REVIEW

Systematic Review: Attention-Deficit/Hyperactivity Disorder and Instrumental Learning

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Objective: Although instrumental learning deficits are, among other deficits, assumed to contribute to attention-deficit/hyperactivity disorder (ADHD), no comprehensive systematic review of instrumental learning deficits in ADHD exists. This review examines differences between ADHD and typically developing (TD) children in basic instrumental learning and the effects of reinforcement form, magnitude, schedule, and complexity, as well as effects of medication, on instrumental learning in children with ADHD.

Method: A systematic search of PubMed, PsyINFO, CINAHL, EMBASE+EMBASE CLASSIC, ERIC, and Web of Science was conducted for articles up to March 16, 2020. Experimental studies comparing instrumental learning between groups (ADHD versus TD) or a manipulation of reinforcement/medication within an ADHD sample were included. Quality of studies was assessed with an adapted version of the Hombrados and Waddington criteria to assess risk of bias in (quasi-) experimental studies.

Results: A total of 19 studies from among 3,384 non-duplicate screened articles were included. No difference in basic instrumental learning was found between children with ADHD and TD children, nor effects of form or magnitude of reinforcement. Results regarding reinforcement schedule and reversal learning were mixed, but children with ADHD seemed to show deficits in conditional discrimination learning compared to TD children. Methylphenidate improved instrumental learning in children with ADHD. Quality assessment showed poor quality of studies with respect to sample sizes and outcome and missing data reporting.

Conclusion: The review identified very few and highly heterogenous studies, with inconsistent findings. No clear deficit was found in instrumental learning under laboratory conditions. Children with ADHD do show deficits in complex forms of learning, that is, conditional discrimination learning. Clearly more research is needed, using more similar task designs and manipulations.

Key words: ADHD, instrumental learning, systematic review

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Attention-deficit/hyperactivity disorder (ADHD) is a common psychiatric disorder characterized by symptoms of inattention and/or hyperactivity/impulsivity, with prevalence rates of 3% to 7%[1] and poor prognosis if not treated effectively.[2] Severe impairments across a broad range of domains and high comorbidity rates are reported, indicating the burden of the disorder.[3−5]

The primary evidence-based nonpharmacological treatment for preschool and school-aged children with ADHD is behavioral parent and teacher training (BPT).[6] However, although positive effects on behavioral problems, parenting, and parents' feelings of competence are reported, reductions in core ADHD symptoms, as rated by independent observers, are mostly not significant.[7] Effect sizes for change in problem behavior and parenting are moderate, leaving room for improvement. Furthermore, they become smaller at follow-up, indicating limited sustainability of effects.[8]

Behavioral parent and teacher training programs are largely based on reinforcement learning principles; parents and/or teachers provide positive reinforcement for appropriate behavior and ignore or punish nonadaptive behavior, with the aim of increasing the frequency of adaptive behavior.[9] Most BPT programs do not take into account potential instrumental learning deficits in ADHD in their design and delivery.[10] Yet, motivational deficits (eg, altered reward/punishment sensitivity and reinforcement learning) are assumed to be one of the underlying causes of ADHD, among other pathways.[11] Theoretically, instrumental learning deficits may have important implications for how BPT programs for ADHD should be conceived and delivered and thus may contribute to improving effectiveness. These insights could indicate how specific elements of learning should be targeted according to the deficits and needs of children with ADHD.[9] However, to date there is no clear and comprehensive overview of instrumental learning in children with ADHD.

In several theoretical accounts, ADHD symptomatology is assumed to arise from altered reinforcement learning.[12–14] The Dynamic Developmental Theory (DDT) posits a deficiency in dopaminergic activity in ADHD that gives rise to altered reinforcement processing.[12] Hypodopaminergic functioning is assumed to lead to a reduced time window in which an association between behavior and subsequent reinforcement can be established, impairing learning, especially when reinforcement is delayed.[12] The Dopamine Transfer Deficit (DTD) hypothesis assumes a dysfunction in the transfer of dopaminergic activity from reward delivery to reward cues, resulting in impaired learning under conditions of delayed or discontinuous reinforcement in individuals with ADHD.[13] Both theories suggest that because of this altered dopaminergic activity, children with ADHD are impaired in the acquisition of behavior under conditions of partial or discontinuous reinforcement, as reinforcement is delayed or intermittently absent.[12,13] Douglas proposes that impaired self-regulation in children with ADHD leads to abnormal responses to reinforcement,[14] evidenced by an increased tendency to seek immediate reward and salient reinforcers together with heightened vulnerability to the arousing and distracting effects of rewards.[14] The assumption is that frustration arises when anticipated rewards are not delivered, as under partial or delayed reinforcement, potentially interfering with instrumental learning.[14] In addition, Douglas states that children with ADHD are more averse to punishment, which may also interfere with learning.[14] Other theoretical accounts, for example, the delay aversion hypothesis, address emotional responses to, and avoidance of, delayed reinforcement.[15] However, the focus of the current review is on learning *per se,* not sensitivity and emotional responsivity to reinforcement more generally.

In general, 3 elements are important in instrumental learning: (1) the discriminative stimulus that precedes the behavior (antecedent); (2) the behavior; and (3) the consequence following the behavior (reinforcement/punishment).[16] The theories above make several predictions regarding the effects of reinforcement and punishment. All theories predict deficient learning when reinforcement is delivered on a partial schedule or is delayed. Douglas assumes that children with ADHD are prone to seek immediate and salient stimuli (rewards) and are strongly averse to punishment, thereby interfering with learning.[12–14]

With regard to evidence for instrumental learning deficits in ADHD, in 2005, Luman *et al.* reviewed the broader sensitivity to reinforcement manipulations in children with ADHD. Findings regarding instrumental learning deficits and the impact of schedule (partial versus continuous reinforcement) on performance in ADHD were mixed, with some studies indicating poorer instrumental learning performance in those with ADHD under partial reinforcement.[17] Other aspects such as form or magnitude of the reinforcer may also affect instrumental learning, as more salient reinforcers are proposed to have more impact in ADHD.[14] Studies have shown differential effects of the form (eg, social versus monetary) or magnitude (small versus big monetary) of reward in children with ADHD compared to TD children, with better performance (eg, on working memory or inhibition tasks) under monetary reward and with large (monetary) magnitude of reward.[17–19] This may indicate a parallel differential effect of magnitude and form of reinforcement on actual instrumental learning performance as well.

More complex forms of learning that better match children's everyday learning experiences may also be affected in ADHD. Based on behavioral observations, it is often argued that children with ADHD fail to take into account environmental cues and expectations, and have particular difficulty recognizing the discriminative events (antecedents) indicating which behavior will lead to a positive outcome (ie, in one context [eg, play time], active behavior is adaptive, whereas in another it is not [eg, classroom]).[20] These problems mirror conditional discrimination learning, in which the response depends on the context or cue stimuli preceding the behavior. Equally relevant is reversal learning, in which reward probabilities of 2 or more responses are reversed throughout the learning task, assessing how fast new learning occurs when prior response–outcome associations have been formed. In instrumental learning in everyday life, prior associations are mostly already present.

Finally, some theories of instrumental learning in children with ADHD assume that altered dopaminergic functioning underlies ADHD symptomatology.[12,13] Stimulant medication, such as methylphenidate, often prescribed for individuals with ADHD, is suggested to enhance dopamine signaling and to facilitate the responses to predictive cues and reinforcement learning.[21,22] Thus, the influence of medication on instrumental learning should also be investigated.

To the best of our knowledge, no review has compared more complex forms of instrumental learning in children with and without ADHD, or the influence of medication on instrumental learning in children with ADHD. The earlier review by Luman *et al.* addressed broader sensitivity to reinforcement and not solely instrumental learning, that is, the learning of responses and stimulus–response relations as a result of reinforcement or punishment.[17] The current review addresses these topics with the aim of developing a comprehensive understanding of instrumental learning in children with ADHD relative to TD children. Empirical studies examining instrumental learning in children with ADHD compared to TD children are reviewed. Five questions are addressed: (1) Do children with ADHD differ from TD children on instrumental learning tasks when no other aspect of reinforcement (eg, form, magnitude or complexity) is manipulated? (2) How do differences in reinforcement form (ie, the nature of reinforcement [eg, candy versus toy or reward versus response cost]) or magnitude (the magnitude of the reinforcer [eg, 10 cents versus 20 cents]) modulate basic instrumental learning in children with ADHD versus TD children? (3) How does the reinforcement schedule (ie, timing and frequency [eg, partial versus continuous reinforcement]) influence basic instrumental learning in children with ADHD and TD children? (4) Do children with ADHD and TD children perform differently under more complex forms of instrumental learning (ie, where aspects other than the simple behavior−consequence relation need to be taken into account)? (5) Among children with ADHD, does medication for ADHD symptom management have an impact on instrumental learning?

Based on theories and studies described above, we expected children with ADHD (1) to demonstrate performance deficits on basic instrumental learning tasks as compared to TD children[12−14]; (2) to perform better with more salient stimuli as reinforcers, compared to less salient stimuli[14]; (3) to perform worse under partial reinforcement conditions, compared to TD children[12,13]; and (4) to perform worse in complex forms of instrumental learning, such as conditional discrimination learning and reversal learning, compared to TD children.[20] Finally (5) we expected a positive impact of methylphenidate on instrumental learning in children with ADHD. [12,13,21]

METHOD

This systematic review and associated protocol are registered in PROSPERO (protocol CRD42020170117 at https://www.crd.york.ac.uk/prospero/). It was conducted and reported in accordance with the PRISMA reporting guidelines (see Figure S1, available online).

Search Strategy

Articles up to March 16, 2020, were included in the search. No start date was applied to allow inclusion of older studies. Electronic databases (PubMed (MEDLINE), PsyINFO, CINAHL, EMBASE+EMBASE CLASSIC, ERIC, Web of Science) were searched for relevant journal articles. The following search terms and synonyms were used: operant conditioning, instrumental conditioning, operant learning, instrumental learning, operant training, instrumental training, reinforcement, punishment, response cost and reward, in combination with the following search terms and synonyms: Attention Deficit Hyperactivity Disorder, Attention Deficit Disorder, Impulsivity and Hyperkinetic Disorder. Subject headings were used when available and relevant (full search syntax: Supplement 1, available online). Wildcards were not used, as search terms included all relevant terms and synonyms. Reference lists of identified articles were hand searched for additional relevant studies.

Inclusion Criteria

Study inclusion criteria were as follows: (1) investigating a sample of children <18 years of age with an (estimated) IQ of ≥70; (2) a sample size of ≥5 children with a validated clinical diagnosis of attention-deficit/hyperactivity disorder, attention-deficit disorder (ADD), or hyperkinetic disorder, or children reaching criterion for ADHD on a normed ADHD questionnaire or interview; and (3) instrumental learning investigated through a task in which reinforcement or a manipulation of reinforcement (ie, form/magnitude, schedule, complexity) is applied, and the study involves a comparison between groups (ie, ADHD versus TD) or a manipulation of reinforcement or medication within an ADHD sample (no TD comparison sample required in the latter case). Studies evaluating sensitivity to reinforcement or performance in tasks other than instrumental learning tasks (eg, working memory, signal detection, go/no-go tasks) or probing processes such as executive functioning, temporal discounting, or delay aversion were excluded.

Quality Assessment

The quality of included studies was assessed by 2 independent raters (AH, HDM), using an adaptation of the Hombrados and Waddington criteria for assessment of risk of bias in (quasi-) experimental studies (see Table S1 and Table S2, available online).[23] In case of disagreement, the whole review team read the paper and reached consensus.

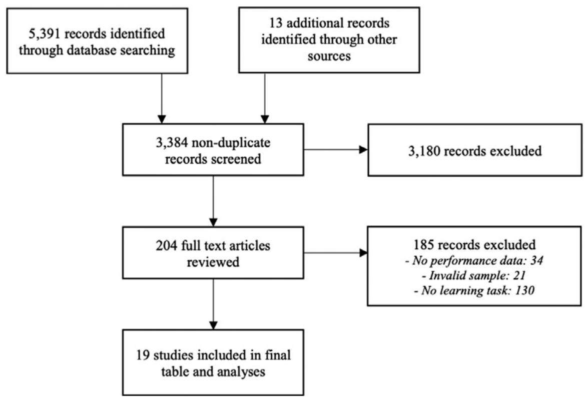
Screening and Selection of Studies

A total of 3,384 titles and abstracts were retrieved and independently screened by 2 reviewers; 204 articles were identified as possibly relevant. Full-text articles were read to determine inclusion or exclusion. In case of disagreement, the papers were discussed by the review team. In all, 19 studies met inclusion criteria and were included in the review (Figure 1).

Outcome Measures

Outcome measures were behavioral measurements reflecting instrumental learning, these included the following: (1) percentage correct, (2) percentage of errors, (3) mean accuracy, (4) number of correctly completed items, (5) relative

FIGURE 1 Flowchart of Selection Process for Included Articles



frequency of correct choices, (6) number of trials required to reach criterion, (7) number of errors before reaching criterion, (8) perseverative errors, and (9) correct trials as a function of completed trials.

Data Extraction and Statistical Analysis

Two reviewers completed data extraction independently, and results were compared. Disagreement was resolved by the entire review team. The following data were extracted for included papers: (1) mean age and range, (2) mean and range of IQ, (3) assessment process to validate ADHD diagnosis, (4) medication use in ADHD sample, (5) sample size, (6) comorbidity and confounding variables (eg, age, IQ, ODD/CD, race/ethnicity), (6) task description, (7) study design, (8) outcome measures, and (9) mean, SD, and group sizes to calculate effect sizes.

Calculation of Effect Size. Where sufficient data were reported or retrieved in a study, effect sizes between groups or instrumental learning manipulations were calculated using standardized mean difference (SMD). Next, a weighted average effect size was calculated when appropriate.[24] The review team decided, by consensus, whether weighted effect sizes could be calculated, based on the following criteria: (1) studies investigated similar samples; (2) similar experimental manipulations and tasks were compared; (3) similar outcome variables were reported; and (4) effects reported were in the same direction.[24]

RESULTS

A total of 19 studies met the inclusion criteria (Table 1).[25-43] Some studies (n = 6) addressed several review questions and are thus discussed multiple times. For studies in which data to calculate effect sizes were not included (n = 9), authors were contacted by e-mail. Data from 6 studies were not available (nonresponse: n = 1; authors indicated that data were no longer available/could not be retrieved: n = 5). Effect sizes as originally reported in the papers are added in Table S3, available online. A range of reasons, based on criteria described above (eg, differences in samples investigated, tasks used, reinforcement manipulations performed, or effects reported), prevented an aggregated statistical synthesis (ie, a meta-analysis) of the included studies and calculation of weighted average effect sizes, necessitating narrative summaries. Detailed argumentation for every category investigated can be found in Table S4, available online.

Quality Assessment

Of 114 individual ratings (6 criteria for 19 studies), 45.61% (n = 52) were rated as good, 29.82% (n = 34) were rated as moderate, and 24.56% (n = 28) were rated as poor. Two studies had no category rated as poor. A total of 17 had at least 1 category rated as poor, of which 6 (31.58%) had 2 or more. Sample size, selective outcome reporting, and failure to report missing data were the most common limitations (Figure 2).

Basic Instrumental Learning

Two studies investigated differences in instrumental learning between children with ADHD and TD children without other reinforcement manipulations. Oades and Müller[25] investigated performance on an instrumental learning task in which participants needed to learn the "safe room" in a virtual house. Correct responses were followed by points, incorrect responses by point loss. No significant difference in the number of trials to criterion was found between groups. In the second study,[26] children were tasked with learning the correct island to travel to. Point-based reward and response cost were simultaneously paired with pleasant or unpleasant sounds and images. The task was completed twice, during an acquisition and a reversal phase. As the reversal phase followed a manipulation of sleep, only data from the acquisition phase are considered here. Although there was a large difference in the relative frequency of correct responses for children with ADHD and TD children, this was not statistically significant ($d = 1.146$; large).

Results of both studies seem to indicate no deficit in basic instrumental learning in children with ADHD under conditions of reward and response cost.

Forms of Reinforcement

Three studies investigated the effect of form or magnitude of reinforcement on learning. Aase and Sagvolden[27]

TABLE 1 Characteristics of Included Studies

Study	Participants	Age	Confounding variables	Assessment procedure ADHD sample	Study Design – reinforcement manipulation[a]	Outcome Measurement	Results	Effect sizes
Instrumental learning								
Oades and Müller (1997)[25]	13 ADHD (off medication) 13 TD (11 TS)	7.4–14.3 y	Age: matched IQ: SIG ODD/CD: *Missing* Race/ethnicity: *Missing*	Prior ADHD diagnosis (*DSM-IIIR*) Questionnaire: Brief Conners parent-teacher assessments (parents and ward staff)	-Between-subjects: Diagnosis Associative learning RF: points	No. of trials to reach criterion	No group differences	/
Wiesner *et al.* (2017)[26]	17 ADHD + ODD/CD *boys* 17 TD *boys*	8–12 y	Age: ND IQ: ND ODD/CD: *Missing* Race/ethnicity: *Missing*	Prior ADHD diagnosis Interview: K-SADS (parents and children)	Between-subjects: Diagnosis R and RC RF: picture, sound and points	Relative frequencies of correct choices	No main effect of diagnosis	Between-subjects: 1.146
Form of reinforcement								
Aase and Sagvolden (2006)[27]	28 ADHD *boys* (off medication) 28 TD *boys*	8–12 y	Age: matched IQ: SIG ODD/CD: *Missing* Race/ethnicity: *Missing*	Prior ADHD diagnosis (*DSM-IV*) Semi-structured interview (parents) Questionnaires: DBRDS + CBCL (parents and teacher)	Between-subjects: Diagnosis Age: young vs older Within-subjects: Schedule: frequent (VI 2 s) vs infrequent (VI 20 s) RF: cartoon vs tangible	% Correct	Age × diagnosis: TD > ADHD in young group only Diagnosis × schedule × RF (*No follow-up analyses*)	/
Cunningham and Knights (1978)[28]	48 Hyperactive *boys* 48 TD *boys*	7 y 9 mo to 12 y 4 mo	Age: matched IQ: *Missing* ODD/CD: *Missing* Race/ethnicity: *Missing*	Questionnaire: Conners Teacher Rating Scale (teacher)[a]	Between-subjects: Diagnosis Age Feedback: R vs RC Schedule: CR vs PR (50%) RF: marbles	*Learning*: No. of trials to reach criterion *Extinction:* % correct	*Learning*: Age × diagnosis: Young HA: RC < R Old HA: RC = R *Extinction*: Feedback × diagnosis Both groups RC < R; larger effect in TD	*Learning*[b]*–Within schedule: feedback (R vs RC)* Young HA, CR: 2.264 Young HA, PR: 1.324 Older HA, CR: 1.118 Older HA, PR: 0.939 *Extinction*[b]*–Within Schedule: Feedback (R vs RC)* Young HA, CR: 2.794 Young HA, PR: 2.248 Old HA, CR: 3.690 Old HA, PR: 0.211
Luman *et al.* (2009)[29]	23 ADHD (off medication) 30 TD (21 ASD)	8–12 y	Age: ND IQ: ND ODD/CD: SIG Race/ethnicity: *Missing*	Prior ADHD diagnosis Interview: P-DISC-IV (parents) Questionnaire: DBDRS (parents and teacher)	Between-subjects: Diagnosis Within-subjects: Schedule: Infrequent (12.5%) vs frequent (50%) Magnitude of reward: Small (2 cents) vs large (8 cents) RF: money	% Correct	Main effect of diagnosis: ADHD < TD Main effect of frequency Frequency × diagnosis ADHD: frequent = infrequent TD: infrequent > frequent	Between-subjects: 1.003 Within-subjects: Magnitude ADHD: 0.071 TD[c]: 0.052
Reinforcement schedule								
Aase and Sagvolden (2006)[27]	28 ADHD *boys* (off medication) 28 TD *boys*	8–12 y	Age: matched IQ: SIG ODD/CD: *Missing* Race/ethnicity: *Missing*	Prior ADHD diagnosis (*DSM-IV*) Semi-structured interview (parents) Questionnaires: DBRDS + CBCL (parents and teacher)	Between-subjects: Diagnosis Age: young vs older Within-subjects: Schedule: frequent (VI 2 s) vs infrequent (VI 20 sec) RF: cartoon vs tangible	% Correct	Age × diagnosis: TD > ADHD in young group only Diagnosis × schedule × RF	/
Barber *et al.* (1996)[30]	45 ADHD *boys* (off medication) 45 TD *boys*	7–10 y	Age: ND IQ: correlated with performance (used as covariate) ODD/CD: *Missing* Race/ethnicity: *Missing* SES: ND	Prior ADHD diagnosis (*DSM-III*) Interview (parents and child) Questionnaire: Conner's teacher questionnaire (teacher) Observation child	Between-subjects: Diagnosis Schedule: CR vs PR (50%) vs NR Within-subjects: Task: related vs unrelated word pairs Continuous feedback RF: money	% Correct	No main effect of diagnosis Main effect of schedule Related task: PR < CR/NR Unrelated task: CR > PR/NR	/

(continued)

TABLE 1 Continued

Study	Participants	Age	Confounding variables	Assessment procedure ADHD sample	Study Design – reinforcement manipulation[a]	Outcome Measurement	Results	Effect sizes
Cunningham and Knights (1978)[28]	48 Hyperactive *boys*[a] 48 TD *boys*	7 y 9 mo to 12 y 4 mo	Age: matched IQ: *Missing* ODD/CD: *Missing* Race/ethnicity: *Missing*	Questionnaire: Conners Teacher Rating Scale (teacher)	Between-subjects: Diagnosis Age Feedback: R vs RC Schedule: CR vs PR (50%) RF: marbles	*Learning*: No. of trials to criterion *Extinction*: % correct	No main or interaction effects regarding Schedule	*Learning*[b]*–Within Feedback: Schedule (CR vs PR)* Young HA, R: 0.094 Young HA, RC: 0.102 Older HA, R: 1.424 Older HA, RC: 0 *Extinction*[b]*–Within Feedback: Schedule (CR vs PR)* Young HA, R: 0.152 Young HA, RC: 0.895 Old HA, R: 12.969 Old HA, RC: 1.216
De Meyer *et al.* (2019a)[31]	55 ADHD (off medication) 64 TD	8–12 y	Age: ND IQ: SIG ODD/CD: SIG Race/ethnicity: *Missing* Gender: ND	Prior ADHD diagnosis (*DSM-IV*) Interview: PDISC or K-SADS (parents) Questionnaire: DBDRS (parents)	Between-subjects: Diagnosis Schedule: CR vs PR vs STR RF: candy (primary) and picture thumbs up (secondary)	*Learning*: No. of trials to reach criterion *Extinction:* No. of correct trials	*Learning:* Main effect of Schedule: CR < STR < PR No main effect of diagnosis *Extinction:* Main effect of schedule: CR < STR, PR No main effect of Diagnosis	*Learning*[b]*Between-subjects: Diagnosis* CR: 0.559 STR: 0.078 PR: 0.056 *Between-subjects: Schedule* CR vs STR: 1.211 CR vs PR: 1.812 STR vs PR: 1.356 *Extinction*[b]*Between-subjects: Diagnosis* CR: 0.349 STR: 1.089 PR: 0.512 *Between-subjects: Schedule* CR vs STR: 1.803 CR vs PR: 1.486 STR vs PR: 0.034
Luman *et al.* (2015)[32]	23 ADHD 27 TD	8–12 y	Age: ND IQ: SIG ODD: SIG CD: *Missing* Race/ethnicity: *Missing* Gender: ND	Prior ADHD diagnosis Interview: P-DISC (parents) Questionnaire: DBDRS (parents and teacher)	Between-subjects: Diagnosis Within-subjects: Medication: placebo vs 3 doses MPH Schedule: fully informative vs probabilistic (88%) R and RC RF: thumbs up/down and money gain/loss	Mean accuracy	*Diagnosis:* Main effect of Feedback: informative > probabilistic No main or interaction effect involving diagnosis	Within ADHD: Feedback: Block 1: 0.647 Block 2: 2.538 Block 3: 5.021 Block 4: 2.404 Within TD: Feedback: Block 1: 11.075 Block 2: 1.849 Block 3: 2.307 Block 4: 2.393
Luman *et al.* (2020)[33]	58 ADHD (off medication) 58 TD	7–13 y	Age: ND IQ: SIG ODD/CD: *Missing* Race/ethnicity: *Missing* Gender: ND	Prior ADHD diagnosis (*DSM-IV*) Questionnaire: DBDRS (parents and teacher)	Between-subjects: Diagnosis Within-subjects: Feedback probability: 100-0 vs 85-15 vs 70-30 R and RC RF: thumbs up/down and money gain/loss	- *Learning*: (1) No. of blocks to reach criterion (2) Learning in first block *Test:* (1) % correct (2) % correct of original pairs	- *Learning* (1) Main effect of diagnosis: ADHD > TD (2) Main effect of diagnosis: ADHD < TD (1) Interaction diagnosis × trial: ADHD < TD only in later trials (2) Interaction diagnosis × feedback: ADHD < TD for 100-0 and 85-15 *Test:* (1) Main effect of diagnosis: ADHD < TD	*Learning–Between-subjects* (1) 0.633 (2) Across trials: 2.066 100-0: 1.108 85-15: 1.200 70-30: 0.229 *Test–Between-subjects:* (1) 1.196 (2) 1.170

(continued)

TABLE 1 Continued

Study	Participants	Age	Confounding variables	Assessment procedure ADHD sample	Study Design – reinforcement manipulation[a]	Outcome Measurement	Results	Effect sizes
							(2) Main effect of diagnosis: ADHD < TD	
Luman *et al.* (2009)[29]	23 ADHD (off medication) 30 TD (21 ASD)	8–12 y	Age: ND IQ: ND ODD/CD: SIG Race/ethnicity: *Missing*	Prior ADHD diagnosis Interview: P-DISC-IV (parents) Questionnaire: DBDRS (parents and teacher)	Between-subjects: Diagnosis- Within-subjects: Schedule: infrequent (12.5%) vs frequent (50%) Magnitude reward: small (2 cents) vs large (8 cents) RF: money	% Correct	Main effect diagnosis: ADHD < TD Main effect of frequency Frequency × diagnosis ADHD: frequent = infrequent TD: infrequent > frequent	Between-subjects: 1.003 Within-subjects: Frequency ADHD: 0.054 TD: 1.142
Parry and Douglas (1983)[34]	33 Hyperactive 33 TD	HA: 9.6 TD: 9.5	Age: matched IQ: matched ODD/CD: *Missing* Race/ethnicity: *Missing* SES: matched Gender: matched	Interview (parents and teacher) Questionnaire (parents and teacher)	Between-subjects: Diagnosis Schedule: CR vs PR (50%) vs modified PR Two tasks (flower and number concept task) RF: marbles	Mean trials to criterion	Main effect of Diagnosis: HA > TD Main effect of schedule Group × schedule *(only flower concept task)* CR: HA = TD PR (both): HA > TD	*Flower concept task: / Number concept task:* Between-subjects: CR: 0.645 PR: 1.555 Modified PR: 0.896
Pelham *et al.* (1986)[35]	30 ADHD	5 y 11 mo to 11 y	Age: ND IQ: ND ODD/CD: *Missing* Race/ethnicity: *Missing*	Interview (parents) Questionnaire (teacher)	Within-subjects: Medication: MPH vs placebo Between-subjects: Schedule: CR vs PR vs NR Continuous verbal praise/ encouragement RF: points exchangeable for money	Mean number of errors	Contrasts: CR = PR CR+PR combined < NR	/
Wigal *et al.* (1998)[36]	22 ADHD 20 TD	7–9 y	Age: *Missing* IQ: *Missing* ODD/CD: *Missing* Race/ethnicity: *Missing* Gender: matched	Interview (*not specified*) Questionnaire: IOWA Conners (parents and teacher)	Between-subjects: Diagnosis Schedule: CR vs PR (but is STR, starts with CR) Within-subjects: Phase Trial Acquisition and extinction Continuous feedback RF: black tokens (nickel) and red tokens (non-reward)	Number of words spelled correctly	Main effect of diagnosis Diagnosis × phase × trial: TD learned words quicker compared to ADHD	/
Complex forms of operant learning: conditional discrimination learning								
De Meyer *et al.* (2019b)[37]	51 ADHD (off medication) 56 TD	8–12 y	Age: ND IQ: SIG ODD/CD: SIG Race/ethnicity: *Missing* Gender: ND	Prior ADHD diagnosis (*DSM-IV*) Interview: PDISC or K-SADS (parents) Questionnaire: DBDRS (parents)	Between-subjects: Diagnosis Within-subjects: Delay: 0, 8, and 16 s RF: smiley picture/red cross	% Correct	Main effect of diagnosis: ADHD < TD Main effect of delay: 0 > 8 > 16 Diagnosis × delay: 0 s: ADHD = TD 8 s: ADHD < TD 16 s: ADHD < TD	Between-subjects: 0 s: 0.105 8 s: 1.176 16 s: 1.064
Gitten *et al.* (2006)[38]	12 ADHD 12 TD	ADHD: 10.65 TD: 11.59	Age: ND IQ: ND ODD/CD: *Missing* Race/ethnicity: *Missing* Years of education: ND	Prior ADHD diagnosis Interview (parents)	Between-subjects: Diagnosis Within-subjects: Task: spatial vs object RF: / (only feedback)	No. of trials to reach criterion	Main effect of diagnosis Main effect of task Diagnosis × task: Spatial task: ADHD > TD Object task: ADHD = TD	Between-subjects Spatial task: 1.072 Object task: 0.829

(continued)

TABLE 1 Continued

Study	Participants	Age	Confounding variables	Assessment procedure ADHD sample	Study Design – reinforcement manipulation[a]	Outcome Measurement	Results	Effect sizes
Complex forms of operant learning: reversal learning								
Chantiluke *et al.* (2015)[39]	15 ADHD 21 TD (18 ASS)	10–17 y	Age: matched IQ: SIG (analyses repeated with IQ as covariate) ODD/CD: *Missing* Race/ethnicity: *Missing*	Prior ADHD diagnosis (*DSM-IV*) Interview: Maudsley diagnostic interview (*not specified)* Questionnaires: SDQ + CPRS-R (parents)	Between-subjects: Diagnosis Within ADHD group: Medication: fluoxetine vs placebo R and P RF: happy/sad smiley and (crossed-out) picture of money	Mean perseverative errors	TD vs ADHD-placebo: /	Between-subjects (TD vs ADHD-placebo): 1.342
Finger *et al.* (2008)[40]	14 ADHD (off medication) 14 TD (14 psycho-pathic traits and ODD/CD)	ADHD: 13.4 TD: 13.6	Age: ND IQ: SIG (inserted as covariant) ODD/CD: *Missing* Race/ethnicity: *Missing*	Interview: K-SADS (parents and children)	Between-subjects: Diagnosis Phase: acquisition vs reversal R and RC RF: points	% Errors	No significant main or interaction effects	/
Hauser *et al.* (2014)[41]	20 ADHD (off medication) 20 TD	12–16 y	Age: ND IQ: ND ODD/CD: *Missing* Race/ethnicity: *Missing* Gender: ND	Interview: K-SADS (children) Questionnaire: Conners-3 scale (*not specified*)	Between-subjects: Diagnosis RF: money	No. of misses	No significant difference between groups	Between-subjects: 0.364
Itami and Uno (2015)[42]	19 ADHD (off medication) 20 TD	10 y 1 mo to 15 y 7 mo	Age: ND IQ: ND ODD ratings: SIG CD: *Missing* Race/ethnicity: *Missing*	Prior ADHD diagnosis Questionnaire: CPRS-R (parents)	Between-subjects: Diagnosis Within-subjects: Phase: acquisition, reversal and extinction R, RC and P RF: points + (un)pleasant sounds	(1) Change of points as function of no. of of trials (2) No. of errors before reaching criterion (3) Persevera-tive errors	(1) *Reversal + extinction*: Slower progress in ADHD (larger effect in extinction) (2) *Acquisition*: ADHD = TD *Reversal:* ADHD > TD *Extinction:* ADHD > TD (3) *Extinction*: ADHD > TD	/
Shephard *et al.* (2016)[43]	13 ADHD MPH: off medication 17 ADHD + TS 20 TD (18 TS) *Between-subjects analysis:* *29 ADHD* *36 No ADHD*	9–17 y	Age: matched IQ: matched ODD/CD: *Missing* Race/ethnicity: *Missing* Gender: ND SES: ND	Prior ADHD diagnosis Interview: DAWBA Questionnaires: CPRS-R + SDQ (parents)	Between-subjects: Diagnosis RF: happy or sad faces	% Correct trials in each learning block	Acquisition Main effect of diagnosis: ADHD < no ADHD Reversal Main effect of diagnosis: ADHD < no ADHD Diagnosis × block	*Acquisition*: between-subjects (ADHD vs no ADHD) Block 1: 1.583 Block 2: 1.000 Block 3: 0.908 - *Reversal*: between-subjects (ADHD vs no ADHD) Block 4: 1.601 Block 5: 1.077
Effects of medication on learning								
Chantiluke *et al.* (2015)[39]	15 ADHD 21 TD (18 ASS)	10–17 y	Age: matched IQ: SIG (analyses repeated with IQ as covariate) ODD/CD: *Missing* Race/ethnicity: *Missing*	Prior ADHD diagnosis (*DSM-IV*) Interview: Maudsley diagnostic interview (*not specified*) Questionnaires: SDQ + CPRS-R (parents)	Between-subjects: Diagnosis Within ADHD group: Medication: fluoxetine vs placebo R and P RF: happy/sad smiley and (crossed-out) picture of money	Mean perseverative errors	TD vs ADHD-placebo: / TD vs ADHD-fluoxetine: ADHD > TD ADHD: placebo vs fluoxetine: /	TD vs ADHD-placebo: 1.342 TD vs ADHD-fluoxetine: 3.516 ADHD: placebo vs fluoxetine: 0.471
Luman *et al.* (2015)[32]	23 ADHD 27 TD	8–12 y	Age: ND IQ: SIG ODD: SIG CD: *Missing* Race/ethnicity: *Missing* Gender: ND	Prior ADHD diagnosis Interview: P-DISC (parents) Questionnaire: DBDRS (parents and teacher)	Between-subjects: Diagnosis Within-subjects: Medication: placebo vs 3 doses MPH Schedule: fully informative vs probabilistic (88%) R and RC	Mean accuracy	*Medication*: Main effect of feedback: informative > probabilistic Main effect of medication: highest dose > placebo No interaction effects	Within-subjects; medication: placebo vs highest dose: 1.074

(continued)

TABLE 1 Continued

Study	Participants	Age	Confounding variables	Assessment procedure ADHD sample	Study Design – reinforcement manipulation[a]	Outcome Measurement	Results	Effect sizes
					RF: thumbs up/down and money gain/loss			
Pelham *et al.* (1986)[35]	30 ADHD	5 y 11 mo to 11 y	Age: ND IQ: ND ODD/CD: *Missing* Race/ethnicity: *Missing*	Interview (parents) Questionnaire (teacher)	Within-subjects: Medication: MPH vs placebo Between-subjects: Schedule: CR vs PR vs NR Continuous verbal praise/ encouragement RF: points exchangeable for money	Mean no. of errors	Main effect of medication: MPH < placebo	Within-subjects: Total: 0.900 CR: 0.738 PR: 0.381 NR: 1.026

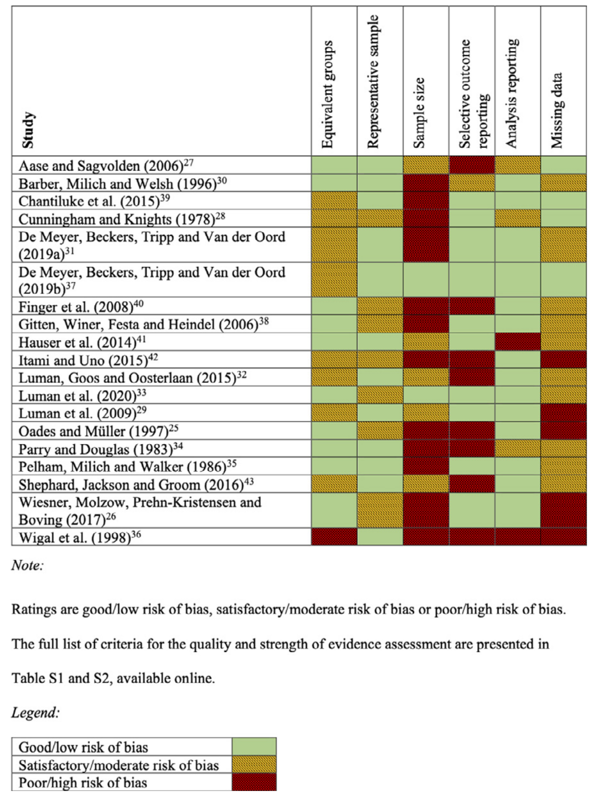
Note: *ADHD = attention-deficit/hyperactivity disorder; CBCL = Child Behavior Checklist; CD = conduct disorder; CPRS-R = Parent-rated Conners Rating Scale Revised; CR = continuous reinforcement; DBDRS = Disruptive Behavior Disorder Rating Scale; DSM = Diagnostic and Statistical Manual of Mental Disorders; HA = hyperactive; IQ = intelligence quotient; K-SADS = Schedule for Affective Disorders and Schizophrenia for School-Age Children—Present and Lifetime version; MPH = methylphenidate; ND = no difference; NR = no reinforcement; ODD = oppositional defiant disorder; P = punishment; P-DISC = Diagnostic Interview Schedule for Children, Parent version; PR = partial reinforcement; R = reward; RC = response cost; RF = reinforcement; SDQ = Strengths and Difficulties Questionnaire; SES = socioeconomic status; SIG = significant; STR = stretching the ratios; TD = typically developing; TS = Tourette syndrome; VI = variable interval.*

[a]*Based on Conners Teacher Rating Scale; no official diagnosis.*

[b]*Only effect sizes of group differences (ADHD vs TD) are reported because of the number of groups.*

[c]*The SDs of both samples were equal; therefore, no pooled SD could be calculated. The value of the SD was therefore used.*

FIGURE 2 Quality Assessment of Included Studies



Note: *Ratings are good/low risk of bias, satisfactory/moderate risk of bias, or poor/high risk of bias. The full list of criteria for the quality and strength of evidence assessment are presented in Table S1 and S2, available online.*

evaluated differential effects of cartoons and tangible objects (eg, trinkets, coins, or sweets) as reinforcers, combined with different reinforcement schedules in children with and without hyperactivity. Children were required to learn which of 2 squares presented on screen was correct. No significant main or interaction effects were found for percentage correct responses. Luman and colleagues[29] investigated the effect of different magnitudes of monetary reward in combination with different reinforcement schedules on a task in which children needed to learn the correct response button (out of 2) for 4 pictures. Results showed a main effect of ADHD diagnosis ($d = 1.000$; large) on percentage of correct responses, with TD children performing better; no effect of magnitude of reinforcement was found for children with ADHD ($d = 0.071$; small) or TD controls ($d = 0.052$, small). Cunningham and Knights[28] assessed the differential effects of reward and response cost in combination with different reinforcement schedules on a 2-choice discrimination task in which children needed to learn to press the correct panel. Children with hyperactivity were compared with TD children during acquisition and extinction; effects of age were also investigated. During acquisition, a significant difference in the younger hyperactive sample only was found for the number of trials to reach criterion, with better performance under response cost compared to reward across both reinforcement schedules (continuous reinforcement: $d = 2.264$, large; partial reinforcement: $d = 1.324$, large). During extinction, a significant interaction between reinforcement condition and diagnostic group was found for the percentage of correct responses (lower for both groups following learning under response cost, compared to reward). This difference was larger in the TD sample.

These studies suggest that neither the magnitude nor the form of the reinforcer (ie, different amounts of money; cartoons versus tangible objects) affected instrumental learning performance. Response cost seemed to result in better performance compared to reward, but only in younger groups. Performance during extinction is better following learning under conditions of reward rather than response cost.

Reinforcement Schedule

Ten studies investigated the effect of reinforcement schedule (eg, variable versus fixed interval; continuous or partial or stretching the ratio's (STR, ie, a schedule characterized by gradually changing reinforcement frequency from very dense to very sparse), on instrumental learning in ADHD and TD samples across a range of different tasks. Aase and Sagvolden[27] compared the effect of a variable interval (VI) reinforcement schedule of 2 seconds and a VI schedule of 20 seconds. The ADHD and TD groups differed under infrequent but not frequent reward, with children with ADHD performing worse.

Several studies[29,30,35,36] investigated the effect of partial reinforcement on performance (money or marbles/tokens exchangeable for money) while delivering continuous feedback on performance accuracy. Luman *et al.*[29] examined the effect of frequent (50%) and infrequent (12.5%) monetary reward on learning, reporting a significant interaction between diagnosis and reinforcement schedule for percentage of correct responses. Contrast analysis indicated a significant effect of reward frequency in the TD group only, with better performance under infrequent reinforcement (ADHD: $d = 0.054$, small; TD: $d = 1.142$, large). Three other studies[30,35,36] compared the effect of a 50% partial reinforcement schedule with a continuous reinforcement schedule and/or no reinforcement. The first study[30] investigated the effects of continuous or partial monetary reward (in addition to feedback on performance accuracy), in a task in which the children needed to learn target words that were combined with related or unrelated cue words. The percentage of correct responses was significantly higher under continuous than under partial reinforcement for both tasks across the groups. The second study[35] investigated the performance of children with ADHD on and off medication in a within-subject design under continuous, partial (50%), and no monetary reward, together with verbal praise for correct responses and verbal encouragement for incorrect responses, on a nonsense words spelling task. Results showed a significantly higher mean number of errors under no reinforcement, compared to the combined performance of children under continuous and partial reinforcement. Medication effects are reported below. The third study[36] investigated the effect of continuous and partial (50%) reinforcement (tokens), in addition to continuous feedback, on performance on a nonsense word task in children with ADHD and TD children. The partial condition began with several trials of continuous reinforcement. A main effect of diagnosis was found for the number of words correctly spelled, with poorer performance in the ADHD group.

Four studies investigated the effect of partial reinforcement schedules with no additional feedback.[28,31,33,34] Cunningham and Knights[28] compared continuous and partial (50%) reinforcement in children with ADHD and TD children. No significant differences were found in the number of trials necessary to reach criterion during acquisition or the percentage correct responses during extinction. Parry and Douglas[34] compared the performance of children with hyperactivity and TD children under schedules of continuous reinforcement, partial reinforcement (50%) with marbles exchangeable for money, and a modified version of partial reinforcement whereby marbles were delivered continuously but only half of them (50%) could be exchanged. Children completed 2 tasks (flower and number concept task), in which they had to learn which of 2 presented pictures was correct. There were significant main effects of diagnosis and schedule for both tasks, and a significant interaction in the flower concept task, for the mean number of trials to reach criterion. In both tasks, children with hyperactivity performed significantly worse than TD children; the interaction effect indicated a difference under partial schedules between both groups, but not under the continuous schedules (number: continuous: $d = 0.645$, medium; partial: $d = 1.555$, large; modified partial: $d = 0.896$, large). De Meyer *et al.*[31] investigated the effect of a combined primary (candy) and secondary (a "thumbs up") reward under continuous, partial (20%), or STR schedules during both acquisition and extinction in a task in which ADHD and TD groups were required to learn the correct colored circle from an array. A main effect of schedule was found in acquisition; children required more trials to reach criterion under STR compared to continuous reinforcement ($d = 1.211$, large), and even more under partial reinforcement ($d = 1.812$, large). A significant main effect of schedule was also found during extinction; children made fewer previously rewarded responses under extinction following continuous reinforcement compared to other conditions (partial: *d* = 1.486, large; STR: *d* = 1.803, large). Luman *et al.*[33] investigated the effect of different feedback probabilities (100%−0%, 85%−15% or 70%−30%) on learning in children with ADHD and TD children. Reward and response cost were delivered through a picture of a thumbs up/thumbs down and the gain/loss of 0.20 euro. Children were required to learn the stimulus with the highest probability of reward in pairs where reinforcement was delivered according to the feedback probabilities above. After the learning phase, a test phase was implemented: original pairs were shown as well as new combinations of the original pairs, with stimuli maintaining their original reinforcement probabilities. During acquisition, there was a significant main effect of diagnosis for the number of blocks to reach criterion (*d* = 0.633; medium) and the first block's percentage of correct trials (*d* = 2.066; large), and children with ADHD performed worse than TD children. There was a significant interaction between diagnosis and trial, indicating differential learning between children with ADHD and TD children in later trials. A significant interaction between diagnosis and feedback probability reflected poorer performance in children with ADHD on the 100%−0% (*d* = 1.108, large) and 85%−15% (*d* = 1.200, large) pairs. Test phase results showed children with ADHD performed below TD children for all pairs (*d* = 1.196, large) and the original pairs separately (*d* = 1.170, large).

Luman *et al.*[32] investigated instrumental learning under conditions of 100% and 88% informative feedback (and 12% invalid feedback). Children with ADHD and TD children learned the correct response from 2 to 4 cue stimuli, using performance feedback (thumbs up/thumbs down) combined with monetary reward and response cost. Children with ADHD performed the task multiple times under placebo and different doses of methylphenidate. Results showed a main effect of feedback, with better performance in the 100% feedback condition across groups. Medication effects are reported below.

In sum, results of schedule of reinforcement are mixed; some studies found worse performance under partial reinforcement in children with ADHD as compared to TD children, whereas others did not.

Complex Forms of Instrumental Learning

Conditional Discrimination Learning. Two studies investigated conditional discrimination learning in children with ADHD compared to TD children. The first study[38] assessed conditional discrimination learning in 2 tasks (spatial or object task) in which children needed to indicate the correct stimulus for a given cue. Correct responses were followed by a new trial, and incorrect responses by the same stimuli to facilitate learning. In the spatial task, children needed to learn the correct stimulus among 5 similar stimuli based on the spatial location of the presented cue. In the object paradigm, the correct choice was based on object characteristics. Main effects of diagnosis and task and the interaction were significant for the number of trials to reach criterion. Children with ADHD performed significantly worse on the spatial (*d* = 1.072, large), but not the object task (*d* = 0.829, large), compared to TD children. In the second study,[37] conditional discrimination learning was investigated in a task in which children needed to learn appropriate stimulus−response associations (correct association feedback by smiley, incorrect association by red cross), under different delays (0, 8, and 16 seconds) between the stimulus and response options. Significant main effects of diagnosis and delay were identified, together with a significant interaction. Children with ADHD performed worse than TD children under the delay conditions (8 seconds: *d* = 1.176, large; 16 seconds: *d* = 1.064, large) but not the immediate condition (*d* = 0.512, medium).

In sum, studies suggest difficulties in conditional discrimination learning in children with ADHD, particularly when there is a delay between the discriminative cue and the opportunity to respond.

Reversal Learning. Five studies investigated reversal learning in children with ADHD compared to TD children. These studies used tasks in which children needed to choose among several stimuli or responses based on which was rewarded most often. The probabilities that certain stimuli are rewarded are reversed during the task. Three studies showed similar performance for children with ADHD and TD children. In the first study,[39] children were asked to choose between 2 stimuli; 1 stimulus was always rewarded (smiley and picture of money), and the other was punished (sad face and picture of crossed-out money). Children with ADHD were administered either placebo or fluoxetine in a within-subjects design, and their performance was compared with that of TD children. No significant group difference was found in the placebo condition for the mean percentage errors (*d* = 1.342, large). Medication effects are reported below. In the second study, children with ADHD and TD children chose between 2 stimuli, one of which was always rewarded with money.[41] There was no significant effect of diagnosis on the number of misses (*d* = 0.364, small). The third study[40] used the same task with ADHD and TD groups, with reinforcement probabilities of 100%−0% and 80%−20% and both reward and response cost (points). No significant difference between children with ADHD and TD children was found for the percentage of errors.

Two other studies found significant differences between children with ADHD and TD children. In 1 study,[43] children with ADHD and TD children (some with comorbid Tourette syndrome) learned to associate 4 stimuli with a right or left button press. Smiling faces were used as reinforcers. During acquisition blocks (block 1: $d = 1.583$, large; block 2: $d = 1.000$, large; block 3: $d = 0.908$, large) and reversal learning blocks (block 4: $d = 1.601$, large; block 5: $d = 1.077$, large), children with ADHD performed significantly worse than TD children (defined as percentage of correct trials). A significant interaction between diagnosis and learning block was found in the reversal phase. Unlike TD children, those with ADHD were unable to achieve the same level of accuracy as during acquisition. In the second study,[42] participants learned to respond to 1 of 2 stimuli. Points were obtained for responding to the correct or ignoring the incorrect stimulus, and were lost for responding to the incorrect or not responding to the correct stimulus. The acquisition and reversal phases were followed by an extinction phase in which participants needed to ignore all stimuli. Results showed no group differences in the acquisition phase. The children with ADHD made more errors than TD children before reaching criterion in both the reversal and the extinction phases. In addition, children with ADHD made more perseverative errors in the extinction phase compared to TD children.

Overall, results of reversal learning in children with ADHD compared to TD children are mixed; 3 studies reported no group differences, and 2 studies reported worse performance in individuals with ADHD.

Effects of Medication on Learning

Three studies investigated the effect of medication (2 studies with methylphenidate, 1 study with fluoxetine) on instrumental learning in children with ADHD.[32,35,39] One study[35] examined the effect of methylphenidate versus placebo under different reinforcement schedules. Across the different reinforcement schedules, children with ADHD made fewer errors on methylphenidate compared to placebo ($d = 0.900$, large). Another study[32] examined different doses of methylphenidate compared to placebo under different feedback probabilities. Results showed a main effect of medication on the mean accuracy of responses; performance was significantly better under the highest dose of methylphenidate only, compared to placebo ($d = 1.074$; large). The third study[39] investigated the effect of fluoxetine on reversal learning. Results showed that children with ADHD taking fluoxetine had a higher mean number of perseverative errors compared to TD children ($d = 3.516$, large), although there was no significant difference when children were taking placebo ($d = 1.342$, large). No differential effect of medication on performance was found, however, as indicated by a nonsignificant interaction effect ($d = 0.471$; medium).

Results regarding the effect of medication on instrumental learning seem to indicate a positive effect of methylphenidate on performance compared to placebo, but no effect of fluoxetine compared to placebo in children with ADHD.

DISCUSSION

This systematic review investigated instrumental learning; its modulation by the form, schedule, or magnitude of reinforcement; and more complex forms of instrumental learning in children with ADHD as compared to TD children. In children with ADHD, the effects of medication on instrumental learning were also evaluated. Although impaired instrumental learning is a core premise of motivational theories of ADHD,[12−14] our literature search identified a limited number of relevant empirical studies. Overall, the evidence generated by those studies is mixed, with some studies showing significant differences and other studies not. Our review also identified a lack of consistency in task design and (reinforcement) manipulations across studies, thereby limiting the possibility of statistical aggregation of findings. Therefore, summary conclusions are necessarily narrative.

With regard to basic instrumental learning, children with ADHD do not appear to show deficiencies, but the available evidence is limited. The 2 studies identified showed no differences in the learning of children with ADHD and TD children under continuous[25] or probabilistic[26] reinforcement. Nevertheless, a large effect size was reported in 1 study, potentially suggesting an underpowered sample or relatively large variation in performance within the groups; therefore, results should be interpreted with caution. Similarly, studies addressing the form[27] or magnitude[29] of reinforcement show no differential effects on instrumental learning in individuals diagnosed with ADHD. Results from studies comparing learning under different reinforcement schedules are inconclusive. Some studies report poorer performance in children with ADHD,[27,29,33,34,36] whereas others do not.[28,30,31,32] A differential effect of reinforcement on the learning of children with ADHD compared to TD children was found in 3 studies. Two studies reported differences only under infrequent reinforcement, whereas the other showed a difference only under frequent reinforcement. The latter effect is possibly a result of the nature of the schedule (probabilistic reward rather than pure partial reinforcement) or floor effects.[33]

For more complex forms of learning (conditional discrimination learning and reversal learning), evidence of poorer performance in individuals with ADHD appears to be more consistent for conditional discrimination learning, although only 2 studies have investigated this. However, although the number of studies is small, effect sizes are large, suggesting greater difficulty in instrumental learning for children with ADHD with increased task complexity. More studies should be undertaken to confirm these results. Whereas in basic instrumental learning, a simple response−outcome association needs to be learned, in conditional discrimination, the correct response is conditional upon the discriminative stimulus, mirroring the complex contingencies often operating in daily life.[38] For reversal learning, results were mixed, with some studies[39−41] finding no difference, whereas in others,[42,43] children with ADHD performed less well than TD children. Finally, studies do show improvement of learning under methylphenidate compared to placebo. However, it is not clear whether this effect is a result of improvement in instrumental learning *per se,* or a more general effect of the medication on, for example, attention to the task.[44]

The results of the studies reviewed suggest that children with ADHD do not suffer from a generalized instrumental learning deficit: that is, they are able to learn from the consequences of their actions. However, this may be something of an oversimplification. It appears that children with ADHD are able to learn from contingencies that differ in form or magnitude, when instrumental learning is assessed under carefully controlled conditions, such as in the laboratory. In such settings, task instructions are clear, distractions minimized, and consequences consistently delivered. Once learning becomes more complex (eg, when there is a delay between the discriminative event and the response), learning problems may arise. Also, the effects of partial reinforcement remain unclear and call for further exploration.

The results of this review can potentially indicate ways to improve the effectiveness of BPT, as BPT is largely based on instrumental learning processes. For example, assuming that conditional discrimination learning is difficult in daily life for children with ADHD, attention should be paid to educating parents and teachers about conditional discrimination learning, including the importance of discriminative events preceding the behavior. The importance of minimizing the delay between the discriminative event and the potential to respond should also be emphasized. A potential avenue to remediate deficits in conditional discrimination learning in BPT is the use of differential outcomes (DO, ie, response-specific reinforcers) in contingency management programs. These have been shown to remediate conditional discrimination learning deficits in ADHD[45] and conditions marked by attentional difficulties such as Down, Prader-Willi, and Korsakoff syndromes and Alzheimer disease.[46−48]

There are some limitations to this study that should be acknowledged. First, the review clearly shows the surprising lack of research available on reinforcement learning in ADHD. The number of studies meeting inclusion criteria was small, and identified studies differed substantially in their samples, tasks, and reinforcement manipulations, warranting care in drawing conclusions. In addition, although it is suggested that punishment interferes with learning in children with ADHD, our review did not identify studies examining this assumption. Because all of the included studies did not report on the race/ethnicity of their participants, it is not clear whether these samples are representative of the diversity in race/culture in the broader society or whether the obtained results generalize to more diverse populations. Furthermore, quality assessment identified problems with sample sizes, selective outcome reporting, and a failure to report missing data. Although differences were mostly nonsignificant, effect sizes were often moderate to large, suggesting underpowered studies. Finally, many of the reversal learning studies were conducted while brain imaging data were collected, conditions very different from those of the other included studies and from daily life circumstances.

To conclude, this systematic review indicates that children with ADHD show no basic instrumental learning deficits when tested under ideal conditions. However, findings regarding partial reinforcement schedules are inconsistent, and results show deficits in complex forms of instrumental learning (especially conditional discrimination learning) that more closely resemble learning in daily life. The absence of deficits in basic instrumental learning notwithstanding, methylphenidate does improve the learning of children with ADHD. Given the heterogeneity of the studies reported and the inconsistencies found, future research should both replicate current findings and elaborate the effects of task characteristics and reinforcement manipulations on learning. Instrumental learning in ecologically valid situations should be explored and complex forms of learning further examined, also in combination with methylphenidate. All of this should permit a better understanding of how to assist learning in children with ADHD. As the burden of symptoms and related problems is often high for children with ADHD and their families, additional research is necessary to refine our understanding of specific deficits in instrumental learning in ADHD and to adapt interventions accordingly.

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