of reinforcement frequency and delays in reinforcement administration) ([Douglas, 1989](#); [Haenlein & Caul, 1987](#); [Quay, 1988a, 1988b, 1988c](#); [Sagvolden, Johansen, Aase, & Russell, in press](#); [Sagvolden & Sergeant, 1998](#); [Sergeant, Oosterlaan, & Van der Meere, 1999](#); [Sonuga-Barke, 2002](#); [Wender, 1972](#)). Since reinforcement is highly associated with motivation, research suggests that an unusually low level of effort or intrinsic motivation accounts for the performance deficits in children with AD/HD ([August, 1987](#); [Barber, Milich, & Welsch, 1996](#); [Borcherding et al., 1998](#); [Sergeant & Van der Meere, 1990](#); [Van der Meere, Hughes, Börger, & Sallee, 1995](#); [Wilkison, Kircher, McMahon, & Sloane, 1995](#)). For example, without supervision or when tasks are extremely boring, the attention span of children with AD/HD is very limited ([Van der Meere, Shalev, Börger, & Gross-Tsur, 1995](#)).

[Haenlein and Caul \(1987\)](#) suggested that children with AD/HD have an elevated reward threshold and, therefore, require higher rates of reinforcement compared to normal children. They hypothesized that children with AD/HD, compared to normal children, perform poorer under partial and delayed reinforcement, since the intensity of reward in these conditions is lower compared to conditions of continuous and immediate reinforcement.

[Johansen, Aase, Meyer, and Sagvolden \(2002\)](#), [Sagvolden, Aase, Zeiner, and Berger \(1998\)](#), [Sagvolden and Sergeant \(1998\)](#), and [Sagvolden et al. \(in press\)](#) claimed that the main symptoms of AD/HD are caused by a deficit in reinforcement processes, in part, due to a hypoefficient central nervous dopaminergic system. According to [Sagvolden et al. \(in press\)](#), children with AD/HD have a shorter and steeper delay-of-reinforcement gradient. The delay gradient describes the time interval between the response and reinforcer and its relation to the impact of a reinforcer. The reinforcing effect is largest, when the reinforcer is delivered immediately after the response. In children with AD/HD, unlike normally developing peers, only responses in close proximity to a reinforcer will be conditioned. In addition, relatively few correct responses between the delivery of two consecutive reinforcers will be maintained. As a result, the association between response and reinforcer will be less consistent and ‘sustained attention’ will be impaired. When reinforcers are powerful and frequent, however, the differences in behavior between children with AD/HD and controls are expected to be minimal.

[Douglas \(1989, 1999\)](#) and [Douglas and Parry \(1994\)](#) suggested that children with AD/HD are unusually sensitive to reward and suffer from a heightened frustration level in response to the loss of anticipated rewards. Because of the heightened frustration level, performance of children with AD/HD is predicted to deteriorate under conditions of partial compared to continuous reward.

Another theoretical position was offered by [Quay \(1988a, 1988b, 1988c, 1997\)](#) who tried to explain AD/HD symptoms in terms of [Gray’s \(1982, 1987\)](#) psychobiological theory of learning and emotion. Gray developed a theory in which three collaborative brain systems modulate behavior. The two most relevant here are the behavioral activation system (BAS), which involves the dopaminergic pathway, nucleus accumbens, and ventral striatum, and the behavioral inhibition system (BIS), which is located in the septo-hippocampal system. The BAS, according to Gray, is activated by conditions of reward, and initiates approach behavior and active avoidance. The BIS is activated by conditions of punishment and nonreward, and interrupts ongoing or anticipated motor behavior. A third system, called the nonspecific

arousal system (NAS), is activated by both the BIS and the BAS, and acts to increase the intensity (speed/force) of behavior. According to Quay (1988a, 1988b, 1988c), in normal children, the BIS and the BAS cooperate with one another to meet situational demands. For example, when response inhibition is required, the BIS is activated and temporarily predominates over the BAS. Quay argued that children with AD/HD have difficulty in inhibiting ongoing and anticipated motor behavior because of an underactive BIS. Furthermore, Quay argued that children with AD/HD are less responsive to signals of punishment and nonreward.

Fowles (1987) reviewed psychophysiological experiments that provide evidence of two independent psychophysiological measures supporting Gray's psychobiological theory of learning and emotion. Fowles (1980, 1987) noted evidence for increased heart rate in normal adults in the face of appetitive stimuli and signals of reward. On the basis of these findings, Fowles proposed that heart rate reflects activity in the BAS. In contrast, skin conductance responses increase in the face of aversive stimuli and signals of punishment, and are unaffected by appetitive or rewarding stimuli. The changes in skin conductance were suggested to reflect activity in the BIS.

The role of reinforcement has been examined by Sonuga-Barke (2002), who proposed a dual-pathway model of AD/HD in which he recognized two distinct subtypes of the disorder. One subtype is associated with diminished inhibitory control. The other subtype is characterized by a motivational style, in which children with AD/HD show aversion to delayed reinforcement, associated with fundamental alternations in reward mechanisms. Children with AD/HD were hypothesized to rate immediate rewards as more and future rewards as less valuable compared to control children. Sonuga-Barke acknowledged Sagvolden et al.'s (1998) theory concerning a steeper and shorter delay-of-reinforcement gradient in AD/HD, as evidence of delay aversion.

In contrast, Sergeant et al. (1999) hypothesized that children with AD/HD suffer from a nonoptimal energetic state explained in terms of the cognitive–energetic model (CEM). This model is based on the assumption that information processing is influenced by both computational (process) factors and state factors such as *effort*, *arousal*, and *activation* (Sanders, 1983; Sergeant, 2000; Sergeant & Scholten, 1985; Sergeant & Van der Meere, 1990; Sergeant et al., 1999). The effort pool controls the state of the lower layers of the model, namely, the arousal and activation pool. Effort (which is related to motivation) is conceived as the energy necessary to meet the demands of the task. Reinforcement contingencies are presumed to have their influence on this pool. The highest level of the CEM is a monitoring system, which is sensitive to 'knowledge of results.' According to the CEM, if children with AD/HD suffer from a deficit in the effort pool, performance may be poor due to a nonoptimal energetic state. Since reinforcement is expected to activate the effort pool, reinforcement will induce the necessary energy to meet the task demands. As a result, performance on cognitive tasks improves.

In addition, from a clinical perspective, children with AD/HD are described as benefiting from reinforcement contingencies. In several behavioral modification programs, reinforcement has proven to be highly effective in the treatment of AD/HD (Barkley, 2002). Reinforcement contingencies are found to normalize behavior that characterizes AD/HD in school, sports, and home settings, and to improve academic functioning (Hupp, Reitman, Northup, O'Callaghan, & LeBlanc, 2002; Kelly & McCain, 1995; Pelham et al., 1993; Pelham & Hinshaw, 1992; Rapport, Murphy, & Bailey, 1982). These findings further emphasize the role of reinforcement contingencies in AD/HD.

Given the heterogeneous findings related to AD/HD and reinforcement contingencies, on one hand, and, on the other hand, the emphasis on reinforcement in several accounts, there is a clear call for a review of the literature related to the impact of reinforcement on AD/HD. The aim of this paper is to

review the literature regarding sensitivity of children with AD/HD to environmental contingencies, such as reward, punishment, and reinforcement schedules. First, we will provide an extensive overview of the studies that have focused on task performance, motivation level, and psychophysiology of children with AD/HD under reinforcement contingencies. Since the publication of the hallmark article by Douglas and Peters (1979), such an attempt has not been made. Secondly, we wish to investigate whether the findings fit into the models encompassing reinforcement contingencies as a central aspect for the theoretical explanations of AD/HD; we will focus on possible shortcomings within this field of research.

1.1. Organization of this review

We will compare the performance of children with AD/HD and normal controls on different tasks that measure cognitive processing (e.g., inhibition) and response output (e.g., reward choice behavior) under various reinforcement conditions. Next, since motivation and reinforcement are thought to be highly associated (e.g., Sergeant et al., 1999), we will specify the role of motivation. We review psychophysiological measures of heart rate (interbeat interval) and skin conductance (skin conductance level and response) under different reinforcement conditions. These measures may provide us with evidence whether children with AD/HD suffer from diminished BIS activity as suggested by Quay (1988a, 1988b, 1988c).

Given the heterogeneous findings in the literature concerning AD/HD and reinforcement contingencies, it seems important to acknowledge possible confounding variables that can influence the results. AD/HD is highly associated with oppositional defiant disorder (ODD) and conduct disorder (CD) (Angold, Costello, & Erkanli, 1999), and the impact of the possible confounding effects of ODD and CD on the findings are reviewed. ODD and CD were combined because ODD is frequently found to be a developmental antecedent of CD, and because ODD is generally considered a milder form of CD (APA, 1994).

Another important potential confounder may be reinforcement allocation policy. This policy concerns whether reinforcement allocation is based on task performance or whether it is based on task participation (irrespective of response accuracy). The expectancy related to reinforcement occurrence may differ between the two policies, which, according to Schultz (2000), may influence the rate of reinforcement learning and task performance.

Important possible confounders are the specific characteristics of the reinforcer that differ between studies reviewed here. It is acknowledged that neurons in the amygdala seem to be involved in processing the intensity of reinforcement (Schultz, 2000). Neurons in the orbitofrontal cortex, in contrast, can discriminate between different forms of reinforcement, such as liquid or solid reward (Schultz, 2000, 2002). Since AD/HD is associated with a deficiency in the orbitofrontal area (Barkley, 1997) and the mesolimbic system (Quay, 1988a, 1988b, 1988c; Sonuga-Barke, 2002, 2003), children with AD/HD may be differentially affected by different intensities and forms (e.g., money, tokens, and presents) of reinforcement. Finally, the impact of AD/HD subtypes, gender, age, and IQ is discussed.

2. Qualitative overview of studies concerning AD/HD, task performance, and reinforcement contingencies

This review covers 22 studies published between 1986 and February 2003, which includes 1181 children. The studies were located in PubMed (Medline), PsycINFO, and ISI Web of Knowledge

databases. We searched for empirical studies that investigated primarily the effect of reinforcement contingencies on task performance of children with AD/HD. We searched for studies that investigated the effects of reinforcement contingencies on measures of motivation and psychophysiology. We combined search terms related to AD/HD (such as AD/HD, hyperactive, and attention) with search term related to reinforcement (such as reward, punishment, response cost, reinforcement, feedback, and contingencies). The reference lists of published articles were used to locate additional relevant studies.

Dissertations, abstracts, as well as clinical studies were not included. In addition, studies that included less than 10 subjects in one of the groups of interest were excluded from this review. Furthermore, studies conducted before 1986 were excluded because of changes in the diagnostic criteria for AD/HD, related to the emergence of the third revised edition of Diagnostic and Statistical Manual of Mental Disorders (DSM III-R). Finally, studies that focused on the perception of reward and response cost and imaging studies that did not report performance data were excluded. The main features of the 22 studies are summarized in [Table 1](#).

Twenty studies in this review compared an AD/HD group with a group of normally developing children (control group) without a psychiatric or learning disorder. Two studies did not include a control group, but compared the performance of children with AD/HD on and off medication ([Pelham, Milich, & Walker, 1986](#); [Wilkison et al., 1995](#)). In three studies included in this review ([Daugherty & Quay, 1991](#); [Oosterlaan & Sergeant, 1998](#); [Sonuga-Barke, Taylor, Sembi, & Smith, 1992](#)), the children in the psychiatric groups were not diagnosed according to DSM III, DSM III-R, or DSM IV criteria, in contrast with the remaining 19 studies.

Although all the studies discussed in this review investigated the effects of reinforcement contingencies in AD/HD, the authors adopted five different approaches to study the effects (see [Table 1](#)). A first approach was to compare reward with nonreward conditions; to compare reward with response cost conditions; to compare reward, response cost, and nonreward conditions; and also to compare mixed reward and response cost with feedback-only conditions. In a second approach, continuous reward schedules were compared to partial reward schedules. In a third approach, reward delay was manipulated. A fourth approach was to study an altered response to reward by manipulating the reward ratio. Changes in the intensity of reward were studied in a fifth approach.

A variety of tasks that study cognitive processing and tasks that study response output were used (e.g., Arithmetic Task, Continuous Performance Task, Choice-Delay Task, Paired Associate Memory Task, Repetitive Motor Task, and a Stop Signal Task). These tasks capture different aspects of cognitive functioning, such as vigilance, working memory, inhibition, perseveration, abstract reasoning, and stimulus detection. Other tasks focus more on aspects of response output such as reward choice behavior. To overcome the problem of heterogeneity in task performance, we focus exclusively on the absolute change in task performance reflected by different dependent measures. This measurement is independent of specific cognitive functions or reward choice studied in this review.

3. Task performance

Performance of children with AD/HD under several different ‘reinforcement conditions’ is compared in this section. Reinforcement conditions refer to the different experimental conditions under which task

Table 1
Experimental studies concerning AD/HD, task performance, and reinforcement contingencies

Study by	Subjects	Age	Confounding variables ^a	Dependent variables	Reinforcement manipulation ^b	Differential group effects ^c
(1) Barber et al. (1996)	45 ADHD 45 NC	7–10	<ul style="list-style-type: none"> • <i>Comorbid</i>: CD, ODD • <i>Not confounding</i>: age, gender, IQ as covariate 	Related and unrelated paired associate memory task • % Correct	<ul style="list-style-type: none"> • Tokens cashed for money • Reward delivered on a trial basis • Contingent upon performance • <i>Conditions</i>: CR versus PR (50%) versus NR • Between-subjects design, subjects randomly assigned to the tasks and conditions • Quantity of reward equal for both groups 	• % Correct:–
(2) Carlson et al. (2000)	40 ADHD 40 NC	8–12	<ul style="list-style-type: none"> • <i>Comorbid</i>: CD, ODD • <i>Possible confounding</i>: age, gender, IQ 	Arithmetic task • % Correct • Self-rated motivation • Observed motivation	<ul style="list-style-type: none"> • Tokens cashed for money • Continuous reward on a trial basis • Contingent upon performance • <i>Conditions</i>: R versus RC versus NR • Between-subjects design, subjects randomly assigned to one of the conditions 	<ul style="list-style-type: none"> • % Correct ADHD: R<RC; NC:– • % Correct R and NR: ADHD<NC; RC:– • Self-rated motivation ADHD: R>NR; NC: R, RC>NR • Observed motivation ADHD: RC>R, NR; NC:–
(3) Carlson and Tamm (2000)	22 ADHD (combined subtype) 22 NC	8–10	<ul style="list-style-type: none"> • <i>Comorbid</i>: CD, ODD • <i>Not confounding</i>: age, gender, IQ 	Figure Matching task and Jet Pack (game-like task) • % Correct • Self-rated motivation • Observed motivation	<ul style="list-style-type: none"> • Immediate money • Continuous reward on a trial basis • Contingent upon performance • <i>Conditions</i>: R versus RC versus NR • Within-subjects design, order tasks and conditions balanced 	<ul style="list-style-type: none"> • % Correct ADHD: R, RC>NR; NC:– • % Correct R and NR: ADHD<NC; RC:– • Self-rated and observed motivation:–

(4) Crone et al. (2003)	22 ADHD 22 NC	6–12	<ul style="list-style-type: none"> • <i>Possible confounding:</i> ODD • <i>Not confounding:</i> age, CD, gender, LD IQ as covariate 	Go/No-go flanker task <ul style="list-style-type: none"> • % Correct • MRT • Heart rate • Skin conductance 	<ul style="list-style-type: none"> • Tokens cashed for money • Reward delivered on a trial basis • Contingent upon performance • <i>Conditions:</i> CR versus R (66%) and RC (33%) versus R (50%) and RC (50%) • Within-subjects design, conditions presented in a fixed order 	<ul style="list-style-type: none"> • % Correct ADHD: CR>R (66%)>R (50%); NC:– • % Correct R/RC: not reported • MRT • Heart rate: see text • Skin conductance:–
(5) Daugherty and Quay (1991)	10 ADD+H CD 9 ADD 10 CD 9 ID 15 NC	8–13	<ul style="list-style-type: none"> • <i>Comorbid:</i> CD • <i>Possible confounding:</i> IQ, ODD • <i>Not confounding:</i> age, gender, ID 	Door opening task (response perseveration task) <ul style="list-style-type: none"> • Amount of responses • Amount of tokens 	<ul style="list-style-type: none"> • Tokens exchanged for presents • Partially rewarded on a trial basis • Contingent upon quantity of responses • <i>Condition:</i> Chance on reward decreases from 90% to 0%, RC random 	<ul style="list-style-type: none"> • Amount of responses: ADD+H/CD, CD>NC, IC • Number of earned tokens: ADD+H/CD, CD<NC
(6) Douglas and Parry (1994)	30 ADD+H 30 NC	Range not reported	<ul style="list-style-type: none"> • <i>Possible confounding:</i> age, CD, gender, IQ, ODD 	Penny tossing task <ul style="list-style-type: none"> • Response Time (RT) (<i>attention measure</i>) • Lever-pulling force (<i>frustration measure</i>) 	<ul style="list-style-type: none"> • Tokens exchanged for presents • Reward delivered on a trial basis • Contingent on the quantity of responses • <i>Conditions:</i> CR versus PR (50%) versus PR (30%) NR following each R condition • Between-subjects design, subjects randomly assigned to one of the conditions 	<ul style="list-style-type: none"> • RT for NC: CR>PR; ADD+H:– • RT under PR: ADD+H>NC; under CR and NR:– • Lever pulling force ADD+H or NC:– • Lever pulling force CR and PR (50%):– ; PR (30%): ADD+H>NC • Lever pulling force NR following CR: ADD+H>NC, other NR:–

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Table 1 (continued)

Study by	Subjects	Age	Confounding variables ^a	Dependent variables	Reinforcement manipulation ^b	Differential group effects ^c
(7) Iaboni et al. (1995)	19 ADHD 17 NC	8–13	<ul style="list-style-type: none"> • <i>Comorbid</i>: CD, ODD • <i>Not confounding</i>: age, IQ, gender (boys only) 	Go/no-go discriminative learning task <ul style="list-style-type: none"> • MRT • Omission errors • Commission errors 	<ul style="list-style-type: none"> • Immediate money • Continuous reward on a trial basis • Contingent upon performance • <i>Conditions</i>: for accuracy on Go and No-go trials, respectively: R-R versus RC-RC versus R-RC versus RC-R • Within-subjects design, conditions presented in a random order 	<ul style="list-style-type: none"> • MRT for ADHD: RC<R; NC:– • MRT under R and RC: not reported • Commission and omission errors :–
(8) Iaboni et al. (1997)	18 ADHD 18 NC	8–13	<ul style="list-style-type: none"> • <i>Comorbid</i>: CD, ODD • <i>Not confounding</i>: age, IQ gender (boys only) 	Repetitive motor task <ul style="list-style-type: none"> • RT • Heart rate • Skin conductance 	<ul style="list-style-type: none"> • Immediate money • Continuous reward on trial basis • Contingent upon performance • <i>Conditions</i>: R versus NR • Within-subjects design, conditions presented in a fixed order • Quantity reward equal for both groups 	<ul style="list-style-type: none"> • RT:– • Heart rate: see text • Skin conductance level: ADHD:– ; NC: R<NR
(9) Konrad et al. (2000)	31 ADHD 37 TBI 26 NC	8–12	<ul style="list-style-type: none"> • <i>Possible confounding</i>: CD, gender, ODD • <i>Not confounding</i>: AD/HD subtypes, age, IQ, LD 	Stop task <ul style="list-style-type: none"> • SSRT • MRT 	<ul style="list-style-type: none"> • Tokens exchanged for presents • Continuous reward on a trial basis • Contingent upon performance • <i>Conditions</i>: R versus NR • Between-subjects design, subjects randomly assigned to one of the conditions after receiving a practice (NR) condition first • Quantity of reward equal for all subjects 	<ul style="list-style-type: none"> • MRT:– • SSRT under R: ADHD, NC<TBI; NR: NC<ADHD, TBI • SSRT in the different groups:–

(10) McNerny and Kerns (2003)	30 ADHD 30 NC	6–13	<ul style="list-style-type: none"> • <i>Possible confounding:</i> CD, ODD • <i>Not confounding:</i> age, gender, IQ 	Time reproduction task <ul style="list-style-type: none"> • Absolute error • Accuracy quotient • Self-rated motivation 	<ul style="list-style-type: none"> • Tokens exchanged for presents • Continuous reward on a trial basis • Noninformative feedback and reward • <i>Conditions:</i> feedback and R versus NR • Within-subjects design, order of the conditions balanced • Quantity of reward and feedback equal for all subjects • Tokens exchanged for presents • Continuous reward on a trial basis • Contingent upon performance • <i>Conditions:</i> R versus RC • Within-subjects design, conditions presented in a random order • Quantity of reward equal for all subjects • Tokens exchanged for presents • Reward delivered on a trial basis • Contingent upon performance • <i>Conditions:</i> CR versus PR (50%) versus NR MPH versus placebo • Between-subjects design, subjects randomly assigned to one of the conditions; MPH and placebo balanced within the group 	<ul style="list-style-type: none"> • Absolute error for ADHD: NR>R; NC:– • Absolute error NR: ADHD>NC; R: ADHD=NC • Accuracy: not reported • Self-rated motivation:– • Chance of inhibition:– • SSRT:– • MRT:– • Accuracy:– • Self-rated motivation:– • Number of errors:–
(11) Oosterlaan & Sergeant (1998)	14 ADHD 14 ODD/CD 14 ID 21 NC	7–13	<ul style="list-style-type: none"> • <i>Comorbid:</i> CD, ODD • <i>Possible confounding:</i> gender • <i>Not confounding:</i> age, ID, IQ 	Stop task <ul style="list-style-type: none"> • Chance of inhibition • SSRT • MRT • Accuracy • Self-rated motivation 	<ul style="list-style-type: none"> • Tokens exchanged for presents • Continuous reward on a trial basis • Contingent upon performance • <i>Conditions:</i> R versus RC • Within-subjects design, conditions presented in a random order • Quantity of reward equal for all subjects • Tokens exchanged for presents • Reward delivered on a trial basis • Contingent upon performance • <i>Conditions:</i> CR versus PR (50%) versus NR MPH versus placebo • Between-subjects design, subjects randomly assigned to one of the conditions; MPH and placebo balanced within the group 	<ul style="list-style-type: none"> • Chance of inhibition:– • SSRT:– • MRT:– • Accuracy:– • Self-rated motivation:– • Number of errors:–
(12) Pelham et al. (1986)	30 ADD	5–11	<ul style="list-style-type: none"> • <i>Possible confounding:</i> CD, ODD • <i>Not confounding:</i> age, gender, IQ 	Spelling task <ul style="list-style-type: none"> • Number of errors 	<ul style="list-style-type: none"> • Tokens exchanged for presents • Reward delivered on a trial basis • Contingent upon performance • <i>Conditions:</i> CR versus PR (50%) versus NR MPH versus placebo • Between-subjects design, subjects randomly assigned to one of the conditions; MPH and placebo balanced within the group 	<ul style="list-style-type: none"> • Number of errors:–

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Table 1 (continued)

Study by	Subjects	Age	Confounding variables ^a	Dependent variables	Reinforcement manipulation ^b	Differential group effects ^c
(13) Rapport et al. (1986)	16 ADD+H 16 NC	6–8	<ul style="list-style-type: none"> • Possible confounding: CD, ODD • Not confounding: ADHD subtypes, age, gender, IQ as covariate 	Arithmetic task <ul style="list-style-type: none"> • Reward choice 	<ul style="list-style-type: none"> • Immediate and delayed presents • Continuous reward after each condition • Contingent upon quantity of responses • Conditions: A: small immediate R or large delayed R versus B: small immediate R or large immediate R • Within-subjects design, conditions presented in a random order • Tokens exchanged for presents • Continuous reward on a trial basis • Contingent upon performance • Conditions: R versus NR • Within-subjects design, conditions presented in a random order • Quantity of reward equal for all subjects • Points as reward • Continuous reward on a trial basis • Contingent upon performance • Conditions: A: R and RC (ratio 1:1) versus B: R and RC (ratio 1: 5) • Within-subjects design, conditions presented in a random order • Quantity of reward equal for all subjects 	<ul style="list-style-type: none"> • Reward choice in A: Small immediate reward: ADD+H>NC • Reward choice in B: Small reward<large reward: ADHD=NC
(14) Scheres et al. (2001)	24 ADHD 21 ODD/CD 27 ADHD +ODD/CD 41 NC	6–12	<ul style="list-style-type: none"> • Not confounding: ADHD subtypes, age, CD, gender, ODD, IQ as covariate 	Stop task <ul style="list-style-type: none"> • % of inhibition • SSRT • Accuracy • MRT • Self-rated motivation 	<ul style="list-style-type: none"> • Tokens exchanged for presents • Continuous reward on a trial basis • Contingent upon performance • Conditions: R versus NR • Within-subjects design, conditions presented in a random order • Quantity of reward equal for all subjects • Points as reward • Continuous reward on a trial basis • Contingent upon performance • Conditions: A: R and RC (ratio 1:1) versus B: R and RC (ratio 1: 5) • Within-subjects design, conditions presented in a random order • Quantity of reward equal for all subjects 	<ul style="list-style-type: none"> • Percent of inhibition, SSRT and accuracy:– • Self-rated motivation:– • MRT: difference between R and NR condition: ADHD+ODD/CD>NC; ADHD>NC (trend) • P(I) for ADHD: A<B; CC and NC:– • P(I) in condition A: ADHD<CC, NC; condition B:– • SSRT for ADHD: A>B; CC and NC:– • SSRT in condition A: ADHD>CC, NC; condition B:–
(15) Slusarek et al. (2001)	33 ADHD (combined subtype) 33 Clinical controls (=ID, ODD, CD) 33 NC	6–14	<ul style="list-style-type: none"> • Possible confounding: gender, IQ • Not confounding: CD, ID, LD, ODD, age as covariate 	Stop task <ul style="list-style-type: none"> • P (inhibition) • SSRT 	<ul style="list-style-type: none"> • Tokens exchanged for presents • Continuous reward on a trial basis • Contingent upon performance • Conditions: A: R and RC (ratio 1:1) versus B: R and RC (ratio 1: 5) • Within-subjects design, conditions presented in a random order • Quantity of reward equal for all subjects 	<ul style="list-style-type: none"> • Percent of inhibition, SSRT and accuracy:– • Self-rated motivation:– • MRT: difference between R and NR condition: ADHD+ODD/CD>NC; ADHD>NC (trend) • P(I) for ADHD: A<B; CC and NC:– • P(I) in condition A: ADHD<CC, NC; condition B:– • SSRT for ADHD: A>B; CC and NC:– • SSRT in condition A: ADHD>CC, NC; condition B:–

(16) Solanto (1990)	20 ADD+H 18 NC	4–11	<ul style="list-style-type: none"> • <i>Comorbid:</i> CD, LD, ODD • <i>Not confounding:</i> age, gender, IQ, LD 	Delayed responding task <ul style="list-style-type: none"> • % Correct 	<ul style="list-style-type: none"> • Immediate money • Continuous reward on a trial basis • Contingent upon performance • <i>Conditions:</i> R versus RC • Within-subjects design, conditions presented in a random order, both R and RC always alternated by NR condition • Quantity of reward equal for all groups 	<ul style="list-style-type: none"> • % Correct:–
(17) Solanto et al. (1997)	22 ADHD 18 NC	6–10	<ul style="list-style-type: none"> • <i>Comorbid:</i> ID, ODD • <i>Possible confounding:</i> age, gender, IQ • <i>Not confounding:</i> CD 	Continuous performance task <ul style="list-style-type: none"> • <i>d'</i> • Hit rate 	<ul style="list-style-type: none"> • Immediate presents • Continuous reward on a trial basis • Contingent upon performance • <i>Conditions:</i> R and RC mixed versus feedback-only MPH versus placebo • Within-subjects design, conditions presented in a random order, MPH and placebo balanced 	<ul style="list-style-type: none"> • <i>d'</i> and hit rate: see text
(18) Sonuga-Barke et al. (1992)	15 Hyperactives 15 NC	6–7	<ul style="list-style-type: none"> • <i>Possible confounding:</i> ODD • <i>Not confounding:</i> age, IQ, gender (boys only) • <i>Confounding:</i> CD 	Reward choice task <ul style="list-style-type: none"> • Reward choice 	<ul style="list-style-type: none"> • Tokens cashed for money • Continuous reward on a trial basis • Contingent upon performance • <i>Conditions:</i> A: small immediate reward or large delayed reward versus B: small immediate reward+postreward delay or large delayed reward+postreward delay • Within-subjects design, conditions presented in a random order 	<ul style="list-style-type: none"> • Reward choice in B: small R<large R for both groups • Reward choice in A: see text

(continued on next page)

Table 1 (continued)

Study by	Subjects	Age	Confounding variables ^a	Dependent variables	Reinforcement manipulation ^b	Differential group effects ^c
(19) Tripp and Alsop (1999)	15 ADHD 15 NC	6–14	<ul style="list-style-type: none"> • <i>Possible confounding</i>: CD, ODD, gender • <i>Confounding</i>: age, IQ 	Signal detection task <ul style="list-style-type: none"> • <i>d'</i> • Response bias • RT 	<ul style="list-style-type: none"> • Tokens exchanged for presents • Partially rewarded on a trial basis • Contingent upon performance • <i>Conditions</i>: discrimination between two alternatives, one alternative is rewarded three times as often ADHD group: MPH versus off medication • Within-subjects design, alternatives presented in a random order; MPH and off medication balanced • Quantity of reward equal for both groups 	<ul style="list-style-type: none"> • <i>d'</i> :– • Response bias:– • RT:–
(20) Tripp and Alsop (2001)	36 ADHD (combined subtype) 36 NC	5–11	<ul style="list-style-type: none"> • <i>Comorbid</i>: CD, ODD • <i>Possible confounding</i>: gender • <i>Not confounding</i>: age • <i>Confounding</i>: IQ 	Signal detection task <ul style="list-style-type: none"> • <i>d'</i> • Response bias • RT 	<ul style="list-style-type: none"> • Tokens exchanged for presents • Partially rewarded on a trial basis • Contingent upon performance • <i>Condition</i>: discrimination between two alternatives, one alternative is coupled to postreward delay and one to prereward delay • Within-subjects design, alternatives presented in a random order 	<ul style="list-style-type: none"> • <i>d'</i> :– • Response bias:– • RT:–

(21) Van der Meere, Hughes et al. (1995)	13 ADHD +CD 13 NC	Range not reported For all groups: M: 10.3	<ul style="list-style-type: none"> • Possible confounding: IQ, ODD • Not confounding: age, CD, gender (boys only) 	Continuous performance task • % Correct • RT	<ul style="list-style-type: none"> • Immediate money • Continuous reward on a trial basis • Reward allocated every 10 seconds • Conditions: R versus NR, amount of reward increases with time • Within-subjects design, conditions presented in a fixed order: NR-R • Tokens cashed for money • Continuous reward on a trial basis • Contingent upon the quantity of responses • Conditions: reward after an ever increasing number of responses MPH versus off medication • Within-subjects design, order MPH and off medication condition balanced 	<ul style="list-style-type: none"> • % Correct:– • RT first half ADHD and NC: R<NR; ADHD+CD: R>NR • RT second half: ADHD and NC: R>NR; ADHD+CD: R<NR • RT under R and NR:– • Not reported
(22) Wilkison et al. (1995)	16 ADHD	8–13	<ul style="list-style-type: none"> • Possible confounding: age, CD, IQ, ODD • Not confounding: gender (boys only), LD 	Reward choice response task • Number of responses • Amount of reward	<ul style="list-style-type: none"> • Immediate money • Continuous reward on a trial basis • Reward allocated every 10 seconds • Conditions: R versus NR, amount of reward increases with time • Within-subjects design, conditions presented in a fixed order: NR-R • Tokens cashed for money • Continuous reward on a trial basis • Contingent upon the quantity of responses • Conditions: reward after an ever increasing number of responses MPH versus off medication • Within-subjects design, order MPH and off medication condition balanced 	<ul style="list-style-type: none"> • % Correct:– • RT first half ADHD and NC: R<NR; ADHD+CD: R>NR • RT second half: ADHD and NC: R>NR; ADHD+CD: R<NR • RT under R and NR:– • Not reported

ADD+H, ADHD=attention deficit hyperactivity disorder; CD=conduct disorder; CR=continuous reward; d' = d prime, measure of sensitivity; ID=internalizing disorder (anxiety and mood disorders); LD=learning disorder; MPH=methylphenidate; (M)RT=(mean) response time; NC=normal control group; NR=nonreward; ODD=oppositional defiant disorder; PR=partial reward; R=reward; RC=response cost; SSRT=stop signal reaction time; TBI=traumatic brain injury.

^a A variable was considered as not confounding either when groups were matched, or when statistics showed that groups did not differ on this variable.

^b Total amount of reward may vary between subjects if not mentioned; tokens could be exchanged for reward at the end of the experiment.

^c For each dependent variable, interactions between groups and reinforcement condition are described.

performance is evaluated. Reinforcement may involve (accuracy) feedback only, reward, response cost, as well as a combination of feedback and reward or response cost.

With the exception of six studies, reinforcement was allocated contingent on performance. In six studies, reinforcement was allocated noncontingent on performance, which implies that allocation of reinforcement is not related to response accuracy. In these studies, reinforcement allocation was related to the number of completed trials (Daugherty & Quay, 1991; Douglas & Parry, 1994; Rapport, Tucker, DuPaul, Merlo, & Stoner, 1986; Wilkison et al., 1995), random reward was provided (McInerny & Kerns, 2003), or reinforcement was allocated at fixed time intervals (Van der Meere, Hughes et al., 1995). Response cost conditions are defined as conditions in which incorrect responses result in deduction of reward, with the exception of one study. In this study, in addition to response cost, reward was allocated following correct responses (Crone, Jennings, & Van der Molen, 2003). Under nonreward conditions, children receive neither reward nor response cost. When a nonreward condition immediately follows a reward condition in a within-subject design, this is referred to as an extinction condition. Partial reward conditions are defined as conditions in which a proportion (e.g., 50%) of the correct responses is rewarded in contrast with continuous reward conditions in which all correct responses are rewarded.

Results of children with AD/HD and normal controls are reported and ODD/CD groups will be discussed additionally. Main effects of reinforcement condition, main effects of group, and interactions between reinforcement condition and group will be discussed for task performance.

3.1. AD/HD versus normal controls under reward, nonreward, and response cost

Nine studies (see Table 2) compared a reward with a nonreward condition. Six of nine studies reported a main effect of reinforcement condition: Across groups, performance improved under reward compared to nonreward. Additionally, across reinforcement conditions, performance of children with AD/HD was inferior to controls in five of nine studies. In three studies, a differential effect of reinforcement condition was revealed: Reward compared to nonreward had a positive effect on performance of the AD/HD group, whereas performance of controls did not change (Carlson & Tamm, 2000; McInerny & Kerns, 2003), or changed to a lesser extent (Konrad, Gauggel, Manz, & Scholl, 2000). In two studies, performance of the AD/HD group 'normalized' under reward (Konrad et al., 2000; McInerny & Kerns, 2003). Six of nine studies failed to find a differential effect of reinforcement condition on task performance for the AD/HD and control group (Barber et al., 1996; Carlson, Mann, & Alexander, 2000; Iaboni, Douglas, & Ditto, 1997; Scheres, Oosterlaan, & Sergeant, 2001; Solanto, 1990; Van der Meere, Hughes et al., 1995). Scheres et al. (2001) revealed a speed–accuracy tradeoff for the AD/HD group in the reward condition: While accuracy improved under reward, response times slowed down. Controls did not show this tradeoff. The dependent measures used in the studies were accuracy (Barber et al., 1996; Carlson et al., 2000; Carlson & Tamm, 2000; McInerny & Kerns, 2003; Solanto, 1990; Van der Meere, Hughes et al., 1995), (mean) response time (Iaboni et al., 1997; Scheres et al., 2001; Van der Meere, Hughes et al., 1995), and Stop Signal Reaction Time (SSRT) (Scheres et al., 2001).

Pelham et al. (1986) compared the performance of children with attention deficit disorder (ADD) receiving methylphenidate (MPH) and placebo, under both reward and nonreward conditions. Performance improved under reward compared to nonreward and with MPH compared to placebo. No differential effects of reinforcement condition were revealed for children with ADD on or off medication. The dependent measure was error rate.

Table 2

Task performance of children with AD/HD versus normal controls under reward and nonreward

Study	Group effects			Dependent variable
	Nonreward	Reward	Reward versus nonreward ^a	
Barber et al. (1996)	ADHD=NC	ADHD=NC		Accuracy
Carlson et al. (2000)	ADHD<NC	ADHD<NC		Accuracy
Carlson and Tamm (2000)	ADHD<NC	ADHD<NC	+ ADHD	Accuracy
Iaboni et al. (1997)	ADHD=NC	ADHD=NC	+ NC, ADHD	RT
Konrad et al. (2000)	ADHD<NC	ADHD=NC	+ NC, ADHD	SSRT
McInerny and Kerns (2003)	ADHD<NC	ADHD=NC	+ ADHD	Absolute error ^b
Van der Meere, Hughes et al. (1995)	ADHD=NC	ADHD=NC		Accuracy
	ADHD=NC	ADHD=NC		RT
Scheres et al. (2001)	ADHD=NC	ADHD=NC	+ NC, ADHD	SSRT ^c
	ADHD<NC	ADHD<NC	- ADHD ^d	MRT
Solanto (1990)	ADHD<NC	ADHD<NC	+ NC, ADHD	Accuracy

AD/HD=attention deficit/hyperactivity disorder; NC=normal controls; (M)RT=(mean) response time; SSRT=stop signal reaction time.

^a (+) Improvement in performance; (-) deterioration in performance under reward compared to nonreward.

^b Absolute error indicates a measure of accuracy.

^c The results for accuracy and percent inhibited responses were similar to the results for SSRT.

^d $p < 0.10$, marginally significant increase in MRT reflecting a speed-accuracy tradeoff.

Three studies compared the effects of response cost and nonreward conditions (Carlson et al., 2000; Carlson & Tamm, 2000; Solanto, 1990). Two studies reported improved performance under response cost compared to nonreward across groups; one study revealed no main effect of reinforcement condition (Carlson et al., 2000). All three studies reported a main effect for group: Performance of children with AD/HD was worse compared to controls across reinforcement conditions. A differential effect of reinforcement condition has been found in two studies: Performance of children with AD/HD improved under response cost compared to nonreward conditions, while performance of controls remained unchanged (Carlson et al., 2000; Carlson & Tamm, 2000). In both studies, response cost was found to 'normalize' performance of children with AD/HD. Solanto (1990) failed to find a differential effect of reinforcement condition. The dependent measure for all three studies was accuracy.

Reward and response cost conditions were compared in six studies. Table 3 shows the results of these studies. A main effect of reinforcement condition was found in three of six studies: Across groups, performance deteriorated under response cost compared to reward (Crone et al., 2003; Iaboni, Douglas, & Baker, 1995; Oosterlaan & Sergeant, 1998). The other studies failed to find any difference in performance between reinforcement conditions (Carlson et al., 2000; Carlson & Tamm, 2000; Solanto, 1990). All six studies showed a main effect of group: Performance of children with AD/HD was inferior to that of controls across reinforcement conditions. Reinforcement condition differentiated children with AD/HD from controls in three of six studies (Carlson et al., 2000; Carlson & Tamm, 2000; Crone et al., 2003). In two studies, the performance of the AD/HD group improved under response cost compared to reward, while the performance of controls remained unchanged (Carlson et al., 2000; Carlson & Tamm, 2000). In both studies, performance of children with AD/HD was found to 'normalize' under response cost. Crone et al. (2003) found a speed-accuracy tradeoff for children with AD/HD: While the mean response time improved in the response cost condition, accuracy deteriorated. Accuracy of controls,

Table 3

Task performance of children with AD/HD versus normal controls under reward and response cost

Study	Group effects			Dependent variable	
	Reward	Response cost	Reward versus response cost ^a		
Carlson et al. (2000)	ADHD<NC	ADHD=NC	+	ADHD	Accuracy
Carlson and Tamm (2000)	ADHD<NC	ADHD=NC	+	ADHD	Accuracy
Crone et al. (2003)	ADHD<NC	ADHD<NC ^b	+	NC, ADHD	MRT
	ADHD<NC	ADHD<NC	–	ADHD	Accuracy
Iaboni et al. (1995)	ADHD<NC	ADHD<NC	–	NC, ADHD	Commission errors
	ADHD=NC	ADHD=NC			MRT
Oosterlaan and Sergeant (1998)	ADHD<NC	ADHD<NC			SSRT ^c
	ADHD<NC	ADHD<NC	–	NC, ADHD ^d	MRT
	ADHD=NC	ADHD=NC			Accuracy
Solanto (1990)	ADHD<NC	ADHD<NC			Accuracy

AD/HD=attention deficit/hyperactivity disorder; NC=normal controls; (M)RT=(mean) response time; SSRT=stop signal response time.

^a (+) Improvement in performance; (–) deterioration in performance under response cost compared to nonreward.

^b This condition involved the allocation of both reward and response cost.

^c The results for percent inhibited responses were similar to the results for SSRT.

^d $p < 0.10$, marginally significant effect.

however, remained unchanged. Three of six studies failed to find a differential effect of reinforcement condition on task performance for the AD/HD and control group (Iaboni et al., 1995; Oosterlaan & Sergeant, 1998; Solanto, 1990). The dependent measures were accuracy (Carlson et al., 2000; Carlson & Tamm, 2000; Crone et al., 2003; Solanto, 1990), commission errors (Iaboni et al., 1995), (mean) response time (Crone et al., 2003; Iaboni et al., 1995; Oosterlaan & Sergeant, 1998), and SSRT (Oosterlaan & Sergeant, 1998).

Solanto, Wender, and Bartell (1997) compared the performance of children with AD/HD between a mixed reward and response cost and a feedback-only condition. Children with AD/HD performed the task while receiving medication and placebo. Performance was more optimal under mixed reward and response cost compared to feedback only, although this effect was statistically of marginal significance. Furthermore, within-group differences revealed that children with AD/HD on medication performed better than the group receiving placebo. There was an interaction between the effect of medication and reinforcement condition: Compared to feedback only, performance of the placebo group improved under mixed reward and response cost. Performance of the medicated group, however, did not improve when reinforcement was given. When the effects of medication and allocation of reinforcement were compared, medication effects were found to be slightly larger. Dependent measures were hit rate and perceptual sensitivity (d').

3.2. AD/HD versus normal controls under partial reward, nonreward, and continuous reward

Three studies compared the impact of partial and nonreward on task performance. In one study, children with ADD were compared receiving both medication and placebo (Pelham et al., 1986). Two studies revealed a reinforcement condition effect: Under partial compared to nonreward, Barber et al. (1996) found that performance deteriorated, while Pelham et al. (1986) found that performance improved,

although this result was of marginal significance. Douglas and Parry (1994) failed to find a reinforcement condition effect. Children with ADD performed more optimally under medication compared to children receiving placebo (Pelham et al., 1986). No differences in performance were found between children with AD/HD and controls. No differential effects of reinforcement condition were revealed (Barber et al., 1996; Douglas & Parry, 1994; Pelham et al., 1986). Dependent measures were response time (Douglas & Parry, 1994), accuracy (Barber et al., 1996), and error rate (Pelham et al., 1986).

A partial reward condition was compared to continuous reward in three studies. All three studies failed to find main effects of reinforcement condition (Barber et al., 1996; Douglas & Parry, 1994; Pelham et al., 1986). Douglas and Parry (1994) found that reinforcement condition had a differential impact on the performance of children with AD/HD and controls: While performance of children with AD/HD deteriorated under partial compared to continuous reward, performance of controls was similar in both conditions. In this study, performance of children with AD/HD was found to ‘normalize’ under continuous reward. The remaining two studies revealed no interaction between reinforcement condition and group (Barber et al., 1996; Pelham et al., 1986). The dependent variables in these studies were error rate (Pelham et al., 1986), (mean) response time (Douglas & Parry, 1994), and percentage correct (Barber et al., 1996).

Douglas and Parry (1994) measured frustration level under both partial and continuous reward, since they predicted frustration level to correlate with task performance. For both the AD/HD and control group, levels of frustration correlated with performance: Under partial reward, frustration level of children with AD/HD increased, while performance deteriorated as noted above. Levels of frustration and performance of normal controls did not differ between the reinforcement conditions.

3.3. AD/HD versus normal controls under immediate and delayed reward

Three studies compared task performance under immediate and delayed reward. When children were required to make a choice between an immediate and a delayed reward, children with AD/HD chose more often for an immediate reward compared to controls (Rappport et al., 1986; Sonuga-Barke et al., 1992; Tripp & Alsop, 2001). They chose more often for the immediate reward, even though the delayed reward was larger (Rappport et al., 1986). In contrast, normal controls chose more often for the larger delayed reward (Rappport et al., 1986), or showed a smaller response bias for the immediate reward (Tripp & Alsop, 2001). In addition, reward choice on earlier trials did not change the preference for an immediate reward for children with AD/HD (Rappport et al., 1986; Tripp & Alsop, 2001). Normal controls, however, seemed to incorporate recently gained reward into their reward choice: When previous reward was small (Rappport et al., 1986) or immediate (Tripp & Alsop, 2001), the preference for an immediate (small) reward in the consecutive trial diminished.

When a maximum amount of reward was predetermined or when the maximum amount of time to complete the task was set, the response pattern of children with AD/HD did not differ from normal controls (Sonuga-Barke et al., 1992). Both groups responded in a pattern that maximized the amount of reward. However, when the number of trials was predetermined, which implied a maximum number of responses, the AD/HD group chose more often for the reward that minimized time-on-task. The normal control group maximized their total amount of reward (Sonuga-Barke et al., 1992). Moreover, when overall delay was similar, by adding a postreward delay, Sonuga-Barke et al. (1992) observed that both children with AD/HD and normal controls chose for the large delayed reward. The result led Sonuga-Barke to conclude that children with AD/HD are extremely sensitive to delay and are delay-averse rather

than reward maximizers (Sonuga-Barke et al., 1992; Sonuga-Barke, 2002). In contrast to the findings of Sonuga-Barke, Tripp and Alsop (2001) found that children with AD/HD preferred immediate reward even when overall delay was similar.

3.4. AD/HD, ODD/CD, and normal controls under different reward ratios

Daugherty and Quay (1991) investigated response perseveration in a two-choice response task, where the chance of receiving reward diminished, while the chance of receiving response cost remained the same. In this task, reward and response cost were allocated independent of the response choice. Daugherty and Quay (1991) found no differences in the response pattern of children with AD/HD and normal controls. In both groups, the response rate diminished, when the chance of receiving reward declined. In contrast, the response rate of children with CD (and also children with AD/HD+CD) remained high. Consequently, children with CD (and children with AD/HD+CD) received a smaller total amount of reward compared to the other groups, indicating that their strategy was less profitable.

Wilkison et al. (1995) compared children with AD/HD on and off medication in a two-choice response task where the chance of receiving reward diminished. Children with AD/HD on medication showed a higher response rate in the face of declining probability of reward compared to children with AD/HD off medication (Wilkison et al., 1995). Consequently, the group receiving medication gained more reward at the end of the experiment. Unfortunately, a normal control group was not included in that study.

Tripp and Alsop (1999) measured performance in a choice task, where one alternative was rewarded three times as often as compared to the other. Children with AD/HD on and off medication were compared to controls. Performance of children with AD/HD on medication was more optimal compared to both controls and children with AD/HD off medication. No interaction between group and reward ratio was revealed. Dependent measures were perceptual sensitivity (d') and response bias.

3.5. ODD/CD, AD/HD, and normal controls under reward, nonreward, and response cost

Two studies included an ODD/CD group when task performance was studied in children with AD/HD under different reinforcement contingencies (Oosterlaan & Sergeant, 1998; Scheres et al., 2001). Strikingly, in both studies, no differences were revealed between children with ODD/CD and children with AD/HD. The same studies compared children with ODD/CD with normal controls. Both studies revealed a main effect of group: Performance of normal controls was more optimal compared to children with ODD/CD. No interaction was found between reinforcement condition and group. Dependent measures were MRT and SSRT.

3.6. Summary task performance

Firstly, a majority of studies described in this section indicate that reward and response cost have a positive effect on task performance of both children with AD/HD and controls. Additionally, in terms of the number of studies showing improvement in performance, the improvement is somewhat more prominent for children with AD/HD than in normal controls (Carlson et al., 2000; Carlson & Tamm, 2000; Iaboni et al., 1997; Konrad et al., 2000; McNerny & Kerns, 2003; Scheres et al., 2001; Solanto, 1990). Six studies that compared reward with response cost conditions found that reinforcement condition did not differentiate performance of children with AD/HD from controls.

Secondly, one of three studies showed that performance of children with AD/HD deteriorated under partial compared to continuous reward (Douglas & Parry, 1994). When children were required to perform a task under partial and nonreward conditions, no differences were found in three studies that compared children with AD/HD (Barber et al., 1996; Douglas & Parry, 1994) or children with ADD (Pelham et al., 1986) and controls.

Third, compared to controls, children with AD/HD seem to choose more often an immediate reward than a delayed reward, irrespective of the previous reward trial and whether the delayed reward was large (Rapport et al., 1986; Sonuga-Barke et al., 1992; Tripp & Alsop, 2001).

Fourth, when reward schedules are manipulated in such a way that the chances of receiving reward diminished over time, no differences in response rate were observed between children with AD/HD and controls (Daugherty & Quay, 1991). Children with CD, however, showed a high response rate irrespective of diminishing chance on receiving reward, which turned out to be a less profitable response strategy.

Fifth, when reward conditions were compared to a condition of response cost or nonreward, the authors failed to find any differential effects on task performance in studies where children with ODD/CD were compared to children with AD/HD (Oosterlaan & Sergeant, 1998; Scheres et al., 2001).

There are some limitations related to the findings described above that need to be highlighted. The main concern is heterogeneity in the dependent variables employed in the empirical studies. Also, the confounding variables that have been taken into account differ between studies. Furthermore, form, amount, and delivery of reinforcement vary, and not all studies make sure that the total amount of reinforcement is similar for all groups. A limitation of a different caliber is that the findings in this review are based on a small number of studies. Finally, a possible ceiling effect of performance in the control group may confound the findings related to task performance.

4. Motivation level

Different methods have been used to assess children's subjective and objective motivation levels. One of the employed methods used to obtain subjective motivation is to ask children to rate their motivation to 'perform a specific task' (Scheres et al., 2001), 'to continue with a task,' or 'to do a task again' (Carlson et al., 2000; Carlson & Tamm, 2000; McInerny & Kerns, 2003; Oosterlaan & Sergeant, 1998). Objective levels of motivation were measured by counting the total number of trials completed, in a task where the number of trials is under the participant's control (Carlson et al., 2000; Carlson & Tamm, 2000).

4.1. AD/HD versus normal controls under: Reward, nonreward, and response cost

Table 4 summarizes the results of four studies that measured levels of motivation of children with AD/HD under a reward and nonreward condition. All four studies revealed that across groups, reward had a positive effect on self-rated motivation (Carlson et al., 2000; Carlson & Tamm, 2000; McInerny & Kerns, 2003; Scheres et al., 2001). No main effects of group or differential effects of reinforcement condition on self-rated motivation were found.

Two of the four studies included both measures of self-rated and observed motivation. The difference between self-rated and observed motivation is noteworthy. While self-rated motivation increased under

Table 4

Levels of motivation of children with AD/HD versus normal controls under reward and nonreward

Study	Group effects			Motivation measure
	Nonreward	Reward	Reward versus nonreward ^a	
Carlson and Tamm (2000)	ADHD=NC	ADHD=NC	+ NC, ADHD	Self-rated
	ADHD<NC ^b	ADHD<NC		Observed
Carlson et al. (2000)	ADHD=NC	ADHD=NC	+ NC, ADHD ^b	Self-rated
	ADHD=NC	ADHD=NC		Observed
McInerney and Kerns (2003)	ADHD=NC	ADHD=NC	+ NC, ADHD	Self-rated
Scheres et al. (2001)	ADHD=NC	ADHD=NC	+ NC, ADHD	Self-rated

AD/HD=attention deficit/hyperactivity disorder; NC=normal controls.

^a (+) Increased motivation; (–) decreased motivation under reward compared to nonreward.^b $p < 0.10$, statistical marginal significance.

reward compared to nonreward, no main effect of reinforcement condition was found for observed motivation (Carlson et al., 2000; Carlson & Tamm, 2000). This could indicate that the different measures of motivation do not reflect the same concept. Furthermore, Carlson et al. (2000) found that self-rated motivation was similar across groups, while observed motivation was higher for controls compared to children with AD/HD. This difference was of marginal significance. In the Carlson and Tamm study, groups did not differ in terms of self-rated or observed motivation. No differential effects of reinforcement condition were found for observed motivation.

Two studies measured levels of motivation of children with AD/HD and controls when comparing a response cost and a nonreward condition (Carlson et al., 2000; Carlson & Tamm, 2000). In both studies, self-rated motivation was higher in the response cost condition; although in the Carlson and Tamm study, the effect was marginally significant. Carlson et al. (2000) reported a differential effect of reinforcement condition on self-rated motivation: Self-rated motivation of controls was higher under response cost compared to nonreward, while self-rated motivation for children with AD/HD remained unchanged. The second study did not find a differential effect (Carlson & Tamm, 2000).

No main effects of reinforcement condition were found for observed motivation. Carlson et al. (2000) found a differential effect of reinforcement condition: Observed motivation of children with AD/HD improved under response cost, while observed motivation of controls did not differ between reinforcement conditions (Carlson et al., 2000). The other study failed to find an interaction effect between group and reinforcement condition for observed motivation (Carlson & Tamm, 2000).

Three studies included measures of self-rated motivation when comparing a reward and a response cost condition. Across groups, one study reported higher self-rated motivation under reward compared to response cost (Carlson & Tamm, 2000). Two other studies failed to find any differences in self-rated motivation between reinforcement conditions (Carlson et al., 2000; Oosterlaan & Sergeant, 1998). None of the studies reported group differences in self-rated motivation, or interaction effects between group and reinforcement condition.

Carlson et al. (2000) and Carlson and Tamm (2000) measured levels of observed motivation and failed to find a main effect of reinforcement condition. One study reported a differential effect of reinforcement condition: Observed motivation of children with AD/HD was higher under response cost compared to reward, while controls showed similar levels of motivation in both reinforcement conditions

(Carlson et al., 2000). The other study failed to find any effects of group, and there was no interaction effect between group and reinforcement condition (Carlson & Tamm, 2000).

4.2. Summary motivational variables

The majority of studies that included measures of motivation found a positive effect of both reward and response cost conditions on self-rated motivation (Carlson et al., 2000; Carlson & Tamm, 2000; McInerney & Kerns, 2003; Scheres et al., 2001). Two studies included both measures of observed and self-rated motivation and, while self-rated motivation improved under reinforcement conditions, observed motivation was not affected by either reward or response cost (Carlson et al., 2000; Carlson & Tamm, 2000). This result was found for both children with AD/HD and controls. No clear differential effects of reinforcement condition on levels of motivation were found for children with AD/HD and controls.

Noteworthy in this section is the discrepancy found between observed and self-rated motivation under different reinforcement conditions. This result may indicate that either the measures do not tap into the same concept, or that children have difficulties in monitoring their motivation while performing a task. As with the studies investigating task performance, studies into motivation are hampered by the small number of studies that contribute to the findings and differences between variables related to reinforcement (form, amount, and reinforcement allocation policy).

5. Psychophysiological variables

Heart rate and skin conductance have been employed in two studies of AD/HD and reinforcement contingencies (Crone et al., 2003; Iaboni et al., 1997). Crone et al. (2003) compared psychophysiological responses of children with AD/HD and controls under three different reinforcement conditions: One reward-only condition and two mixed reward and response cost conditions (see Table 1). In that study, heart rate level and skin conductance level were measured during the different reinforcement conditions and also heart rate responses immediately following reinforcement were obtained (Crone et al., 2003). Heart rate of both children with AD/HD and controls increased during the mixed reward and response cost compared to the reward-only condition. Furthermore, heart rate increased following positive reinforcement (reward or escape from punishment) compared to negative reinforcement (punishment or response cost). A main effect for group was found: Heart rate of children with AD/HD was higher compared to controls. In addition, reinforcement condition differentiated children with AD/HD from controls on heart rate: Compared to controls, heart rate of children with AD/HD exhibited smaller differences when responses to positive and negative reinforcement were contrasted (Crone et al., 2003). With respect to skin conductance, children with AD/HD responded like controls and no main effects of reinforcement condition or interactions between group and reinforcement condition were found.

Iaboni et al. (1997) compared the psychophysiological responses of children with AD/HD under conditions of reward and nonreward/extinction (see Table 1). A main effect of reinforcement condition was found: Heart rate increased during the reward compared to the extinction conditions (Iaboni et al., 1997). In contrast to Crone et al. (2003), Iaboni et al. failed to find any main effects of group on heart rate. Heart rate of children with AD/HD and controls was differentially affected by the reinforcement conditions: Compared to controls, heart rate of children with AD/HD showed smaller differences between the reward and extinction conditions. The heart rates of both groups decreased across the

reward trials; however, this habituation commenced earlier for children with AD/HD. Over reinforcement conditions, children with AD/HD responded like controls with respect to skin conductance level. However, the skin conductance of children with AD/HD and controls was differentially affected by reinforcement condition: While skin conductance levels of normal controls increased during the extinction compared to the reward conditions, skin conductance level of children with AD/HD remained unchanged (Iaboni et al., 1997).

Thus, both studies found evidence of reduced psychophysiological responding in children with AD/HD compared to controls. Compared to controls, children with AD/HD exhibited smaller differences in heart rate between the reward and extinction conditions (Iaboni et al., 1997) and in response to positive and negative reinforcement (Crone et al., 2003). Iaboni et al. (1997) found smaller skin conductance levels under extinction compared to reward conditions for children with AD/HD compared to controls. This result may indicate that children with AD/HD are less sensitive psychophysiologically to reinforcement.

The main limitation here is the small number of studies investigating the effect of external contingencies on heart rate and skin conductance in AD/HD. The current studies did not find strong clues for the underlying mechanisms that could account for reinforcement deficits in AD/HD.

6. Confounding variables

6.1. Comorbid disorders

The studies in this review reported on the presence of learning disorder (LD), internalizing disorder (ID) (anxiety and mood disorders), ODD, and CD. Nine of 22 studies in this review assessed the possible presence of ODD symptoms in children with AD/HD, and all studies reported that a subgroup of children with AD/HD was classified for a DSM diagnosis of ODD. Twelve studies assessed the possible presence of CD symptoms in children with AD/HD, and 10 studies reported a comorbid DSM diagnosis of CD. Almost half of the studies (10 studies) included groups of children with an AD/HD diagnosis but did not examine possible comorbid ODD in children with AD/HD, and one third of the studies (seven studies) did not check for possible comorbid CD. In one of four studies that assessed the possible presence of LD in children with AD/HD, a comorbid DSM diagnosis of LD was confirmed. One of six studies that checked for possible ID in children with AD/HD reported a comorbid diagnosis of ID for a subgroup of children with AD/HD.

When studying AD/HD from a psychophysiological perspective, the presence of comorbid anxious and antisocial behavior disorders (ODD and CD) should be taken into account (Gray, 1982; Quay, 1988a). Quay (1988a, 1988b, 1988c) indicated that these psychiatric groups show different psychophysiological responses to reinforcing stimuli. In contrast to children with AD/HD, children with oppositional and delinquent behavior disorders were predicted to be oversensitive to signals of reward because of an overactive BAS. Children with anxious symptoms, on the other hand, are predicted to suffer from an overactive BIS and, therefore, are highly sensitive to signals of punishment and nonreward. Interestingly, the comorbid diagnosis of AD/HD with an anxiety disorder is suggested to eliminate the dysfunction within the BIS (Quay, 1988a, 1988b, 1988c). In these children, the 'dysfunctional' BIS is hypothesized to normalize due to the combination of an underactive BIS related to AD/HD and an overactive BIS related to the anxiety disorder.

6.2. Reinforcement allocation policy

Reinforcers were administered based on either performance or task participation. According to Schultz (2000), the rate of reinforcement learning in a task depends on the discrepancy between the occurrence and the predicted occurrence of reward. When reward is based on participation, reward expectancy seems to be highest and reinforcement learning is expected to be lower compared to performance-based reinforcement allocation. The two different reinforcement allocation policies were compared in a study by Carlson and Tamm (2000). No differential effects of allocation policy on either performance or motivation level were observed. The majority of studies allocated reinforcement contingent upon the accuracy of the response, which minimized the possible confounding effect of reinforcement allocation policy and maximized stimulus response learning (Schultz, 2000, 2002). More research is needed in order to clarify the role of reinforcement allocation policy.

6.3. AD/HD subtypes, gender, age, and IQ

In this review, three studies explicitly compared the performance of children with AD/HD inattentive subtype and AD/HD hyperactive/impulsive subtype under different reinforcement contingencies and found no differences (Konrad et al., 2000; Rapport et al., 1986; Scheres et al., 2001). Seven studies included only children with AD/HD combined subtype according to the DSM IV or children with ADD+H according to the DSM III. One study included only children with ADD according to DSM III. Since the remaining 11 studies did not provide information on the AD/HD subtypes, no firm conclusions can be drawn on this issue.

Nine studies matched groups on gender. Five studies statistically checked for possible effects of gender and found no differences between boys and girls (Carlson & Tamm, 2000; Daugherty & Quay, 1991; Pelham et al., 1986; Rapport et al., 1986; Solanto, 1990). There seems no reason to suspect any confounding influences of gender on the dependent variables in the remaining eight studies.

Nine studies matched groups on age. Eleven other studies tested for possible group differences in age: Two studies found a difference in age between groups. In one study, age was entered as a covariate in the analyses (Slusarek, Velling, Bunk, & Eggers, 2001). These data suggest that age does not have much influence on the dependent variables in this review.

IQ is unlikely to effect the findings noted here. Five studies matched their experimental groups on IQ. All other studies tested for possible group differences in IQ and three studies found a difference in IQ between groups (Rapport et al., 1986; Scheres et al., 2001; Tripp & Alsop, 2001). Two studies entered IQ as a covariate.

6.4. Form and intensity of reinforcement

In the studies reviewed here, children received either tokens (14 studies), money (five studies), presents (two studies) or diminished intertrial delays as reinforcement. Children received tokens, which could be exchanged for presents at the end of the experiment (nine studies), or received tokens that could be cashed for money (five studies). The intensity (amount) of reinforcement may differ between studies (i.e., reward allocation of 1, 2, 5, or 10 cents per trial). One study manipulated the intensity of reinforcement (Slusarek et al., 2001). In this study, response cost intensity was found to differentiate children with AD/HD from normally developing controls: While performance of children with AD/HD

is less optimal compared to controls in the low-intensity condition, performance of children with AD/HD is found to normalize in the high-intensity condition.

7. General discussion

The goal of this review was twofold. On one hand, we have charted the behavioral findings regarding the role of reinforcement contingencies in AD/HD—an attempt that has not been made for some time (Douglas & Peters, 1979). On the other hand, we wished to study the implications of the behavioral findings for the theoretical frameworks related to this body of research.

We first summarize the results of the studies in this review: We found clear evidence that reward and response cost have a positive effect on performance and on levels of motivation of both children with AD/HD and normal controls. Additionally, a performance improvement was reported more often for the AD/HD group than for controls (Carlson et al., 2000; Carlson & Tamm, 2000; Konrad et al., 2000; McNerny & Kerns, 2003). With respect to the levels of motivation, no significant interactions were found between group and reinforcement condition. Another evident finding is that compared to controls, children with AD/HD seem to choose more often for an immediate reward irrespective of the previous reinforcement trial or whether the delayed reward was large (Rappoport et al., 1986; Sonuga-Barke et al., 1992; Tripp & Alsop, 2001). Less clear is the role of partial reward. In one of three studies, performance of children with AD/HD diminished under partial compared to continuous reward, while performance of controls remained the same (Douglas & Parry, 1994). Furthermore, children with AD/HD and normal controls responded in a similar pattern, when response perseveration was measured in a task where the chance on receiving reward diminished (Daugherty & Quay, 1991). When heart rate and skin conductance measures are investigated, children with AD/HD seem to be psychophysiological less sensitive to reinforcement contingencies (Crone et al., 2003; Iaboni et al., 1997). The decreased sensitivity for reinforcement at a psychophysiological level seems to contrast with the findings related to performance: At a performance level, in some studies, reinforcement contingencies are more beneficial for children with AD/HD than for controls (Carlson et al., 2000; Carlson & Tamm, 2000; Konrad et al., 2000; McNerny & Kerns, 2003).

We now discuss the implications of the findings in terms of five models described in the Introduction. Haenlein and Caul (1987) suggested that children with AD/HD require higher amounts of reward in order to perform optimally due to an elevated reward threshold. A more prominent improvement in performance of children with AD/HD under reward conditions supports this hypothesis (Carlson & Tamm, 2000; Konrad et al., 2000; McNerny & Kerns, 2003). Partial reward was suggested to result in diminished task performance. The findings, however, only partly support this suggestion, since only one of three studies revealed clear evidence on this issue (Douglas & Parry, 1994). When the chance of receiving reward diminished (Daugherty & Quay, 1991), children with AD/HD showed a similar response pattern compared to controls, in contrast to the ideas of Haenlein and Caul. In addition, Haenlein and Caul argued that that medication would lower the reward threshold. When confronted with a diminishing chance of receiving reward, children with AD/HD on medication showed a more optimal performance compared to children with AD/HD receiving placebo (Wilkison et al., 1995). The psychophysiological findings concerning a diminished sensitivity to reinforcement are in line with the suggestion of an elevated reward threshold. The preference for immediate reward of children with AD/HD supports Haenlein and Caul's model, since they suggested that the impact of a reward is larger when

it is administered immediately compared to when it is delayed. A limitation of this model is that Haenlein and Caul did not make any suggestions concerning response cost. Response cost seems to be as effective as reward for children with AD/HD, especially when reward intensity is high (Slusarek et al., 2001). As noted above, an elevated reward threshold model of AD/HD can account for a considerable number of behavioral findings discussed in this review; however, question, related to the exact elevation of the reward threshold could not be answered.

Douglas (1989, 1999) proposed that children with AD/HD are unusually sensitive to reward and suffer from a heightened frustration level in response to the loss of anticipated reward. These suggestions by Douglas are moderately supported: One of three studies found deteriorating performance under partial reward compared to continuous reward for children with AD/HD (Douglas & Parry, 1994). In this study, children with AD/HD exhibited higher levels of frustration compared to normal controls under partial reward. The preference for immediate reward for children with AD/HD is in line with the ideas of Douglas. Although the hypothesis of an increased sensitivity to reinforcement is supported by the findings in this review (Carlson et al., 2000; Carlson & Tamm, 2000; Konrad et al., 2000; McNerny & Kerns, 2003), no specific predictions were made for the effect of reward or response cost onto performance. The finding that performance of children with AD/HD is like controls in a task where the chances on receiving reward diminished, contrasts the ideas of Douglas (1989, 1999), since Douglas theorized that children with AD/HD are extremely sensitive to the absence of anticipated reward. The diminished psychophysiological responding to reinforcement of children with AD/HD may be in contrast with the suggestion of increased reward sensitivity and increased sensitivity to extinction.

According to the CEM (Sergeant et al., 1999), the contributing role of effort to poor performance in AD/HD is caused by a deficit in effort allocation. Since the effort pool is activated by reinforcement contingencies, performance improvement for the AD/HD group under both reward and response cost is in line with the CEM. The finding that a higher ratio of reinforcement (continuous versus partial reward) (Douglas & Parry, 1994) or a higher intensity of reinforcement (Slusarek et al., 2001) had a differential effect on performance for children with AD/HD and controls could also be explained by a lack of effort allocation in AD/HD. The preference for immediate reward for children with AD/HD, however, is more difficult to explain in terms of the CEM, since the exact specifications of how the effort pool is activated are not provided. According to the CEM, under reward and response cost, improvement in task performance is expected to be associated with an enhanced motivation level. A correlation between improved task performance and motivation level, however, was found in one study only (McNerny & Kerns, 2003). The findings in this review only partly support the CEM on this issue. The psychophysiological findings concerning an underresponsive BIS and BAS could explain the need for external incentives in AD/HD for optimal performance. The CEM does not make any specific predictions concerning the preference for immediate reward or concerning a diminishing reward ratio. Although findings related to motivation are not in line with the CEM, a suboptimal energetic state could explain a wide range of behavior related to reinforcement contingencies and AD/HD.

Sonuga-Barke (2002, 2003) explained the symptoms of AD/HD in terms of two separate dysfunctional brain mechanisms in a dual-pathway model. One pathway is associated with diminished inhibitory responses and the other with increased reward sensitivity. The dual-pathway model predicts delayed and noncontinuous reward to result in diminished task performance for children with AD/HD. The preference for immediate reward in children with AD/HD is in line with the dual pathway model. Tripp and Alsop (2001), however, found that children with AD/HD preferred immediate above delayed reward irrespective whether the overall delay was similar, which contrasts with the findings by Sonuga-Barke et al. (1992).

One of three studies revealed evidence for a deteriorating effect of partial reward on performance in AD/HD (Douglas & Parry, 1994). The finding that performance of children with AD/HD was similar to controls when the chances of receiving reward diminished could not be explained by the dual-pathway model (Daugherty & Quay, 1991). According to Sonuga-Barke, AD/HD is in part associated with a dysfunction in the mesolimbic system, which may explain the psychophysiological findings: The regulation of the cardio-respiratory components of the defense and vigilance reactions involves several brain regions, including limbic system structures as the amygdala (Brownley, Hurwitz, & Schneiderman, 2000). If the two pathways of the model are independent, we may expect a double dissociation between the behavioral dysfunctions (inhibition and reward sensitivity) related to the pathways. Future research needs to confirm this prediction. No specific predictions were made concerning the moderating effects of both reward and response cost on performance of children with AD/HD.

The fifth model, the BIS/BAS model by Quay (1988a, 1988b, 1988c, 1997), proposed that children with AD/HD suffer from a weak BIS, associated with a diminished sensitivity to signals of punishment and nonreward. Psychophysiological, children with AD/HD would show a decreased skin conductance response to conditions of response cost and extinction. The findings related to task performance only partially support Quay's model, since both reward and response cost have a positive effect on performance in AD/HD. The psychophysiological findings related to skin conductance, however, are in line with the BIS/BAS model (Iaboni et al., 1997). The findings of Slusarek et al. (2001) concerning a positive effect of response cost in AD/HD, when intensity is high, may indicate diminished sensitivity to punishment. On the other hand, children with AD/HD showed smaller differences in heart rate, when comparing positive with negative feedback, which may indicate an underresponsive BAS in addition to an underresponsive BIS. When the chance of receiving reward diminishes, while response cost levels remain unchanged, response rate of children with AD/HD is similar to controls (Daugherty & Quay, 1991), in contrast to the predictions of the BIS/BAS model. Quay did not make any predictions concerning the timing of reinforcement allocation, motivation, or partial versus continuous reward. The behavioral findings in this review provide some support for the BIS/BAS model. However, only a few psychophysiological studies that may provide evidence for an underresponsive BIS (and BAS) in AD/HD are conducted.

By comparing the behavioral findings and the theoretical models related to reinforcement contingencies in AD/HD, some important shortcomings in this field of research are revealed. First, the number of studies contributing to the theoretical models is small: For example, only two studies measured heart rate and skin conductance under different reinforcement contingencies in children with AD/HD (Crone et al., 2003; Iaboni et al., 1997). To test the functionality of the models, research in this field should be more theory-driven.

Secondly, all five models showed insufficiencies in explaining the findings in this review (see Fig. 1). Some important issues, for example, related to response cost, were not taken into account by the models of Haenlein and Caul (1987), Douglas (1989), and Sonuga-Barke (2003). These shortcomings may touch upon the domain specificity of the frameworks that explain the role of reinforcement contingencies in AD/HD. The BIS/BAS model, for example, states hypotheses at a psychophysiological and neuro-anatomical level. However, specific suggestions at a performance level are minimal. The CEM, in contrast, explains AD/HD at both a performance and a psychophysiological level. The model lacks suggestions at a biochemical or neuro-anatomical level, which are important domains in explaining an aberrant sensitivity to reinforcement in AD/HD (Schultz, 2000, 2002; Sonuga-Barke, 2002, 2003). The findings in this review emphasize the complexity of the disorder: Different mechanisms (e.g., learning

Theoretical Models	Elevated reward threshold (Haenlein & Caul, 1987)	Enhanced reward sensitivity (Douglas, 1989)	Cognitive energetic model (Sergeant et al., 1999)	BAS/BIS model (Quay, 1988)	Dual pathway model (Sonuga-Barke, 1995)
Review Findings					
Improvement performance under reward and response cost (RC)	+		++	+/-	
Preference for immediate reward	+	++			++
No clear evidence of performance deterioration under partial reinforcement or under diminishing reinforcement ratio	+/-	+/-	+	-	+/-
No correlation between performance and motivation			+/-		
Psychophysiological less sensitive for reinforcement				+	+

Fig. 1. The level of support for each of the five theoretical models provided by the findings in this review. ‘-’, ‘+/-’, ‘+’ and ‘++’ indicate that there is, respectively, no, weak, some, or strong support. An empty box indicates that no predictions are specified by the theoretical model. BAS/BIS=behavioral activation system/behavioral inhibition system.

and arousal mechanisms) seem to underlie the behavior related to an aberrant reinforcement sensitivity. In our opinion, a future model of AD/HD needs to explain AD/HD from a multilevel perspective using a bio-psycho-social approach. The dual-pathway model (Sonuga-Barke, 2003) seems most extensive in describing the impact of reinforcement contingencies in AD/HD from diverse domains of functioning (e.g., biochemical and performal). Fig. 1 shows the five different models described in this review and the extent in which the models are supported by the findings presented here: None of the models seems able to explain all findings in this review.

In the studies reviewed here, different cognitive functions (e.g., inhibition, working memory, and time estimation) and reward choice behavior were evaluated. To overcome heterogeneity in the dependent measures in this review, we measured absolute changes in performance, without examining specific cognitive functions or behavior related to reinforcement choice. Research suggested that children with AD/HD may suffer from deficits in specific cognitive or executive functions (e.g., Pennington & Ozonoff, 1996). Whether the effect of reinforcement contingencies is function-specific remains an issue to be investigated.

An important issue is related to the variable ‘reinforcement condition.’ When comparing the different studies, we found heterogeneity in the reinforcement conditions: Different forms (e.g.,

money, tokens, and presents) or various intensities of reinforcement and reinforcement allocation policies may have a confounding effect on the dependent variables of studies in this review (Fowles, 1987; Schultz, 2000, 2002; Slusarek et al., 2001). Observing differences in reinforcement intensity is important, since several theoretical models consider the degree of reward as being significant in differentiating children with AD/HD from controls (e.g., Haenlein & Caul, 1987; Sergeant et al., 1999; Sonuga-Barke, 2002, 2003).

Another issue is the possible confounding effects related to the psychiatric groups. For example, a striking finding in this review is that not all studies take comorbid disorders into account. Although several researchers emphasized that ODD/CD groups perform different compared to children with AD/HD (Quay, 1988a, 1988b, 1988c), an AD/HD group was seldom compared to an ODD/CD group. Two studies that did include a separate ODD/CD group failed to find any differences in measures of inhibition, between children with AD/HD and ODD/CD (Oosterlaan & Sergeant, 1998; Scheres et al., 2001). Future research should seriously take possible diagnoses such as ODD and CD in children with AD/HD into account. In particular, when measuring psychophysiological responses, determining the presence of comorbid ODD and CD is important because children with AD/HD and children with ODD or CD are hypothesized to show different psychophysiological responses to reinforcement (Quay, 1988a, 1988b, 1988c).

A related question is the possible effect of development factors that may influence the impact of reinforcement in children with AD/HD. The prognosis and age of onset of CD, for example, are highly variable (Loeber, Burke, Lahey, Winters, & Zera, 2000); longitudinal cross-validation studies that systematically investigate the developmental factors in relation to reinforcement contingencies are necessary. Furthermore, the impact of gender on reinforcement sensitivity is never extensively investigated.

In half of the studies, performance of normal controls is superior compared to children with AD/HD. Possible performance improvement under conditions of reinforcement may not have been revealed due to a ceiling effect in the control group. The use of a paradigm in which task difficulty is independent on performance would be an elegant solution for this problem. A final issue is the face validity and content validity of the studies in this review. Differences in the intrinsic value of reward or response cost, for example, are difficult to measure and we may question whether 'response cost' or the loss of a reward refers to a form of punishment; children never actually lose. In addition, the test-retest reliability of most studies is (still) unknown. Finally, the ecological validity of the studies remains an issue to be investigated.

In conclusion, the findings support the suggestion that children with AD/HD are aberrantly sensitive to reinforcement and the importance of reinforcement in AD/HD is further emphasized by recent imaging research (Castellanos & Tannock, 2002). The findings are promising: Reward and response cost seem useful methods to improve task performance in children with AD/HD. Further research, however, needs to specify to what extent an aberrant sensitivity to reinforcement could account for the problems of inattention, impulsivity, and hyperactivity. In addition, the impact of different AD/HD subtypes, gender, and comorbid ODD and CD should be further investigated. For a more comprehensive investigation of the effect of reinforcement contingencies on task performance, intensity and form of reinforcement could be manipulated. There is a clear call for extension of the current theoretical frameworks, since all five models described above show shortcomings in explaining the findings in this review related to the impact of reinforcement contingencies in AD/HD.

References¹

- American Psychiatric Association. (1994). *Diagnostic and statistical manual of mental disorders*. (4th ed.). Washington, DC: Author.
- Angold, A., Costello, E. J., & Erkanli, A. (1999). Comorbidity. *Journal of Child Psychology and Psychiatry*, *40*, 57–87.
- August, G. J. (1987). Production deficiencies in free recall: A comparison of hyperactive, learning-disabled, and normal children. *Journal of Abnormal Child Psychology*, *15*, 429–440.
- *Barber, M. A., Milich, R., & Welsh, R. (1996). Effects of reinforcement schedule and task difficulty on the performance of attention deficit hyperactivity disorder and control boys. *Journal of Clinical Child Psychology*, *25*, 66–76.
- Barkley, R. A. (1997). Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of ADHD. *Psychological Bulletin*, *121*, 65–94.
- Barkley, R. A. (2002). Psychosocial treatments for attention-deficit/hyperactivity disorder in children. *Journal of Clinical Psychiatry*, *63*(Suppl. 12), 36–43.
- Borcherding, B., Thompson, K., Kruesi, M., Bartko, J., Rapoport, J. L., & Weingartner, H. (1998). Automatic and effortful processing in attention deficit/hyperactivity disorder. *Journal of Abnormal Child Psychology*, *16*, 333–345.
- Brownley, K. A., Hurwitz, B. E., & Schneiderman, N. (2000). Cardiovascular psychophysiology. In J. T. Cacioppo, L. G. Tassinary, & G.G. Bernston (Eds.), *Handbook of Psychophysiology* (2nd ed.) (pp. 224–264). Cambridge: Cambridge University Press.
- *Carlson, C. L., Mann, M., & Alexander, D. K. (2000). Effects of reward and response cost on the performance and motivation of children with AD/HD. *Cognitive Therapy and Research*, *24*, 87–98.
- *Carlson, C. L., & Tamm, L. (2000). Responsiveness of children with attention deficit-hyperactivity disorder to reward and response cost: Differential impact on performance and motivation. *Journal of Consulting and Clinical Psychology*, *68*, 73–83.
- Castellanos, F. X., & Tannock, R. (2002). Neuroscience of attention-deficit/hyperactivity disorder: The search for endophenotypes. *Nature Reviews. Neuroscience*, *3*, 617–628.
- *Crone, E. A., Jennings, J. R., & Van der Molen, M. W. (2003). Sensitivity to interference and response contingencies in attention-deficit/hyperactivity disorder. *Journal of Child Psychology and Psychiatry*, *44*, 224–226.
- Daugherty, T. K., & Quay, H. C. (1991). Response perseveration and delayed responding in childhood behavior disorders. *Journal of Child Psychology and Psychiatry*, *32*, 453–461.
- Douglas, V. I. (1989). Can Skinnerian theory explain attention deficit disorder. A reply to Barkley. In L. M. Bloomingdale, & J. A. Sergeant (Eds.), *Attention deficit disorder: Current concepts and emerging trends in attentional and behavioral disorders of childhood* (pp. 235–254). Elmsford, NY: Pergamon.
- Douglas, V. I. (1999). Cognitive control processes in attention-deficit/hyperactivity disorder. In H. C. Quay, & A. E. Hogan (Eds.), *Handbook of disruptive behavior disorders* (pp. 105–138). New York: Kluwer Academic Publishing/Plenum.
- *Douglas, V. I., & Parry, P. A. (1994). Effects of reward and non-reward on frustration and attention in attention deficit disorder. *Journal of Abnormal Child Psychology*, *22*, 281–302.
- Douglas, V. I., & Peters, K. G. (1979). Toward a clearer definition of the attentional deficit of hyperactive children. In G. A. Heale, & M. Lewis (Eds.), *Attention and cognitive development* (pp. 173–247). New York: Plenum.
- Fowles, D. C. (1980). The three-arousal model: Implications of Gray's two-factor learning theory for heart rate, electrodermal activity, and psychopathy. *Psychophysiology*, *17*, 87–104.
- Fowles, D. C. (1987). Psychophysiology and psychopathology: A motivational approach. *Psychophysiology*, *25*, 373–391.
- Gray, J. A. (1982). *The neuropsychology of anxiety: An inquiry into the functions of the septo-hippocampal system*. Oxford: Oxford University Press.
- Gray, J. A. (1987). Perspectives on anxiety and impulsivity: A commentary. *Journal of Research in Personality*, *21*, 493–509.
- Haenlein, M., & Caul, W. F. (1987). Attention deficit disorder with hyperactivity: A specific hypothesis of reward dysfunction. *Journal of the American Academy of Child and Adolescent Psychiatry*, *26*, 356–362.
- Hupp, S. D., Reitman, D., Northup, J., O'Callaghan, P., & LeBlanc, M. (2002). The effects of delayed rewards, tokens, and stimulant medication on sportsmanlike behavior with ADHD-diagnosed children. *Behavior Modification*, *26*, 148–162.

¹ References marked with an asterisk indicate studies included in this review.

- *Iaboni, F., Douglas, V. I., & Baker, A. G. (1995). Effects of reward and response costs on inhibition in AD/HD children. *Journal of Abnormal Child Psychology*, *104*, 232–240.
- *Iaboni, F., Douglas, V. I., & Ditto, B. (1997). Psychophysiological response of AD/HD children to reward and extinction. *Psychophysiology*, *34*, 116–123.
- Johansen, E. B., Aase, H., Meyer, A., & Sagvolden, T. (2002). Attention-deficit/hyperactivity disorder (ADHD) behaviour explained by dysfunctioning reinforcement and extinction processes. *Behavioural Brain Research*, *130*, 37–45.
- Kelly, M. L., & McCain, A. P. (1995). Promoting academic performance in inattentive children: The relative efficacy of school-home notes with and without response cost. *Behavior Modification*, *19*, 76–85.
- *Konrad, K., Guggel, S., Manz, A., & Scholl, M. (2000). Lack of inhibition: A motivational deficit in children with attention deficit/hyperactivity disorder and children with traumatic brain injury. *Child Neuropsychology*, *6*, 286–296.
- Loeber, R., Burke, J. D., Lahey, B. B., Winters, A., & Zera, M. (2000). Oppositional defiant and conduct disorder: A review of the past 10 years: Part I. *Journal of the American Academy of Child and Adolescent Psychiatry*, *39*, 1468–1484.
- *McInerney, R. J., & Kerns, K. A. (2003). Time reproduction in children with ADHD: Motivation matters. *Child Neuropsychology*, *9*, 91–108.
- *Oosterlaan, J., & Sergeant, J. A. (1998). Effects of reward and response cost on response inhibition in AD/HD, disruptive, anxious, and normal children. *Journal of Abnormal Child Psychology*, *26*, 161–174.
- Pelham, P. A., Carlson, C., Sams, S. E., Vallano, G., Dixon, M. J., & Hoza, B. (1993). Separate and combined effects of methylphenidate and behavior modification on boys with attention deficit-hyperactivity disorder in the classroom. *Journal of Consulting and Clinical Psychology*, *61*, 506–515.
- Pelham, P. A., & Hinshaw, S. P. (1992). Behavioral intervention of attention deficit hyperactivity disorder. In S. M. Turner, K. S. Calhoun, & H. E. Adams (Eds.), *Handbook of Clinical Behavior Therapy*, vol. 2 (pp. 259–283). New York: Wiley.
- *Pelham, W. E., Milich, R., & Walker, J. L. (1986). Effects of continuous and partial reinforcement and methylphenidate on learning in children with attention deficit disorder. *Journal of Abnormal Psychology*, *95*, 319–325.
- Pennington, B. F., & Ozonoff, S. (1996). Executive functions and developmental psychopathology. *Journal of Clinical Child Psychology and Psychiatry*, *37*, 51–78.
- Quay, H. C. (1988a). Attention deficit disorder and the behavioral inhibition system: The relevance of the neuropsychological theory of Jeffrey A. Gray. In L. M. Bloomingdale, & J. A. Sergeant (Eds.), *Attention deficit disorder: Criteria, cognition, intervention* (pp. 117–125). Oxford: Pergamon.
- Quay, H. C. (1988b). The behavioral reward and inhibition system in childhood behaviour disorder. In L. M. Bloomingdale (Ed.), *Attention Deficit Disorder*, vol. 3 (pp. 176–185). Oxford: Pergamon.
- Quay, H. C. (1988c). Reward, inhibition, and attention deficit hyperactivity disorder. *Journal of the American Academy of Child and Adolescent Psychiatry*, *27*, 262–263.
- Quay, H. C. (1997). Inhibition and attention deficit hyperactivity disorder. *Journal of Abnormal Child Psychology*, *25*, 7–13.
- Rappoport, M. D., Murphy, H. A., & Bailey, J. S. (1982). Ritalin versus response cost in the control of hyperactive children: A within-subject comparison. *Journal of Applied Behavior Analysis*, *15*, 205–216.
- *Rappoport, M. D., Tucker, S. B., DuPaul, G. J., Merlo, M., & Stoner, G. (1986). Hyperactivity and frustration: The influence of control over and size of reward in delay gratification. *Journal of Abnormal Child Psychology*, *14*, 191–204.
- Sagvolden, T., Aase, H., Zeiner, P., & Berger, D. (1998). Altered reinforcement mechanisms in attention-deficit/hyperactivity disorder. *Behavioural Brain Research*, *94*, 61–71.
- Sagvolden, T., Johansen, E. B., Aase, H., & Russel, V. A. (in press). A dynamic developmental theory of attention-deficit/hyperactivity disorder (ADHD) predominantly hyperactive/impulsive and combined subtypes. *Behavioral and Brain Sciences*.
- Sagvolden, T., & Sergeant, J. A. (1998). Attention deficit/hyperactivity disorder—From brain functions to behaviour. *Behavioural Brain Research*, *94*, 1–10.
- Sanders, A. F. (1983). Towards a model of stress and human performance. *Acta Psychologica*, *53*, 61–97.
- *Scheres, A., Oosterlaan, J., & Sergeant, J. A. (2001). Response inhibition in children with DSM-IV subtypes of AD/HD and related disruptive disorders: The role of reward. *Child Neuropsychology*, *7*, 172–189.
- Schultz, W. (2000). Multiple reward signals in the brain. *Nature Reviews. Neuroscience*, *1*, 199–207.
- Schultz, W. (2002). Getting formal with dopamine and reward. *Neuron*, *10*, 241–263.
- Sergeant, J. A. (2000). The cognitive-energetic model: An empirical approach to attention-deficit hyperactivity disorder. *Neuroscience and Biobehavioral Reviews*, *24*, 7–12.

- Sergeant, J. A., Oosterlaan, J., & Van der Meere, J. J. (1999). Information processing in attention-deficit/hyperactivity disorder. In H. C. Quay, & A. E. Hogan (Eds.), *Handbook of disruptive behavior disorders* (pp. 75–104). New York: Plenum.
- Sergeant, J. A., & Scholten, C. A. (1985). On resource strategy limitations in hyperactivity: Cognitive impulsivity reconsidered. *Journal of Child Psychology and Psychiatry*, *26*, 97–109.
- Sergeant, J. A., & Van der Meere, J. J. (1990). Converging approaches on localizing the hyperactivity deficit. In B. B. Lahey, & A. E. Kazdin (Eds.), *Advancements in Clinical Child Psychology*, vol. 13 (pp. 207–245). New York: Plenum.
- *Slusarek, M., Velling, S., Bunk, D., & Eggers, C. (2001). Motivational effects on inhibitory control in children with AD/HD. *Journal of the American Academy of Child and Adolescent Psychiatry*, *40*, 355–363.
- *Solanto, M. V. (1990). The effects of reinforcement and response—Cost on a delayed response task in children with attention deficit hyperactivity disorder: A research note. *Journal of Child Psychology and Psychiatry*, *31*, 803–808.
- *Solanto, M. V., Wender, E. H., & Bartell, S. S. (1997). Effects of methylphenidate and behavioral contingencies on sustained attention in attention-deficit hyperactivity disorder: A test of the reward dysfunction hypothesis. *Journal of Child and Adolescent Psychopharmacology*, *7*, 123–136.
- Sonuga-Barke, E. J. (2002). Psychological heterogeneity in AD/HD—A dual pathway model of behaviour and cognition. *Behavioural Brain Research*, *10*, 29–36.
- Sonuga-Barke, E. J. (2003). The dual pathway model of AD/HD: An elaboration of neuro-developmental characteristics. *Neuroscience and Biobehavioral Reviews*, *27*, 593–604.
- *Sonuga-Barke, E. J. S., Taylor, E., Sembi, E., & Smith, J. (1992). Hyperactivity and delay aversion: I. The effect of delay on choice. *Journal of Child Psychology and Psychiatry*, *33*, 387–398.
- *Tripp, G., & Alsop, B. (1999). Sensitivity to reward frequency in boys with attention deficit hyperactivity disorder. *Journal of Clinical Child Psychology*, *28*, 366–375.
- *Tripp, G., & Alsop, B. (2001). Sensitivity to reward delay in children with attention deficit hyperactivity disorder (AD/HD). *Journal of Child Psychology and Psychiatry*, *42*, 691–698.
- *Van der Meere, J., Hughes, K. A., Börger, N., & Sallee, F. R. (1995). The effect of reward on sustained attention in AD/HD children with and without CD. In J. A. Sergeant (Ed.), *European approach to hyperkinetic disorder* (pp. 241–253). Zurich, Switzerland: Fotorotar.
- Van der Meere, J., Shalev, R., Borger, N., & Gross-Tsur, V. (1995). Sustained attention, activation and MPH in ADHD: A research note. *Journal of Child Psychology and Psychiatry*, *36*, 697–703.
- Wender, P. H. (1972). The minimal brain dysfunction syndrome in children. *Journal of Nervous and Mental Disease*, *155*, 55–71.
- *Wilkison, P. C., Kirscher, J. C., McMahon, W. M., & Sloane, H. N. (1995). Effects of methylphenidate on reward strength in boys with attention-deficit/hyperactivity disorder. *Journal of the American Academy of Child and Adolescent Psychiatry*, *34*, 897–901.