FINAL REPORT
Behavioral Correlates of Action Control in Children with Attention-Deficit/Hyperactivity Disorder

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STUDY OVERVIEW

Our previous research has shown that action-control is impaired in ADHD (cite 3 papers). Using the outcome devaluation paradigm, we showed that children with ADHD seem to rely on reflexive habitual, rather than goal-directed, behavior to deploy their actions. In this paradigm, participants are given a choice between an outcome that is valued, and another outcome that is devalued in previous training sessions. If they are goal-directed (healthy children), they choose the valued outcome; conversely, if they are habitual (children with ADHD), they do not show a preference and choose both outcome reflexively at a similar rate. In this proposal, we aim to conduct a parallel study to investigate the opposite pattern of action-control and valuation behavior in children with ADHD compared to healthy children (HC). Specifically, we used an overvaluation, as opposed to a devaluation, paradigm to characterize whether children with ADHD have a selective deficit in goal-directed behavior. Our hypothesis states that, similar to our findings using the outcome devaluation paradigm, actions in ADHD are dominated by habits at the expense of goal-directed behavior.

METHODS

We tested eleven ADHD and eight HC participants (age 6-10 years) for this study. Children with ADHD were recruited from Children's Specialized Hospital and underwent a structured clinical diagnosis by a neurodevelopmental pediatrician. All participants were screened for ADHD and other neurologic or psychiatric conditions that could contribute to attention impairment using the SNAP-IV rating scale. Participants completed a set of the Woodcock-Johnson® IV assessments including Short-Term Working Memory; Verbal Attention; Story Recall; Concept Formation; Numbers Reversed; Pair Cancellation. They were tested using the overvaluation computer-based task described in the proposed study. During learning, participants acquired stimulus-reward associations in the acquisition phase, as well as the contingency training phase. In the latter, one of the rewards was delivered in a similar contingency to the acquisition phase (*contingent*), while the other reward was randomly accompanied by an extra reward in 10% of the trials (*contingent-overvalued*) **(Figure 1)**. After the contingency training phase, participants were presented with two stimuli (associated with a contingent, and a contingent-overvalued outcomes, respectively) and were asked to choose one stimulus in extinction. We expect that goal-directed children will choose the contingent-overvalued stimulus over the contingent stimulus; while habitual children will choose both stimuli at the same rate.

RESULTS

SNAP-IV and WJ Tests

The SNAP-IV rating scale was used to assess for ADHD symptoms, co-morbid symptoms, and classroom performance. Independent-samples t-test showed that children with ADHD scored significantly higher than HC scores in the following measures: ADHD_inattention, ADHD_hyperactive/Impulsive, ADHD_combined, inattention/overactivity, Conner's index, inattention domain, hyperactive/impulsive domain, and general anxiety disorder screening (P-value for all is <0.003). Similarly, independent-samples t-test showed that children with ADHD had lower scores on Woodcock–Johnson® IV tests related to short-term working memory and attention control and capacity (Table 1).

Computer-based Cognitive Task

In the learning phases, independent-samplea t-test showed that HC have a significantly higher accurate response rate ($t(17)=2.74$, $p=0.014$); while children with ADHD had a significantly higher inaccurate response rate ($t(17)=2.68$, $p=0.016$) in the degradation phase (Figure 1). In the extinction phase, our results show that HC responded at a higher rate on the stimuli that were associated with the contingent-overvalued outcome vs. the stimuli that were associated with the contingent outcome; indicating goal-directed behavior, while children with ADHD responded equally on both stimuli; indicating habitual behavior (Figure 2). These results however were short of statistical significance.

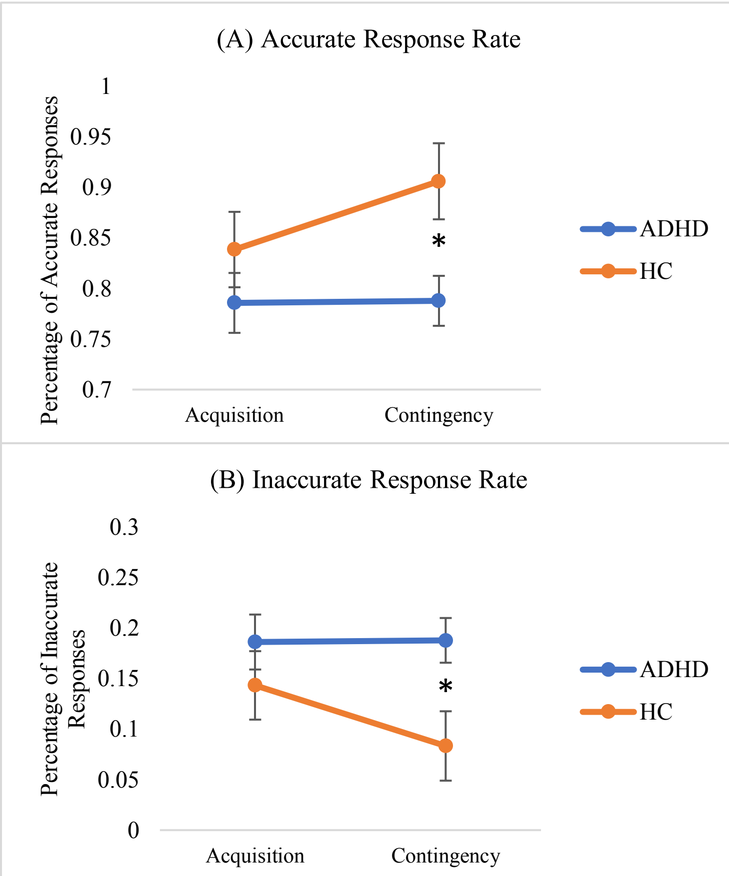

Figure 1: Percentage of Accurate Responses (A) and Inaccurate Responses (B) during the first and the second phases of the cognitive task (Acquisition and Contingency Training) in children with ADHD (N=11) and HC (N=8) (error bars = ±SEM**)** (* = significant at $p<0.05$)**.**

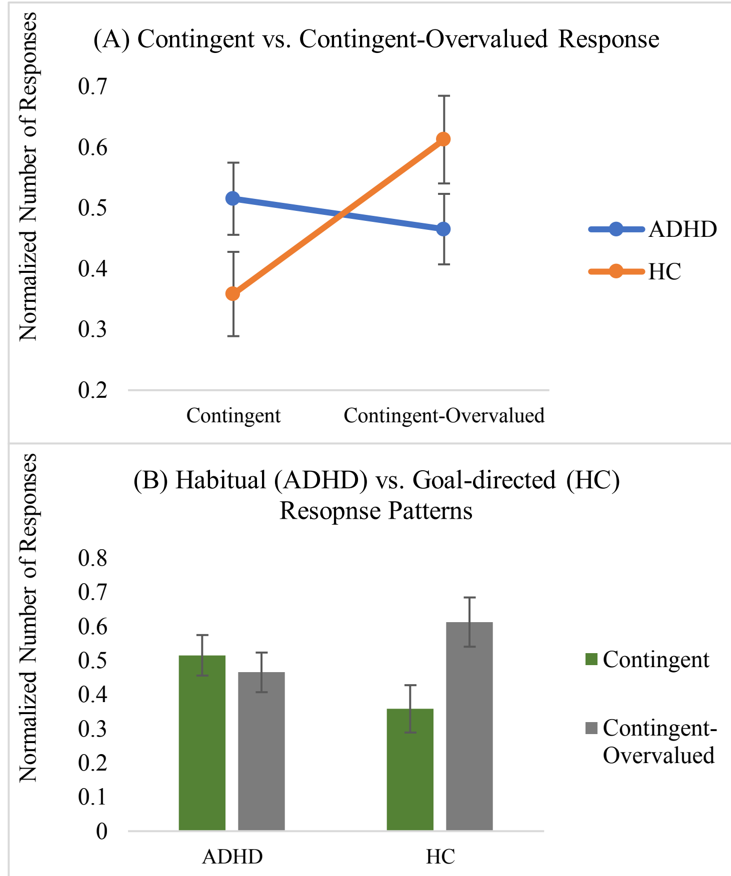

Figure 2: (A) Normalized (%) number of responses during the choice test phase (extinction) of the cognitive task on the stimuli associated with the contingent and the contingent-overvalued outcomes and B) Representation of habitual vs. goal-directed behavior in children with ADHD (N=11) and HC (N=8) (error bars = ±SEM**)** (* = significant at $p<0.05$)**.**

PROGRESS AND PLANS

We proposed to test 20 children with ADHD and 20 HC for this study. The grant was awarded in summer 2018. We obtained IRB approval at Kessler Foundation by the end of 2018, and we started the recruitment process in January 2019. Our rate limiting step was receiving an updated list of children with ADHD that fits our criteria of inclusion from Children's Specialized Hospital. This phase took about 6 months (Jan – Jul 2019). During this time, we finalized developing and validating the computer-based task. Between July 2019 and February 2020, we successfully recruited and tested 13 participants. However, the study progress was severely affected by the pandemic and we were only able to resume recruitment in August 2020. Since then, we managed to test 9 participants. The total number of participants tested for this study is 22. In this report, we present data for 19 participants (11 ADHD, and 8 HC) as data from the last 3 participants are still being processed. We plan to increase the number of participants until our analyses reach statistical significance for manuscript writing and submission.

Test	**Group**	**M±SD**	**P-value**
Short-Term Working Memory	ADHD	92.9±13.1	0.02*
	HC	110.6±15.7	
Verbal Attention	ADHD	95.4±14.9	0.07
	HC	107.9±12.9	
Story Recall	ADHD	90.2±14.7	0.87
	HC	91.5±18.7	
Concept Formation	ADHD	96.4±16.6	0.27
	HC	105.9±19.7	
Numbers Reversed	ADHD	92.4±16.9	0.03*
	HC	111.1±16.2	
Pair Cancellation	ADHD	93.5±7.2	0.81
	HC	92.5±10.1	

Table 1 Mean and standard deviation of Woodcock–Johnson Cognitive Tests used in the study in children with ADHD (N=11) and HC (N=8) (* = significant at $p<0.05$).