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Errors on a Computer Task and Subclinical Symptoms of Attention-Deficit/Hyperactivity Disorder (ADHD)

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Abstract

Previous reports have found increased error rate for children with attention-deficit/hyperactivity disorder (ADHD) on response time (RT) computer tasks. Here we attempt the conceptual replication and extension of two studies that examined error rate in a general population of children ($N = 203$). Study 1 followed Johnstone and Galletta (2013) but considered associations between scores on a dimensional measure of ADHD symptoms (rather than comparing those with or without an ADHD diagnosis) and the frequency of commission and omission errors. Study 2 followed Shiels et al. (2012) and examined post-error adjustment in the same group of children as for Study 1. Study 1 did not replicate previous findings of no increase in errors of commission in those with higher ADHD symptoms (Johnstone & Galletta, 2013). Instead, we found that younger children with lower ADHD symptoms were more likely to make commission errors, while omission errors did not vary with age. Study 2 replicated the previous finding of less RT slowing in children with more ADHD symptoms, extending this finding to a general population of children. Namely, as ADHD symptoms increase, RT slowing is less likely, putting children with higher ADHD symptoms at risk of additional errors. Overall, we extend previous ADHD research to typically developing children with ADHD symptoms.

Keywords

reflexive attention; orienting; commission errors; omission errors; RT slowing

Attention-Deficit/Hyperactivity Disorder (ADHD) is a neurodevelopmental disorder characterized by a pattern of inattention, hyperactivity, and impulsivity (American Psychiatric Association, 2013) (APA). A diagnosis of ADHD can lead to a variety of problems that impact many aspects of daily living. For example, individuals with ADHD may experience problems paying attention, following directions, staying organized, or managing their time (Balogh & Czobor, 2014; Das, Cherbuin, Butterworth, Anstey, & Easteal, 2012; Faraone, Sergeant, Gillberg, & Biederman, 2003). In some cases, ADHD has been associated with a variety of difficult behavioral problems, which might include being

impatient, being interruptive, breaking rules, talking incessantly, or exhibiting defiance and aggression (Balogh & Czobor, 2014; Corkum & Siegel, 1993; Daley & Birchwood, 2010; Faraone et al., 2003). Although not all children diagnosed with ADHD have these behavioral problems, between 7% and 16% of children in the United States have ADHD (Faraone et al., 2003). Due to the high percentage of children affected by attention-related problems, researchers sought to understand some of the implications for these children as well as to develop ways by which these problems might be addressed.

Although patterns of hyperactivity and impulsivity most obviously manifest as difficulties with behavioral control, important cognitive control functions, such as attentional control and response inhibition, might be foundational to more observable behaviors. Defined as an individual's ability to pay attention to task-relevant stimuli, attentional control allows individuals to concentrate during a specific task (Johnstone & Galletta, 2013; Posner, 1980). Likewise, response inhibition refers to an individual's capacity to suppress responses to task-irrelevant stimuli (Johnstone & Galletta, 2013). Both attentional control and response inhibition are often measured by assessing the number and types of errors committed during specific computer tasks (Johnstone & Galletta, 2013; O'Connell et al., 2009; Shaw, Grayson, & Lewis, 2005).

Impairments in attentional control and response inhibition are often associated with decreased performance on computer tasks (Johnstone & Galletta, 2013; O'Connell et al., 2009; Van De Voorde, Roeyers, & Wiersema, 2010). For example, individuals with ADHD tend to make more errors on attention tasks of both omission (associated with inattentiveness) and of commission (associated with impulsivity) (Johnstone & Galletta, 2013; O'Connell et al., 2009; Van De Voorde et al., 2010). An increased number of task-related errors may indicate impairments in concentrating as well as difficulties responding to or withholding from responding during a specific task. Indeed, problems with attentional control and response inhibition may be related to issues with other cognitive control functions, such as error monitoring.

Error monitoring is another important cognitive control function that allows individuals to adapt to the changing demands of their environment and regulate their behavior (Dhar & Pourtois, 2011). It is often conceptualized into two main components: error detection and post-error behavior (Dhar & Pourtois, 2011). Appropriate changes in post-error behavior require accurate error detection and appropriate adjustments to avoid future errors. As such, error monitoring is often measured by reporting an individual's post-error slowing rate (Balogh & Czobor, 2014; Gupta & Kar, 2009; Mohamed, Börger, Geuze, & van der Meere, 2016; Plessen et al., 2016; Schachar et al., 2004; Shiels, Tamm, & Epstein, 2012; Tam, Moore, & Huang-Pollock, 2010; Van De Voorde et al., 2010; van Meel, Heslenfeld, Oosterlaan, & Sergeant, 2007). Most individuals will slow down (have higher response times [RTs]) after committing an error in order to improve their accuracy and to avoid making additional errors on subsequent trials (Mohamed et al., 2016; van Meel et al., 2007). However, various studies have demonstrated that individuals with ADHD are less likely to slow down following an error, thereby increasing their chances of committing more errors on ensuing trials (Balogh & Czobor, 2014; Schachar et al., 2004; Shiels et al., 2012; Tam et al., 2010). Thus, individuals with ADHD might experience impairments in the pathway from

error detection to behavioral adjustment. These impairments may result in less post-error slowing and subsequently result in more errors. These findings may also have implications for individuals within the general population who experience some symptoms of poor attention, but do not necessarily have an ADHD diagnosis.

Indeed, much of the research in the field suggests that individuals with symptoms of poor attention but without ADHD will make more errors of commission (respond impulsively) and omission (be inattentive) and will fail to slow down after an error on RT tasks. Several studies suggest that these trends are true for individuals with more ADHD symptoms. For example, Mohamed et al. (2016) found that university students with more ADHD symptoms are less likely to slow down after making an error on a computer task and are more likely to commit errors on the task as compared to individuals with lower ADHD scores. Another researcher used a meta-analysis to support both increased error-making and decreased post-error slowing in children and adults with symptoms of poor attention (Balogh & Czobor, 2014). However, solely using studies that categorized individuals into one of two groups (those with ADHD and those without ADHD) fails to account for individual variation in severity of ADHD symptoms Balogh and Czobor (2014). Further research is necessary in order to explore these patterns of errors using a dimensional evaluation of ADHD symptoms in a general population of children. As opposed to a categorical approach, a dimensional approach quantifies attributes of ADHD, such as impulsivity or inattention. This approach is especially helpful for continuously distributed attributes such as ADHD symptoms (Das et al., 2012) and may provide researchers with a better understanding about problems of attention over a range of severity.

Here we attempt to replicate two studies that used ADHD-diagnosed children and typically developing children to examine problems with making errors and failing to slow down after errors (Johnstone & Galletta, 2013; Shiels et al., 2012). However, rather than using a case-control design, we use a dimensional measure of ADHD symptoms. We model our first study after Johnstone and Galletta (2013), who investigated increased error making, specifically omission and commission errors, in children with ADHD. They found that children with ADHD made more omission errors, but ADHD did not seem to affect the frequency of commission errors. We model our second study after Shiels et al. (2012), who focused primarily on RT slowing after an error. They found that children with ADHD failed to slow down after errors. These studies suggest problems with attentional control and error monitoring in children with ADHD.

In the studies presented in this manuscript, we aimed to determine if (1) children with more symptoms of ADHD were more likely to make omission and/or commission errors during a RT task relative to children with fewer ADHD symptoms, and if (2) RT slowing is reduced in children with more ADHD symptoms relative to children with fewer ADHD symptoms. Because symptoms of ADHD exist within the general population, we hoped to discover if error monitoring also was disrupted in children with more symptoms of poor attention (as with those with ADHD) by examining their performance on a cognitive task. Consistent with Johnstone and Galletta (2013), we hypothesized that children with higher scores of ADHD would experience higher frequencies of commission and omission errors and would

be less likely to slow down after making an error relative to children with lower scores of ADHD.

Study 1

We designed Study 1 to replicate a study performed by Johnstone and Galletta (2013), which compared the rates of omission and commission errors on an attention task in children with ADHD to typically developing children. In this study, we determined if children with more parent-reported ADHD symptoms had higher frequencies of commission and omission errors relative to children with fewer ADHD symptoms.

Study 1 Method

Participants—As part of a longitudinal follow-up study (Lundwall, Dannemiller, & Goldsmith, 2015), we invited children ($N = 203$) who lived in the Madison, Wisconsin area to visit the Waisman Center to complete attentional tasks. The parents of all children completed a questionnaire that assessed ADHD symptoms. Of the 203 children in the analyzed data set, 51% were male and 97% were Caucasian. Age ranged from 10.58 to 16.55 years ($M = 12.94$ years, $SD = 1.73$).

Measures—There were two measures: a spatial-cueing (SC) task that the child completed and a questionnaire that the parent completed about the child.

Spatial-cueing task: We used a Posner-like reflexive attention task (Posner, 1980). Reflexive attention is the ability to orient and respond to a moving or suddenly-appearing target stimulus. In contrast, sustained attention is the ability of participants to maintain focus on the target stimulus despite changing conditions (Posner, 2016). Our task was similar to the one used in our previous study conducted with adults (Lundwall et al., 2015). By designing the task as a game with friendly “earth” rockets and alien spaceships, we modified the adult version of the task to engage the interest of children while still maintaining its ability to measure visual reflexive attention to suddenly-appearing stimuli (Figure 1). Earth rockets acted as cues and spaceships acted as targets. The cues could be valid (i.e., appear near where the target would appear) or invalid (i.e., appear contralateral to the target). Fifty percent of the cues were valid. In addition to valid and invalid cues, there were also neutral cues, with one cue on each side of the display. This condition does not bias attention to either the left or the right side and was used as a baseline in RT difference-score calculations. With the use of two different cue contrasts (faded and unfaded, described herein as dim and bright, respectively) and a no cue condition, we had seven conditions (i.e., No Cue, Neutral Dim, Neutral Bright, Single Bright Valid, Single Bright Invalid, Single Dim Valid, and Single Dim Invalid). There were 24 trials of each condition intermixed and pseudorandomly presented over the course of the task. There were also 12 catch trials (with no target) on which participants were instructed to withhold responding.

Questionnaire data: We asked parents to complete the MacArthur Health Behavior Questionnaire for Parents (HBQ-P) (Armstrong, Goldstein, & The MacArthur Working Group on Outcome Assessment, 2003; Essex et al., 2002), which included questions regarding any ADHD symptoms in the participating child. The ADHD symptom scores

included impulsivity and inattention subscores. Impulsivity questions included items such as how frequently the child struggles to stay seated when required to do so, difficulty the child has in waiting his or her turn in games or conversations, and how often the child acts without thinking. Measures of inattention included items such as difficulty the child may have in following directions, how frequently the child cannot concentrate on a task, or how frequently the child jumps from activity to activity. In the current study, we focused on ADHD symptom scores to ascertain any potential relationships between symptom scores and errors on the SC task.

Procedure—We tested participants in a darkened room on a 381×305 mm monitor with a 60 Hz refresh rate. We maintained viewing distance at 57 cm with a chin rest and used E-Prime (Sharpsburg, PA) to present stimuli. Cues had an inner edge 7.0 deg from central fixation. Targets had an inner edge 5.7 deg from fixation. As previously stated, we designed the task as a game with friendly “earth” rockets and alien spaceships. Earth rockets flashed briefly (67 msec) and acted as cues. After a brief gap (83 msec) an alien spaceship could appear. The spaceships were targets to which children were instructed to make a right or left key press mapped to the location of the target. Since the percentage of valid cues did not differ from chance, we told children that paying attention to the earth rockets would not help them.

Statistical Analyses—Here we describe both planned data preparation and the main analysis.

Data preparation: For Study 1, we marked trials as having an omission error, a commission error, or no error. All trials were marked according to the method employed by Johnstone and Galletta (2013). “No response” to a trial with a target counted as an omission error. Omission errors also included key presses before 200 msec (anticipations) and after 1500 msec. Commission errors included responses made in the correct time window (200 – 1500 msec) but to the wrong side (responding with a left key press to a right target, or vice versa). We then created an aggregated dataset and used this in the main analysis, as described below.

Main analysis: We used a general linear model (GLM) to examine the effect of continuous ADHD symptoms on both omission and commission errors, in line with the MANOVA used by Johnstone and Galletta (2013), who examined ADHD as a categorical variable instead (ADHD vs. control).

Study 1 Results

Behavioral Data—The proportion of commission errors ranged from 0.00 to 0.36 ($M = 0.06$) per participant. The proportion of omission errors ranged from 0.00 to 0.35 per participant. Commission errors were marked first and omission errors were only marked for trials on which the child pressed the correct key in the correct time frame (200 – 1500 msec). We checked all outcome variables for normality. Commission was significantly skewed (2.55, $SE = .17$) and omission was also skewed (3.13, $SE = .17$). Both omission errors and commission errors were log base 10 transformed. After transformation, both were normally

distributed (omission skewness = .48, $SE = .17$; commission skewness = $-.45$, $SE = .17$). Omission errors significantly correlated with commission errors ($r = .59$, $p < .001$). While these two variables were significantly correlated, they were not correlated at such a high r -value as to preclude GLM (Maxwell, 2001).

We used the HBQ-P summary score for ADHD symptom because Johnstone and Galletta (2013) found increased omission errors associated with ADHD diagnosis. We thought this might also apply to children without an ADHD diagnosis but with some ADHD symptoms. This summary score consisted of 15 items, each of which could be scored by the parent as 0 (never, or not true), 1 (somewhat true), or 2 (often, or very true). Summary scores for ADHD symptoms ranged from 0 to 22 ($M = 4.09$, $SD = 4.37$).

Main Analysis—We determined that ADHD symptom scores did not predict omission or commission errors ($p > .25$). However, our model showed that age predicted one or more of the dependent variables, Pillai's Trace = .04, $F(2, 195) = 3.53$, $p = .03$, $\eta^2 = .04$. Follow-up analyses (ANOVAs) indicated that age was significant in predicting commission errors ($F[1, 196] = 5.67$, $p = .02$) as opposed to omission errors ($F[1, 196] = .22$, $p = .64$).

Study 1 Discussion

Our attempt to replicate the study conducted by Johnstone and Galletta (2013) did not demonstrate a significant difference in the overall frequency of commission or omission errors based on ADHD symptoms. However, we found an interesting trend regarding age and type of error, which may have implications for future researchers to consider. This supplemental finding suggests that younger children made more commission errors than older children. However, omission errors did not vary by age.

It might have been expected that younger children would make more errors overall. However, it appears that younger children did not make more errors by failing to respond (omission errors) to trials during the computer task. Instead, younger children tended to make more errors by pressing the computer key on the opposite side of the target (commission errors or wrong-side errors). Please note that Johnstone and Galletta (2013) found significance for omission (but not commission) errors. However, the children in their study were younger (7.83 years to 14.58 years [$M = 11.09$, $SD = 2.15$]) than the children in our study (10.58 to 16.55 years [$M = 12.94$ years, $SD = 1.73$]), which may have impacted the results of our study and contributed to the lack of replication of Johnstone and Galletta's (2013) findings. Nevertheless, our finding supports other findings that the ability to control attention develops earlier than inhibitory control (Gupta & Kar, 2009). Our finding also adds new information. While past research has found that younger children have more difficulty with sustained attention (Schachar et al., 2004), our finding indicates that regardless of whether the task measures sustained or reflexive attention, younger children commit more errors on attentional tasks than older children.

Although we were not able to directly replicate the Johnstone and Galletta (2013) study, our findings are consistent with some of the findings of other attentional studies. In the past, researchers have sometimes found no significant differences in overall commission or omission errors between children with ADHD and those without (Bioulac et al., 2012;

Corkum & Siegel, 1993; Shaw et al., 2005). These researchers have suggested that there may be certain contexts in which children with ADHD may have no worse inhibition (make no more commission errors) than children without ADHD. For example, Shaw et al. (2005) found that children with ADHD performed as well as typically developing controls on tasks that resembled computer games. Tasks modeled after popular computer games may elicit higher levels of arousal, interest, and motivation in children both with and without ADHD (Shaw et al., 2005). For some children within our study, our task may have seemed similar to a computer game due to stimuli and the backstory we initially told each child prior to starting the task. This may have elicited similar levels of motivation and interest regardless of the child's number of ADHD symptoms. However, most children who commented on the computer task after the study described the task as "boring." Thus, lower levels of arousal, interest, and motivation seem more likely.

Contrary to our findings, some researchers have observed increased commission and omission errors in ADHD participants (Dhar & Pourtois, 2011; McPherson & Salamat, 2004; Michelini et al., 2016; O'Connell et al., 2009; Van De Voorde et al., 2010; van Meel et al., 2007). Many of these studies used different types of attentional tasks, such as adapted versions of a Go/ No-Go task (Dhar & Pourtois, 2011; O'Connell et al., 2009; Van De Voorde et al., 2010), a continuous performance task (McPherson & Salamat, 2004), or an Eriksen Flanker task (Michelini et al., 2016; Plessen et al., 2016), to study ADHD symptoms among participants. Because many of these studies used tasks in which participants were instructed to withhold responding under multiple conditions, participants might have naturally committed more errors. This might have led to a better chance of detecting a significant difference between groups. Future studies using reflexive attention tasks should increase task difficulty to make it more likely to detect a difference in commission errors based on ADHD symptoms, if such a difference exists.

On a final note, many of these tasks measured participants' sustained attention as opposed to their reflexive attention. Because our task measured a different type of attention, our results might not have been consistent with the findings of other studies. Nevertheless, our findings demonstrate that children with more ADHD symptoms may have comparable reflexive attention relative to children with fewer ADHD symptoms. Our study extends previous research into the realm of reflexive attention, and it also may be applied to a population of children who might experience attentional difficulties, but who do not have ADHD.

Study 2

We designed Study 2 to replicate a study performed by Shiels et al. (2012), which compared children with ADHD to typically developing controls regarding RT slowing on an attention task. Specifically, we used Study 2 to determine if children with more parent-reported ADHD symptoms were less likely to slow down after an error on the given task than children with fewer ADHD symptoms.

Study 2 Method

Participants, Measures, and Procedures—The participants, measures used, and procedures followed were identical for Study 2 as those for Study 1. The same sample of

children and the same SC task and behavioral questionnaire were used for Study 2 as for Study 1.

Statistical Analysis

Data preparation: For Study 2, we classified each trial according to three features: error status (i.e., determined if there was an error and, if there was, what type of error), the status of the trial that preceded the given trial, and the status of the trial that followed the given trial. Specifically, trials could be marked as one of the following: precedes an omission error, is an omission error, precedes a commission error, is a commission error, follows a commission error, both precedes and follows a commission error, or is correct and not otherwise specified. Trials that *followed* commission errors had their RTs compared to trials that were not errors and did not follow an error. We did this to determine if RT slowing following an error occurred more often in those with fewer ADHD symptoms. We excluded from analysis trials that were commission errors, that preceded an omission or commission error, or that both preceded and followed trials with commission errors.

Main analysis: For Shiels et al. (2012) replication attempt, we used a multilevel model (MLM) analysis with trial-by-trial dataset. A MLM analysis is similar to a regression analysis, but it accounts for the nested nature of the data. Nested data implies that the trials were not independent but associated with the characteristics of the individual from which the trials came (Peugh, 2010; Roberts, 2004). Using MLM accounts for the non-independence of the data. We note that a significant proportion of the variance came from the individual-level data ($Z = 105.63$, $p < .001$), which also indicates the need for MLM.

Study 2 Results

Behavioral Data—As stated previously, we used the HBQ-P summary score related to ADHD symptoms. See Behavioral Data for Study 1. Overall RT slowing ranged from -216.67 to 296.14 msec ($M = -49.20$, $SD = 59.56$ msec). Negative values of RT slowing indicate RT speeding (faster responding after an error). For example, higher negative values indicate taking less time to respond to a subsequent trial following an error (less RT slowing and continuing at their normal speed), while smaller negative or positive values indicate taking more time to respond to a trial following an error (more RT slowing). RT slowing was normally distributed without transformation (skewness = $-.30$, $SE = .01$).

Main Analyses—The second study asked, “Do subjects with more ADHD symptoms have reduced RT slowing?” To answer this question, we used MLM. Overall, the model predicting RT slowing from ADHD symptoms, age, and sex was significantly better than a model with no predictors ($\chi^2 [31, N = 34725] = 9316.29$, $p < .001$). Each predictor, including ADHD symptoms ($F[16, 34153] = 157.44$, $p < .001$), age ($F[1, 34153] = 164.04$, $p < .001$), and sex ($F[1, 34153] = 14.33$, $p < .001$) was significant. In addition, the interaction between ADHD symptoms and sex was significant, $F[11, 34153] = 68.25$, $p < .001$. This interaction indicates that, for boys, having fewer ADHD symptoms is associated with having less RT slowing (taking less time to respond to a trial following a trial on which an error was made).

Study 2 Discussion

We successfully replicated the study by Shiels et al. (2012). As ADHD symptoms increased, RT slowing following an error became less likely. That is, subjects with more ADHD symptoms were less likely to slow down after committing an error than subjects with fewer ADHD symptoms. In the previous study, Shiels et al. (2012) found impaired post-error slowing in children with ADHD. We extend this finding by using a dimensional measure of ADHD symptoms to indicate that post-error slowing is impaired in children from the general population who have more ADHD symptoms. Therefore, children who are not diagnosed with ADHD, but whose parents report symptoms, are also at risk for reduced error monitoring.

Our findings are consistent with those of other researchers who have found an association between ADHD and reduced RT slowing (Balogh & Czobor, 2014; Gupta & Kar, 2009; Schachar et al., 2004; Tam et al., 2010). In each study, researchers found that children with ADHD were less likely to slow down following a computer-task error. However, by using a continuous measure of ADHD symptoms rather than a categorical diagnosis, our study adds to the literature in the field and extends findings to individuals who experience ADHD symptoms, but might not have enough symptoms to justify a formal diagnosis. Since ADHD symptoms are normally distributed in the general population of children (Das et al., 2012), our approach provides insight that generalizes to more children, including those who have not been formally diagnosed with ADHD.

While our research supports reduced RT slowing in those with ADHD symptoms, some studies have found contradictory results. For example, Wiersema, Van Der Meere, and Roeyers (2009) found that although adults with ADHD had decreased ability in detecting and interpreting errors after making a mistake, there was no difference in RT slowing between those with ADHD and those without. It is possible that these researchers did not find RT slowing because they tested adults rather than children. As individuals with ADHD mature and gain experience, they may learn to slow down after committing an error and therefore no longer show significant differences from those without ADHD. In another study, Plessen et al. (2016) researched RT slowing in children and found no evidence of RT slowing following an error in those with ADHD. However, the sample size included only 54 children (25 of whom had ADHD). When the sample size is over 200, RT slowing differences can be found in children (Gupta & Kar, 2009).

Learning to slow down and adapt behavior to a given task after committing an error may be something that children can be actively taught. For instance, if children with more ADHD symptoms can learn to adjust their reactions to stimuli following a behavior, they may be more accurate in subsequent trials. Indeed, unless children receive direct instruction on managing and adapting to errors, this problem might persist into adulthood. Failure to manage errors can affect individuals in many aspects of life including educational pursuits and future careers in which error monitoring is important. Generally speaking, error monitoring is applicable for children when taking a test, making decisions throughout the day, or when completing homework or other tasks. Because error monitoring plays such a ubiquitous role in everyday performance and success, it may be crucial to discover a way to assist children with ADHD symptoms in improving error monitoring.

General Discussion

Overview

We attempted to replicate two studies to determine if attentional problems that occur in children diagnosed with ADHD extend to children in the general population who merely have some symptoms of ADHD. Because ADHD symptoms lie on a normal distribution in the general population (Das et al., 2012), a dimensional measure of ADHD symptoms, as opposed to a diagnostic one, may provide additional information to researchers about attentional problems over a range of severities. We modeled the first study, examining omission and commission errors, after the study by Johnstone and Galletta (2013). In our replication, there was no significant difference in omission errors based on age, but age was significant in predicting commission errors. We found that age showed a negative association with the proportion of commission errors, regardless of the number of ADHD symptoms reported. In our follow-up regression analysis, we were also able to predict ADHD symptoms from age and error types made on a computer task. Depending on the situation, the latter perspectives might be useful in screening child for ADHD symptoms. However, this would require further study. Future studies could also examine how error monitoring develops in children over time. For example, it is possible that the ability to avoid omission errors may develop first, but that the ability to avoid commission errors continues across a broader age span (10.58 to 16.55 years). Accordingly, age and error type may be important indicators in determining the individuals who may have attentional problems within the general population.

The second study, examining RT slowing Shiels et al. (2012) found that as ADHD symptoms increase, RT slowing after an error decreases. In other words, higher scores on a dimensional measure of ADHD are predictive of less RT slowing. This finding suggests that, even if a child does not have an ADHD diagnosis, those with more ADHD symptoms may have difficulties with error monitoring and may be more likely to engage in a behavior that makes future errors more likely (Balogh & Czobor, 2014; Schachar et al., 2004; Shiels et al., 2012; Tam et al., 2010). Thus, poor RT slowing may play an important role in discriminating between individuals with attentional difficulties and those without.

Overall, by employing a dimensional approach in assessing the number of ADHD symptoms within a general population of children, our research findings extend to those who have symptoms of poor attention, but are not diagnosed with ADHD. Not all children with attentional difficulties have the same severity of symptoms. Our dimensional approach allows researchers increased understanding of the effects that various levels of attentional difficulties may have on a child's performance. Having an understanding of the types of cognitive errors with which a child struggles may be useful in helping researchers to uncover beneficial methods by which children with attentional difficulties may be helped in a variety of settings.

Study Limitations and Future Directions

Despite its strengths, our study has certain limitations that should be addressed in the future. For instance, our research would benefit by using a more diverse sample as well as a more

sensitive task. As a function of the region from which we collected data, our study mostly includes Caucasians and therefore might not be representative of more ethnically and culturally diverse populations. By including a more diverse sample, future research might address the question of whether the error processes studied here are universal or are limited to a certain population of individuals. Furthermore, the task used in our study may not have been difficult enough to induce many errors. Many children only committed a few errors throughout the task, yielding a ceiling effect. Using a task that is more sensitive to the tendency to commit errors may benefit future research by allowing such tendencies to better associated with a varying number of ADHD symptoms.

Conclusion

However, our study successfully predicted certain types of error monitoring based on the number of ADHD symptoms. Namely, younger children made more commission errors than older children, while omission errors did not vary by age. In addition, ADHD symptoms predict RT slowing, but there are some differences by sex. Boys with fewer ADHD symptoms had less RT slowing (i.e., take less time to respond following an error). Our research contributes to a growing body of literature reporting insufficient error monitoring in individuals with ADHD symptoms. Individuals with ADHD symptoms appear to be limited in detecting errors and subsequently slowing down in order to prevent further mistakes. Improving our understanding of ADHD symptoms and their effect on error monitoring may enhance the lives of individuals diagnosed with ADHD and those who exhibit some ADHD symptoms.

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Figure 1.

Schematic of the child spatial-cueing (SC) task. Earth rockets acted as cues and spaceships acted as targets. The cue onset to target onset interval (SOA) was 150 msec., including a 83 msec gap between cue offset and target onset.