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The Effects of Preresponse Cues on Inhibitory Control and Response Time in Adults with ADHD

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Abstract

Objective—To examine the effects of preresponse cues on behavioral control in adults with attention-deficit/hyperactivity disorder (ADHD).

Method—Eighty-eight adults with ADHD and 67 adults with no history of ADHD completed a cued go/no-go task. This task requires participants to respond or inhibit a response to go and no-go targets, respectively, and preresponse cues provide participants with predictive information about the upcoming target.

Results—Overall, participants with ADHD made more inhibitory failures and responded more slowly than controls. These group differences were only present in the valid-cue condition, and there were no significant group differences in the invalid-cue conditions.

Conclusion—These findings suggest that adults with ADHD are less able to utilize predictive environmental information to facilitate behavioral control.

Adults with ADHD are characterized by impaired behavioral control. This notion is supported by numerous studies using laboratory tasks to measure aspects of behavioral control such as response time (RT) and inhibitory control (Aron, Dowson, Sahakian, & Robbins, 2003; Oosterlaan, Logan, & Sergeant, 1998; Roberts, Fillmore, & Milich, 2011a). These studies have found that individuals with ADHD show a slower but paradoxically more impulsive response style relative to their nonclinical peers. Many of these studies are conducted using tasks, such as go/no-go tasks and stop-signal tasks, that require participants to make speeded responses to go targets and inhibit that response when presented with an infrequent stop target (Schachar, Mota, Logan, Tannock, & Klim, 2000; Yong-Liang, Robaey, Karayanidis, Bourassa, Pelletier, & Geoffroy, 2000). These tasks model events where an unexpected need to exert inhibitory control occurs; however, events that require inhibitory control in the real world are often preceded by cues indicating that an inhibitory response will be required. Understanding how behavior is influenced by antecedent cues is important, because these types of situations may be the exception rather than the rule in the natural environment. For example, motorists approaching a traffic light that is turning red would be prepared to stop by the preceding yellow light. Indeed, preresponse cues have been shown to facilitate faster responding and more consistent inhibition in go/no-go tasks in the general population (Miller, Schaffer, & Hackley, 1991). This cue-facilitated enhancement of response speed and accuracy may be particularly important for groups characterized by

deficits of behavioral control. Examining how preparatory cues affect behavioral control in such groups, such as individuals with ADHD, may provide insight into the specific cognitive deficits contributing to their symptoms of impulse control.

Cues in the environment can provide predictive information about what behavior will be adaptive in a given situation. If a cue reliably predicts an upcoming response demand over several occasions, then one can begin preparing to react (or inhibit a reaction) even before the response-eliciting stimulus is observed. These cues can facilitate behavioral control by allowing one to initiate cognitive processing required for the upcoming response demand (Duncan, 1981). This “head start” reduces the amount of information that needs to be processed when the actual response is required, so the response can be executed (or inhibited) more quickly and consistently. The effects of antecedent cues on behavioral control can be modeled in the laboratory using cue-dependent go/no-go tasks (Fillmore, 2003; Marczinski & Fillmore, 2003; Miller et al., 1991). This task is similar to a stop-signal task in that it measures behavioral control as the ability to quickly execute and suddenly suppress responses. Unlike in the stop-signal task, however, targets are preceded by visual cues that signal the likelihood that a go or no-go target will be presented. By modeling these predictive cues, the cued go/no-go task can be used to examine how such cues can affect participants’ ability to execute and inhibit responses.

Each trial of the cued go/no-go task consists of a go or no-go cue followed by a go or no-go target that requires a response to be either executed (i.e., go trial) or suppressed (i.e., no-go trial). The cue-target relationship is manipulated so that cues have a high probability of correctly signaling a target. Specifically, go targets are preceded by go cue during 80% of the trials and no-go targets during 20% of the trials, respectively, and the converse is true for no-go cues. Correct (i.e., valid) cues tend to facilitate response execution and response inhibition. For example, responses to go targets are faster when they are preceded by a go cue, and the likelihood of suppressing a response to a no-go target is greater when it is preceded by a no-go cue. Invalid cues produce a prepotent tendency to respond (or withhold a response) that must be stymied when the target appears.

Studies have used cued go/no-go models to examine how antecedent cues influence response speed and inhibitory control in groups characterized by impaired behavioral control (Leland, Arce, Miller, & Paulus, 2008; Marczinski & Fillmore, 2003; O’Brien et al., 2011). Studies on the acute effects of alcohol suggest that valid prereponse cues protect against alcohol-impairment of response speed and inhibitory control (Fillmore, 2004; Marczinski & Fillmore, 2003), and similar protective effects of predictive cues have been shown in adults with methamphetamine dependence (Leland et al., 2008). These studies suggest that some individuals can use environmental cues to retain intact control over otherwise impaired processes. Although most groups benefit from predictive cues, some clinical groups appear to benefit less from environmental cues than their nonclinical peers. O’Brien and colleagues (2011) used fMRI to examine patterns of brain activation in children with a history of prenatal alcohol exposure performing a cued go/no-go task. Brain activation patterns in the alcohol exposed group suggested that they were not processing cues as effectively as their nonclinical peers. Another study found that children with ADHD/Inattentive subtype made a similar number of inhibitory failures on a cued go/no-go task regardless of cue condition,

suggesting that they were not able to utilize the cues to improve their accuracy rate (Derefinko, Adams, Milich, Fillmore, Lorch, & Lynam, 2008).

In the current study, we examined performance on the cued go/no-go task in a group of young adults with ADHD and a group of nonclinical comparison adults. On the basis of prior research (Miller et al., 1991; Weafer, Fillmore, & Milich, 2009), we hypothesized both groups would make fewer inhibitory failures and respond more quickly to targets following valid cues. Specifically, we expected that participants would respond to go targets preceded by go cues more quickly than those preceded by no-go targets, and they would make fewer inhibitory failures to no-go targets preceded by no-go cues than those preceded by go cues. Further, we expected that the ADHD group would show less cue dependency than their nonclinical peers. That is, we expected that cue condition would have a smaller effect on inhibitory failure rate and response speed in the ADHD group.

Method

Participants

Participants were 88 individuals with ADHD and 67 individuals with no history of ADHD. The sample was obtained by aggregating several data sets from three separate experiments conducted in our laboratory (Roberts, Fillmore, & Milich, 2012; Roberts, Milich, & Fillmore, 2012; Roberts, Milich, & Fillmore, *in press*). These studies used similar procedures, and the tasks were administered under standardized conditions. Volunteers were recruited through advertisements (i.e., newspaper ads and posters) seeking adults with and without ADHD for a study of neurological and motor functioning. Participants were predominately European American ($n = 155$), although several participants identified as African American ($n = 7$), Native American ($n = 4$), Asian ($n = 4$), Latina ($n = 2$), and biracial ($n = 1$). Participation was limited to individuals who were between the ages of 19 and 30 and had no uncorrected vision problems. Volunteers with recent psychiatric episodes related to severe psychiatric illness (i.e., bipolar disorder, schizophrenia), as determined through self-report, were not invited to participate. Demographic information is shown in Table 1.

Because many of the participants in the study were college students, we took several steps to ensure that participants were actively experiencing clinically significant ADHD symptomatology. Participants' ADHD diagnosis was also verified using self-report measures of ADHD symptomatology. Although there were minor changes in the diagnostic procedure that occurred between the studies, all participants completed the Conners Adult ADHD Rating Scale—Self Report: Long Version CAARS—S:L; (CAARS: S-L; Conners, Erhardt, & Sparrow, 1999). We required that participants received a T score of 66 or higher on either the *DSM-IV* Inattentive Symptoms subscale or the *DSM-IV* Hyperactive/Impulsive Symptoms subscale, which are based on the *Diagnostic and Statistical Manual of Mental Disorders* criteria for ADHD (4th ed. [*DSM-IV*]; American Psychiatric Association, 1994). Further, we only recruited volunteers who were currently prescribed stimulant medication for ADHD. This ensured that participants' symptoms were sufficient to require pharmacological treatment.

Participants also completed the 30-item Barratt Impulsiveness Scale (BIS; Patton, Stanford, & Barratt, 1995) as an additional measure of impulsivity. The BIS was used to test whether participants in the ADHD reported significantly more problems with impulse control in their day-to-day lives. This questionnaire measures impulsivity through items such as “I act on impulse” and “I consider myself always careful.” Participants indicated how frequently each statement applies to them on a 4-point Likert scale (*never, occasionally, often, almost always*). Possible score totals range from 30 to 120 and higher scores indicating greater total levels of impulsiveness. BIS scores are reported in Table 1.

Participants were required to abstain from using their medication for 24 hours prior to the study to ensure that they were unmedicated during the testing sessions, and the experimenter verbally confirmed compliance with this request at the beginning of each session.

Materials

Cued go/no-go task—Participants performed a cued go/no-go reaction time task that was operated using E-Prime experiment generation software (Schneider, Eschman, & Zuccolotto, 2002) and was performed on a PC. A trial involved the following sequence of events: (a) presentation of a fixation point (+) for 800 ms; (b) a blank white screen for 500 ms; (c) a cue was displayed for one of five stimulus onset asynchronies (SOAs = 100, 200, 300, 400, and 500 ms); (d) a go or no-go target that remained visible until a response occurred or 1,000 ms had elapsed; and (e) an intertrial interval of 700 ms.

The cue was a rectangle framed in a 0.8-mm black outline presented in the center of the computer monitor against a white background. The cue was presented in either a horizontal (7.5 cm × 2.5 cm) or a vertical (2.5 cm × 7.5 cm) orientation. The go and no-go targets were the colors green and blue, respectively. They were displayed on the monitor as a solid hue that filled the interior of the rectangle cue. Participants were instructed to press the forward slash (/) key on the keyboard as soon as a go (green) target appeared and to withhold any response when a no-go (blue) target was presented. Key presses were made with the index finger of the preferred hand. The go and no-go targets were presented in hues that were easily distinguishable by all participants.

The orientation of the cue (horizontal or vertical) signaled the probability that a go or no-go target would be displayed. Cues that were presented vertically preceded the go target on 80% of the trials and preceded the no-go target on 20% of the trials. Cues that were presented horizontally preceded the no-go target on 80% of the trials and preceded the go target on 20% of the trials. Therefore, on the basis of cue-target pairings, vertical and horizontal cues operated as go and no-go cues, respectively. The different SOAs (100, 200, 300, 400, and 500 ms) between the cues and targets encouraged participants to pay attention to the cues, and the randomness of the SOAs prevented the participants from anticipating the exact onset of the targets.

A test consisted of 250 trials that presented the four possible cue-target combinations. An equal number of vertical (125) and horizontal (125) cues were presented before an equal number of go (125) and no-go (125) target stimuli. Each cue-target combination was presented at each of the five SOAs, and an equal number of SOAs separated each cue-target

combination. The presentation of cue-target combinations and SOAs was random. For each trial, the computer recorded whether a response occurred, and if so, RT was measured from the onset of the target until the key was pressed. To encourage quick and accurate responding, feedback was presented to the participant during the intertrial interval by displaying the words “correct” or “incorrect” and RT in milliseconds. A test required approximately 15 minutes to complete.

Procedure

This study was conducted in a laboratory setting in the university’s Department of Psychology. Participants completed the cued go/no-go task as part of three separate studies: one study included a large battery of neuropsychological tasks and two studies that measured the acute effects of alcohol on cognitive functioning. In all of the studies, participants first attended an individual familiarization session and became acquainted with the behavioral tasks and provided background information. After providing informed consent, participants were interviewed and completed diagnostic and demographic questionnaires. The experimenter then administered the Kaufman Brief Intelligence Scale (Kaufman & Kaufman, 2004) to measure participants’ IQ. Participants completed a familiarization version of the cued go/no-go task to ensure that they understood the procedure. Depending on the study, participants scheduled between one and three additional testing sessions. Participants in the alcohol studies ($n = 78$) completed the cued go/no-go several times under different doses of alcohol, although the performance data reported in the current manuscript were collected while these participants were in a drug free state.

Criterion Variables

Response inhibition—Response inhibition was measured as the proportion of no-go trials in which the participant failed to inhibit a response (p -failures). Separate scores were calculated for go cue/no-go target trials and no-go cue/no-go target trials.

Response Execution—Response execution was measured as RT to go targets. A mean RT score for a participant was calculated for each cue condition. Responses with RTs less than 100 ms and greater than 1000 ms were excluded.

Cue Dependency—Cue dependency was measured as the difference in performance between the cue conditions (i.e., $RT_{\text{no-go cue}} - RT_{\text{go cue}}$; $p\text{-failures}_{\text{go cue}} - p\text{-failures}_{\text{no-go cue}}$).

Data Analysis

The criterion measures of interest were the participants’ failures to inhibit responses to no-go targets (i.e., failures of response inhibition) and their speed of responding to go targets (i.e., response execution). Data analyses were first conducted with SOA as a within-subject factor. No interaction effect involving SOA and group was significant, so the criterion measures are collapsed across SOA in the interest of clarity. The hypothesis that prereponse cues would have less effect on performance for participants with ADHD was tested using a series of 2 (Group: ADHD vs. Control) $\times$ 2 (Cue: go cue vs. no-go cue) mixed-designed analyses of variance (ANOVA). *A priori* t tests examined group differences separately for

each cue condition. One sample *a priori* *t* tests examined whether cue dependency effects differed significantly from 0 in each group.

Results

Covariate Analysis

We first examined whether the criterion variables were associated with demographic variables such as age, education, and IQ. Age and education were correlated with RT in both cue conditions, $ps < .05$. However, when age and education were included as covariates in an ANCOVA of RT, there was no appreciable change in the size or significance of the effects. Thus, the results are presented without controlling for any covariates.

Inhibitory Control

P-inhibition failures are plotted separately by group in Figure 1. There was a significant main effect of cue, $F(1, 153) = 40.2, p < .001, d = 0.48$, as participants made fewer inhibitory failures when the no-go target was preceded by a no-go cue. Although the main effect of group was not significant, $F(1, 153) < 0.1, p = .945, d = 0.01$, there was a significant cue $\times$ group interaction, $F(1, 153) = 5.2, p = .024, d = 0.37$. This interaction supports a group difference in cue sensitivity. As seen in Figure 1, the ADHD group made more inhibitory failures relative to controls only during no-go cue trials. Indeed, the *a priori* comparisons confirmed that the ADHD group made significantly more inhibitory failures than controls during the no-go cue condition, $t(153) = 2.9, p = .004, d = 0.47$, but not in the go-cue condition, $t(153) = 1.0, p = .305, d = 0.17$. The control group showed significant cue dependency, $t(66) = 4.5, p < .001, d = 0.73$, as did the ADHD group, $t(88) = 4.3, p < .001, d = 0.48$. As seen in Figure 1, although both groups showed cue dependency, the effect was larger in the control group.

RT

RT is plotted separately by group in Figure 2. There was a main effect of cue, $F(1, 153) = 143.2, p < .001, d = 0.93$, confirming that participants responded more quickly to go targets preceded by go cues. The main effect of group was not significant, $F(1, 153) = 2.4, p = .121, d = 0.25$, although there was a significant cue $\times$ group interaction, $F(1, 153) = 4.9, p = .028, d = 0.36$. The ADHD group made slower responses in both conditions, but the group difference was smaller in the go cue condition. The *a priori* comparisons found that the ADHD group was significantly slower to respond than controls in the go cue condition, $t(153) = 2.1, p = .041, d = 0.33$, but not in the no-go cue condition, $t(153) = 0.9, p = .369, d = 0.15$. The control group showed significant cue dependency, $t(66) = 8.5, p < .001, d = 0.87$, as did the ADHD group, $t(88) = 8.1, p < .001, d = 0.38$. As seen in Figure 2, the cue dependency effect was larger in the control group.

Discussion

This study examined the effects of prereponse cues on inhibitory control and response speed in a group of high functioning adults with ADHD and a group of comparison adults. Consistent with prior research (Miller et al., 1991), participants responded more quickly and

made fewer inhibitory errors during trials with valid prereponse cues. Although valid cues improved performance in both groups, the ADHD group appeared to benefit less from the valid prereponse cues relative to the comparison group. Indeed, although the ADHD group was significantly slower to respond in the valid (go) cue condition, they were no slower to respond than controls in the invalid (no-go) cue condition. Valid cues did not protect participants with ADHD from making inhibitory failures to the same degree as controls. In fact, the ADHD group only made more inhibitory failures during trials with valid no-go cues, which is especially remarkable considering the robust finding that adults with ADHD show inhibitory control deficits (Carr, Henderson, & Nigg, 2010; Lijffijt, Kenemans, Verbaten, & van Engeland, 2005; Roberts, Fillmore, & Milich, 2011b). Interestingly, the ADHD group performed comparably to their nonclinical peers when the cues provided incorrect predictive information (i.e., invalid cues). Taken together, these findings suggest that adults with ADHD are less sensitive to predictive cues relative to their nonclinical peers.

These findings have implications for understanding inhibitory control deficits in adults with ADHD. Behavioral inhibition is defined by Nigg (2000, *p.* 223) as “primary control of a motor response in compliance with changing context cues.” Barkley (1997, *p.* 67) similarly defines one component of inhibition as “[the] inhibition of the initial prepotent response to an event.” Included in both of these definitions is the requirement that inhibition refers to exercising control over *prepotent* action. Consider the results of the inhibitory failures on the cued go/no-go task in terms of response prepotency. The invalid cue trials are more difficult, because the mismatch between the go cue and no-go target engenders response conflict in the participant. They must exercise inhibitory control to resolve this conflict and withhold the response (Fillmore, 2003; Randall & Smith, 2011). These high conflict trials place greater demands on inhibitory control, and as a result, disinhibited groups typically show more pronounced impairments on these trials (Fillmore, Rush, & Hays, 2005; Marczinski & Fillmore, 2003). Our findings suggest that adults with ADHD only show appreciable impairment when response conflict is low. Conversely, their rate of inhibitory failures was comparable to that of controls in the high conflict condition. Given current models of ADHD as a disinhibitory disorder (Barkley, 1997; Nigg, 2001), this pattern of results is surprising. Such disinhibition-based models would predict that individuals with ADHD should show the largest deficits in the more challenging invalid-cue condition (i.e., go cue/no-go target). Although replication of this finding will be necessary before firm conclusions can be made about its significance, it may provide constraints on disinhibition-based theoretical models of ADHD.

The reduced cue sensitivity in the ADHD group may be related to dysfunction of alerting mechanisms of attention (Berger & Posner, 2000). Indeed, several authors have argued that dysfunctional alerting mechanisms may explain some of the symptoms of individuals with ADHD (e.g., Swanson, 2003). Alerting mechanisms are engaged by stimuli signaling an upcoming response demand and result in an increase in response readiness (Posner & Petersen, 1990). This increase in response readiness is typically adaptive, because the mechanisms are engaged when a response will most likely be required. If a response is not appropriate, however, being in an alert state may reduce response accuracy. With regards to

the current study, the cue condition can be viewed as a manipulation of response state. Viewing the go cue appeared to increase response-readiness, which allowed participants to respond more quickly to go targets but impaired accuracy to no-go targets. The ADHD group, however, showed less change in accuracy and RT according to cue condition, suggesting that the go cue had less of an effect on response readiness in this group.

The findings of the current study add to the literature suggesting that individuals with ADHD have difficulty adjusting their behavior based on cues in the environment. Although both groups showed significant cue dependence, the magnitude of this effect was larger in controls relative to those with ADHD. Other studies provide indirect evidence that individuals with ADHD are less sensitive to relevant cues in the environment. First, Landau and Milich (1988) observed social behavior in children with and without ADHD in a simulated talk show activity in which two children took the role of either the host or the guest. Whereas the control children adjusted their interpersonal style based on the situational cues of their role (e.g., asking more questions and lowering conversational dominance as the host), the children with ADHD made fewer changes in their behavior to accommodate role demands. Second, Ströhle and colleagues (2008) examined brain activity in adults with and without ADHD in response to rewards, as well as cues signaling upcoming reward. This study found that the adults with ADHD showed reduced activity when viewing the reward cue. Finally, our group (Weafer et al., 2009) showed that valid prereponse cues did not protect adults with ADHD against the disinhibiting effects of alcohol, whereas these cues protected nonclinical adults against alcohol impairment. These studies provide converging evidence that individuals with ADHD may not be able to utilize situational cues to the same extent as their nonclinical peers. This reduced sensitivity to environmental cues appears to affect seemingly unrelated domains of functioning (i.e., motivation, social functioning, attentional and behavioral control), so it may be associated with a wide range of symptoms in the ADHD phenotype. Further, this reduced sensitivity has been found among diverse groups of individuals with ADHD, including children and the high-functioning adults in the present study. It is important to note, however, that because many of the participants in the ADHD group were high-functioning college students, it is unclear whether these participants showed impairment across multiple domains of functioning.

The current study provides important information about cue sensitivity in adults with ADHD, but several limitations should be considered. First, our sample was drawn from a predominately college population. It is unclear whether these findings would generalize to a lower functioning group of adults with ADHD. However, all of the participants in the ADHD group met criteria on self-report measures of ADHD symptomatology and required stimulant medication to treat their symptoms. Further, participants in the ADHD group reported significantly more problems with impulsivity in their day-to-day lives than did those in the control group. Second, the sample only included individuals who were between the ages of 19 and 29, so it may not be appropriate to generalize to children, adolescents, or older adults with ADHD. However, a similar pattern of findings has been reported by our group in a sample of children with ADHD (Derefinko et al., 2008), so it appears that the reported effects may be robust across different developmental stages. Third, we were unable to test for subtype differences, and it is possible that the reduced sensitivity to environmental cues is more pronounced in a specific ADHD subtype (Booth, Carlson, & Tucker, 2007;

Derefinko et al., 2008). Finally, it is possible that the group differences in performance, although statistically significant, do not translate to impairment outside of the laboratory. Studies have shown that behavioral measures of cognitive functioning suffer from poor ecological validity (e.g., Mitchell & Miller, 2008). However, laboratory tasks are advantageous because they can examine isolated cognitive functions that may contribute to functional impairment outside of the laboratory (Castellanos & Tannock, 2002; Fillmore, 2003). Nonetheless, future studies should utilize measures of cue sensitivity with established ecological validity.

In sum, the current study provides new information about the effects of predictive cues on behavioral control in adults with ADHD. Specifically, these adults appear to be less able to adjust their behavior in response to predictive cues. These findings may help explain why individuals with ADHD act impulsively despite cues in the environment signaling that their behavior is inappropriate.

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Figure 1.

Mean (+SE) proportion of inhibitory failures separated by group and cue condition (left).

Mean (+SE) cue dependency effect on proportion of inhibitory failures separated by group (right).

Figure 2. Mean (+ SE) response time on go trials separated by group and cue condition (left). Mean (+SE) cue dependency effect on RT separated by group (right).

Table 1

Demographic and diagnostic information by group

	Group				<i>t</i>	<i>d</i>
	Control (<i>n</i> = 67)		ADHD (<i>n</i> = 88)			
	Mean	SD	Mean	SD		
Demographic						
Age	22.8	2.0	21.7	1.8	3.6*	0.6
Gender (% male)	65.7		72.7			
Education	15.9	1.4	15.5	1.5	1.6	0.3
IQ: Verbal	105.9	10.4	104.8	11.4	0.6	0.1
IQ: Nonverbal	107.6	12.3	105.4	12.4	1.1	0.2
IQ: Composite	107.6	10.7	105.9	11.5	0.9	0.1
BIS	57.8	10.2	72.1	11.6	8.0*	1.3
Diagnostic						
CAARS: DSM-IA	48.1	9.8	74.4	11.5	15.0*	2.4
CAARS: DSM-HI	43.9	8.6	65.8	14.3	11.1*	1.8
CAARS: DSM-Tot	45.7	9.9	74.3	12.7	15.2*	2.5

Note. Group contrasts were tests by independent sample *t* tests. For all comparisons, *n* = 155, *df* = 153. Age is reported in years. Education refers to years education completed. IQ: Verbal, IQ: Nonverbal, and IQ: Composite refers to respective scaled scores of the Kaufman Brief Intelligence Test. BIS refers to total score on the Barratt Impulsiveness Scale. CAARS scores are T-scores; DSM-IA is DSM-IV Inattentive Symptoms; DSM-HI is DSM-IV Hyperactive-Impulsive Symptoms; DSM-Tot is DSM-IV ADHD Symptoms Total.

* *p* < .001