THE N-2 TASK-SWITCHING PARADIGM AND ATTENTION-DEFICIT/HYPERACTIVITY DISORDER

BY

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LIST OF ABBREVIATIONS

ADHD: Attention Deficit/Hyperactivity Disorder

ANOVA: Analysis of Variance

BDEFS: Barkley Deficits in Executive Functioning Scale

BDEFS-LF: Barkley Deficits in Executive Functioning Scale – Long Form

BDEFS-SF: Barkley Deficits in Executive Functioning Scale – Short Form

CSI: Cue-Stimuli Interval

EF: Executive Functioning

MS: Milliseconds

OSPAN: Operation Span

RCI: Response-Cue Interval

RT: Reaction Time

ABSTRACT

Individuals with Attention-Deficit/Hyperactivity Disorder (ADHD) have been shown to experience greater deficits in executive functioning (EF). While less is known about the extent to which deficits in EF continue into adulthood, research suggests that adults with ADHD have more difficulty on measures of EF that rely on inhibition (Boonstra et al., 2010). Task-switching paradigms are cognitive tasks that require behavioral inhibition, as one must be able to inhibit responses that are no longer relevant to the current task in order to readily shift from one task set to the next. Thus, task-switching paradigms provide a method to assess inhibition in adults with ADHD. The purpose of the current study was to examine task-switching performance to determine if there are differences in persisting inhibition in adults with ADHD. To test this hypothesis, performance on a task-switching paradigm with various response-cue intervals, an operation span task (OSPAN), and self-reported deficits in EF were compared between an ADHD and control group. The results showed that individuals in the ADHD group experienced persisting inhibition on the task-switching paradigm and performed as well as the control group on the OSPAN task but reported significantly more problems with EF. These results suggest that EF processes different from those involved in task-switching may be compromised in ADHD.

INTRODUCTION

Attention-Deficit/Hyperactivity Disorder (ADHD) is one of the most common psychiatric diagnoses in children as it affects about 5% of all children (Centers for Disease Control and Prevention [CDC], 2017). The hallmark symptoms of ADHD are the inability to maintain attention throughout completion of a task, hyperactivity, and impulsive-like behavior in comparison to what is expected for an individual's age (Biederman, 2005). There are three distinct diagnoses for ADHD: 1) predominantly inattentive, 2) predominantly hyperactive/impulsive, and 3) a combined presentation (CDC, 2017). The inattentive type is characterized by being easily distracted with an inability to focus on a given task for a prolonged period of time whereas the hyperactive/impulsive type is characterized by fidgeting, excessive movements, excessive talking, and restless behavior. Children diagnosed with the combined presentation of ADHD demonstrate symptoms that are exhibited in both the inattentive and hyperactivity/impulsive types (Biederman, 2005). In order to receive a diagnosis of ADHD, several of these symptoms must be present by the age of 12, a symptom must persist across two settings, and there must be evidence that the symptoms interfere with, or reduce, the quality of social, academic, or occupational functioning for the individual (CDC, 2017).

ADHD is typically diagnosed in childhood, which is the time when it is most easily identified, but it can also be diagnosed at later ages. Moreover, the symptoms that are detected early on in a child's life can prevail throughout adulthood. The symptoms of ADHD can often interfere with the everyday functioning and life of a child or adult diagnosed with this disorder, and can have serious repercussions and consequences, such

as financial burden and stress to families, along with adverse academic and vocational outcomes (Biederman, 2005). For this reason, it is important to conduct research in this field and gain a better understanding of the cognitive deficits associated with ADHD in order to create more effective diagnostic measures and treatments.

Some of the hallmark differences between individuals with ADHD and those without the disorder include a number of cognitive deficits that can be classified as part of executive functioning. Executive functioning (EF) consists of a collection of control processes, such as planning, organization, task initiation and control that are responsible for regulating individuals' thoughts and behaviors (Miyake & Friedman, 2012), and originate from brain areas within the prefrontal cortex (Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). In particular, the differences in performance between children with ADHD and healthy controls were found on measures of response inhibition, vigilance, working memory, and planning abilities (Willcutt et al., 2005). Research examining children with ADHD has identified distinct deficits in EF, but the extent to which these deficits persist and impact cognitive performance in adults with ADHD is less understood (Boonstra, Oosterlaan, Sergeant, & Buitelaar, 2005). To understand the cognitive implications of adult ADHD, Boonstra et al. (2010) compared the performance of 49 adults with ADHD who had never taken any medication for ADHD with 49 age and gender matched controls on tests of five facets of EF (inhibition, WM, fluency, planning, and set shifting). Individuals with ADHD performed significantly worse on tests of inhibition and demonstrated some deficits in set shifting in comparison to the controls, suggesting that ADHD that persists into adulthood primarily results in impairments in inhibition. Other studies have similarly found that set-shifting and task-switching are

specific facets within EF that have proven to be impaired in both children and adults with ADHD (Bueno, da Silva, Alves, Louza, & Pompeia, 2017; Cepeda, Cepeda, & Kramer, 2000; King, Colla, Brass, Heuser, & von Cramon, 2007). As discussed more below, successful task-switching relies on inhibition and different aspects of working memory, such as set shifting and task set maintenance, which could make it a useful approach for further understanding cognitive dysfunction in ADHD when examined in a more fine-grained manner.

Overview of Task-Switching Performance

Task-switching paradigms involve a design in which participants are asked to perform two or more different tasks, and over the course of a series of trials, they either continue to perform the same task, or switch from performing one task to another task. For each task, participants must develop a task set, which is the organization of all of the cognitive processes that enable them to act in accordance with the requirements of the task (Kiesel et al., 2010). Many different types of tasks have been used in these paradigms, including word reading, color naming, digit categorization by magnitude or parity, and responding to stimuli according to their location (Kiesel et al., 2010). For example, participants may be presented with a number between one and nine on any given trial but for one task they must determine whether that number is lower or higher than five (magnitude judgment), whereas for the other they must determine whether the number is even or odd (parity judgment). Repetition or non-switch trials are ones in which participants are asked to perform the same task from one trial to the next, while switch trials require participants to switch from performing one type of task to performing a different task (Cepeda, Cepeda, & Kramer, 2000). Performance on the

switch trials is then compared to performance on the repetition trials to determine whether differences in accuracy or speed occur between the two types of trials. Results typically show that individuals have lower accuracy scores and slower reaction times when completing the switch trials in comparison to the repetition trials (Kiesel et al., 2010). These differences in performance are referred to as switch costs (Yeung & Monsell, 2003).

Researchers have proposed various explanations for the exhibition of switch costs but generally, switch costs are thought to represent the amount of time needed to prepare for the upcoming task when participants change from performing one task to another. More specifically, task reconfiguration has been thought to occur when additional processing time is needed during switch trials to recognize that the current task set has changed and to then re-orient and re-direct performance efforts towards the newly relevant task set (Yeung & Monsell, 2003). However, when researchers investigated the process of preparing for a new task, they determined that preparation could not account for the entirety of the observed switch costs (Costa & Friedrich, 2012). This was evident in that switch costs could only be reduced, but not fully eliminated, when participants were given longer time intervals (150, 300, 450, 600, and 1,250 ms) to prepare for the upcoming task set (Rogers & Monsell, 1995). Switch costs alternatively may result from interference, as the influence of task sets from earlier trials seem to persist into later trials. That is, the rules and the task set of the previous task may still be active and thus negatively impact performance on the following task, especially if the task set of the latter conflicts with that of the no longer relevant task (Costa & Friedrich, 2012).

One of the ways that participants can successfully manage interference when task-switching is through inhibitory processes. Inhibition, in this case, is the ability to disengage from one task set and "block" its requirements when switching to another, which enables conflict resolution among the competing task sets (Costa & Friedrich, 2012). Thus, when efficiently utilizing inhibitory processes, individuals should have faster reaction times and lower switch costs when switching between tasks.

Persisting Inhibition (N-2 Repetition Costs)

While inhibition during task switching allows an individual to successfully switch from one task to another and can contribute to minimized switch costs, the effects of inhibition can continue to suppress the recently disengaged task set over multiple trials, even when the task set needs to be re-activated and performed again. Thus *persisting inhibition* means that while performing the second of two tasks the task set for the now current task is still suppressed by cognitive processes after having been inhibited during the performance of the previous task (Yeung & Monsell, 2003).

Evidence for persisting inhibition, which is also referred to as *backward inhibition*, comes from use of the N-2 repetition task-switching paradigm in which the task sequence follows an ABA or a CBA pattern (Mayr & Keele, 2000). In this paradigm, the sequence of the tasks is randomly ordered, and half of the trials follow the ABA task sequence (N-2), where the N trial is the same as the N-2 trial (A and A), and the other half of the trials follow the CBA task sequence. This procedure produces what are called N-2 repetition costs. That is, when comparing performance on ABA trials versus CBA trials (in which all three tasks are different), participants are slower and less accurate when performing the task that has recently been switched away from (i.e., the

second “A” task in the ABA series) than the new task (i.e., the “A” task in the CBA series). The N-2 repetition cost demonstrates how inhibition of the previously abandoned task set persists and continues to be inhibited throughout the task sequence, making the task set more difficult to perform when it becomes relevant again (Costa & Friedrich, 2012; Grange, Juvina & Houghton, 2013; Philipp & Koch, 2006). Researchers have explored the N-2 repetition cost by examining manipulations of stimulus timing, type of stimuli, and degree of interference to uncover the processes that are critical for successful task-switching performance. Most notably for the current work, Mayr and Keele (2000, Experiments 1A and 1B) manipulated the cue-stimuli interval (CSI), the time between the task cue and the presentation of the next stimuli, and the response-cue interval (RCI), the time between a response and the presentation of the following task cue, to gain a better understanding of when inhibitory processes are involved in the N-2 repetition cost. More specifically, one view of the N-2 repetition cost proposes that it is a reflection of the length of the RCI, the time needed to prepare for and switch to perform the upcoming task. It was thought that increased RCI would aid task performance by allowing more time for the task set to decay resulting in less inhibition. On the other hand, the CSI manipulation served as a test of the expectancy account of the N-2 repetition cost. That is, when performing the third task in the ABA task sequence in a task-switching paradigm, the participants expect to see a task that is different from the previous two tasks, which makes it harder to re-activate a task set that has been recently inhibited. Thus, the condition with the longer CSI should provide the participants with more time to recover from that expectation and prepare for the upcoming task (Mayr & Keele, 2000).

The results showed that the backward inhibition effect was present across all conditions in which the CSI was manipulated, meaning that the N-2 repetition cost was larger for the ABA task sequence in comparison to the CBA task sequence regardless of the size of the CSI. Thus, the amount of time that was allowed for preparation of the following task set did not significantly change the magnitude of the N-2 repetition cost (Mayr & Keele, 2000, Experiments 1A and 1B). However, in Experiment 1B the researchers found that manipulations of the length of the RSI did result in a decay effect, as longer RSIs led to less inhibition from the previous task set, and a smaller N-2 repetition cost. This finding suggests that inhibition from previous task sets may be reduced simply by the passage of time. Moreover, such decay has been viewed as important. Altmann and Gray (2008) propose that decay of the previous task set is necessary so that the current task set is more highly activated and thus easier to perform than the previous one. They also argue that if there were no decay effect then each shift in task would need increasing levels of activation, making it sequentially harder for individuals to engage the current task set, and to continuously switch between tasks.

Assessing group differences using the N-2 paradigm. Researchers have also utilized the N-2 task-switching paradigm to study and highlight differences in inhibitory abilities at the group level in populations known to experience deficits in EF (Grange et al. 2011). For example, Moritz, Hubner and Kluwe (2004) looked at task switching performance in individuals with Obsessive-Compulsive Disorder (OCD). There were three groups of participants: 40 OCD patients, 20 psychiatric controls (individuals diagnosed with other anxiety disorders besides OCD), and 20 healthy controls. The researchers hypothesized that the patients with OCD would have increased N-2 repetition

costs in comparison to the psychiatric control and healthy control groups because the characteristic deficit in OCD is the inability to quickly and adaptively control/inhibit one's stream of thoughts, resulting in worse task-switching performance. The results showed that individuals with OCD displayed the slowest RTs and the largest N-2 repetition costs, although the interaction effect between group type and task sequence was not statistically significant. The authors discuss that their non-significant findings may have been due to weak statistical power, and suggest that more studies should be done to follow up on their work. Surprisingly, the psychiatric control group did not display an N-2 repetition cost at all, as their RTs did not significantly differ between the ABA and CBA task sequences[1]. The fact that the psychiatric control group showed no N-2 repetition cost suggests that this group may experience a lessened ability to inhibit the irrelevant task set.

ADHD and Task-Switching

Differences in task-switching capabilities among children with ADHD (both those who were on and off medication) have been found when compared to age and IQ matched controls (Cepeda et al., 2000). More specifically, children with ADHD demonstrate larger switch costs, and have a harder time switching between two types of tasks than children who do not have ADHD, suggesting there is an impairment in inhibition associated with the disorder, as discussed above. Larger switch costs are generally thought to be a cognitive deficit, as they indicate that the individual is less successful in transitioning from the performance of one task to the performance of a different task, something that we frequently do in our everyday lives. Other evidence

[1] When discussing comparisons between performance on the CBA and ABA trials, it is specifically performance on the final "A" task from the CBA and ABA trial sequences that is being compared.

suggesting participants with ADHD may show larger switch costs comes from patients with damage to their frontal lobes, as these individuals have more difficulty and struggle to disengage from the irrelevant task set when performing task switching measures (Mayr & Keele, 2000). To re-iterate an earlier point, research has shown that individuals with a diagnosis of ADHD have deficits in EFs such as thinking, planning, and initiating tasks, that are thought to be controlled by regions of the brain within the prefrontal cortex (Boonstra et al., 2005; Willcut et al., 2005). Due to these deficits in EFs that are associated with ADHD, individuals diagnosed with ADHD may also have a harder time disengaging from the irrelevant task set, and have worse task-switching performance in a manner like patients with damage to their frontal lobe.

The Current Study

While task-switching studies have shown that children with ADHD demonstrate difficulties in their inhibitory processing skills, less is known about the extent to which inhibition is impaired in adults with ADHD (Cepeda et al., 2000). Consequently, the purpose of the current study was to examine the effects of persisting inhibition on task-switching performance between an ADHD and control group across different RCIs. If individuals with ADHD have less inhibitory abilities, they should have an easier time performing the ABA task sequence where they have to switch back to performing a recently abandoned task set. On the other hand, if the control group experiences greater levels of inhibition that persist throughout the series of trials, they should have a harder time switching back to perform a task set again. More specifically, due to the lack of inhibition that is associated with the diagnosis of ADHD, the ADHD group should have faster RTs on the ABA task sequences and smaller N-2 repetition costs in comparison to

the control group. Additionally, manipulating the length of the RCIs should impact the size of the N-2 repetition cost for both the ADHD and the control group due to the decay of inhibition. However, if the control group displays stronger persisting inhibition than the ADHD group, as predicted, a longer RCI should be more beneficial for the control group as it would allow more time for decay of the previous task set and result in a greater reduction in the N-2 repetition cost. In fact, the ADHD group may not demonstrate any reduction in the size of the N-2 repetition cost at a longer RCI, if this group does not experience persisting inhibition at the short RCI.

To test these ideas, young adults with and without ADHD were recruited from the Introductory to Psychology course at Wake Forest University to complete a task-switching paradigm. In this paradigm, participants were presented with numbers in either their numeric or word form and were asked to perform one of three different tasks: parity (odd/even), magnitude (lower/higher), and form (word/number) judgments. These tasks were administered across two different types of trial blocks, N-1 and N-2 blocks. The N-2 blocks consisted of ABA and CBA task sequences, which were designed to measure persisting inhibition and calculate repetition costs as discussed above. In contrast, the N-1 blocks contained non-switch trials (AA) mixed with N-1 switch trials (AB). The non-switch trials were included to ensure that there were no differences between the ADHD and control groups in their ability to perform the number-judgement tasks, while the N-1 switch trials were presented so that participants did not come to expect only repetition trials before starting the N-2 blocks. Moreover, the inclusion of both AA and AB trials allowed for a comparison of N-1 switch costs between the groups. In addition, RCI was manipulated for both the N-1 and N-2 blocks such that participants had either 100 ms,

500 ms, or 1,000 ms between completing one trial and starting the next one. Following the task-switching blocks, participants were given the Advanced OSPAN task (Draheim, Harrison, Embretson & Engle, 2018), which is a cognitive measure used to assess working memory, to examine group differences in an aspect of EF believed to be related to task-switching performance.

For the N-1 blocks, it was hypothesized that all participants would have better performance on the non-switch trials in comparison to the switch trials (Keisel et al., 2010). It was also expected that due to their deficits in inhibition, the ADHD group would demonstrate worse performance on the switch trials, but similar performance on the non-switch trials in comparison to the control group. On the N-2 blocks, it was hypothesized that all participants would have faster RTs on the non-repetition trials (CBA task sequence) compared to the repetition trials (ABA task sequence). It was also expected that RTs on the ABA trials and N-2 repetition costs would decrease at longer RCIs for the control group (Mayr & Keele, 2000), and the control group would benefit from the increased RCI to a much greater extent than the ADHD group, as there would be increased time for the persisting inhibition experienced by the control group to decay. For the Advanced OSPAN task, it was hypothesized that the ADHD group would recall fewer items in comparison to the control group.

It is important to note that participants in the ADHD group were not asked to withhold from taking their ADHD medication prior to their participation in the study. As a result, it is possible that a participant's medication status at the time of the study may have influenced his or her performance, however the literature assessing the effects of medication on EF and cognitive performance remains inconclusive (Advokat, 2010;

Boonstra et al., 2005). Information about the medication status of the individuals in the ADHD group was collected at the time of their participation so that it could be used to interpret task-switching and OSPAN performance if needed.

METHOD

Participants

Participants for the current study were selected from the Wake Forest University Introductory to Psychology subject pool. At the beginning of the spring semester, all individuals enrolled in the Introductory to Psychology course were invited to participate in a series of tests, known as "Mass Testing", to determine their eligibility for the various studies being conducted across the Wake Forest Psychology department. During Mass Testing, subjects responded to a number of surveys including the ones relevant for the current study, which consisted of questions such as "Do you currently have a diagnosis of ADD/ADHD?" along with the 11-item ADHD Index of Barkley's Deficit in Executive Functioning Scale-Long Form (BDEFS-LF; Barkley, 2011). This question and scale were used to identify individuals with and without ADHD (see Appendix A). In addition, participants were given the 20-item EF Index of the Barkley's Deficits in Executive Functioning Scale-Short Form (BDEFS-SF; Barkley, 2011) during Mass Testing to further characterize the groups (see Appendix B). Participants who were eligible to take part in the current study based on their Mass Testing responses were able to sign-up for a study session via Sona Systems (Sona Systems Ltd., 2018). In exchange for their participation, they received 1 hour of research participation credit.

Although the original goal was to test 30 individuals with ADHD and 30 control participants, data collection ended prematurely due to COVID-19 and the closure of the University campus, which severely restricted the size of the ADHD sample. Consequently, the control group consisted of 28 individuals (20 females) who did not report a diagnosis of ADHD and scored below the 75th percentile on the ADHD Index of

the BDEFS-LF (see Table 1). The ADHD group consisted of only 5 individuals (4 females) who reported a diagnosis of ADHD and scored above the 65th percentile on the ADHD Index of the BDEFS-LF [2] (see Table 1) during Mass Testing. Unfortunately, data from two participants in the control group had to be excluded as there was a trial cue error in the task-switching program during the beginning of data collection.

Table 1

Means and Standard Deviations for Age and Responses to the BDEFS-LF and BDEFS-SF questionnaire

	Control		ADHD	
	All Control	Revised	All ADHD	Revised
N	28	26	5	4
Age	18.44 (0.58)	18.50 (0.58)	18.60 (0.55)	18.50 (0.58)
BDEFS-LF (ADHD Index)	15.32 (2.75)	15.11 (2.73)	24.60 (4.84)	25.75 (4.76)
BDEFS-SF(*EF Summary Score*)	28.07 (5.87)	27.81 (5.82)	46.60 (18.48)	54.00 (12.37)

Note. This table compares the means and standard deviations for the control and ADHD groups before ("All") and after ("Revised") participants were excluded due to data collection issues.

Data from one member of the ADHD group also had to be excluded as the computer program failed to properly record the participant's responses due to aggressive key presses during the task-switching paradigm (see Table 1).

[2] A BDEFS ADHD Index score at the 95th percentile or above is used in clinical settings to indicate the need for further evaluation for ADHD. Sams et al. (2018) and the current work relied on self-reported diagnoses to classify participants as those with ADHD or controls along with the ADHD Index scores. In doing so, Sams et al. (2018) set the 75th percentile as the cut off for inclusion in the ADHD group. However, due to the fact that only 18 individuals reported having ADHD in the Spring 2020 Participant Pool, in the current study all individuals who had received an ADHD diagnosis and a BDEFS score above the 65th percentile were eligible for the ADHD group to try to achieve an adequate sample size for statistical analyses, although this later became impossible due to the COVID-19 campus closing.

During testing, the participants included in the data analysis for the ADHD group were asked to provide additional information about their ADHD diagnosis and medication status (see "Demographic Information and ADHD Status Questionnaire" section below). Within the ADHD group, the earliest age of initial ADHD diagnosis was 6 years old and the oldest reported age of initial diagnosis was 18 years old (M = 13.2, SD = 4.76). All four individuals reported being diagnosed by a psychologist or a psychiatrist. In addition to the initial age of ADHD diagnosis, individuals also reported the year of their most recent evaluation of their ADHD diagnosis. The oldest reported year of evaluation for ADHD diagnosis was 2017 and the most recently reported evaluation of ADHD diagnosis was 2020, with the most frequent evaluation year being 2017. When asked about their medication status at the time of the study, one individual reported that they had last taken their medication eight hours prior to the study, two participants reported that they had taken medication 48 hours prior to the study, and one participant responded N/A.

Materials and Procedures

Barkley's Deficits in Executive Functioning Scale (BDEFS). Participants were assessed using a combination of items taken from the ADHD Index of the BDEFS-LF plus the BDEFS-SF adapted from Barkley (2011) to determine the extent to which the individual has experienced symptoms typical of ADHD and deficits in EF (see Appendix A and B)[3]. These measures, which were both presented during Mass Testing using the online survey software Qualtrics (Qualtrics Lab, Inc., 2020), asked participants to rate the

[3] For the current study, there is no way to know whether participants in the ADHD group who were taking medication reported the frequency of their ADHD symptoms and executive functioning difficulties according to their medicated or non-medicated state at the time of Mass Testing.

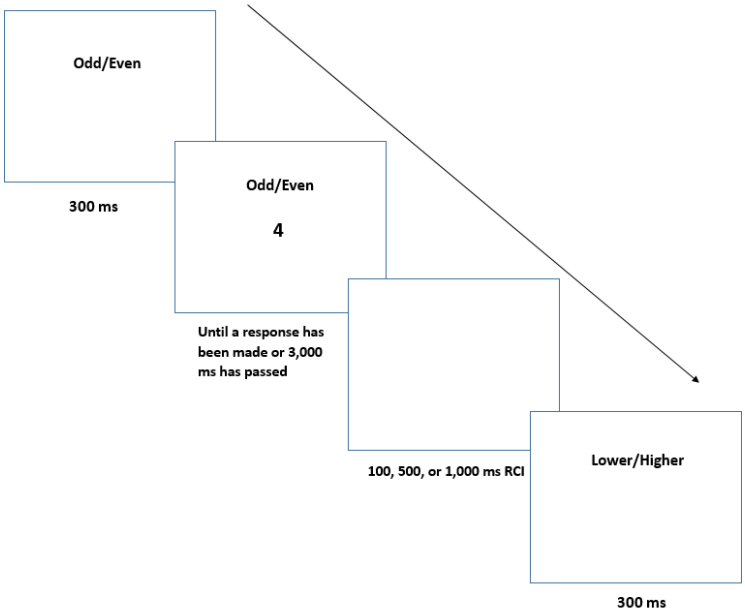
frequency with which they have experienced various ADHD-like symptoms and EF deficits in the past 6 months of their life, such as "I have trouble organizing my thoughts" and "I can't seem to hold in mind the things I need to remember to do". The participants rated frequency on a 4-point Likert scale; a rating of 1 indicated that they *Never or Rarely* experienced this, while a rating of 4 (*Very Often*) indicated that this was a common experience. Higher scores on the ADHD Index of the BDEFS-LF indicated that the individual experiences symptoms typically associated with a diagnosis of ADHD. Scores on the EF Index of the BDEFS-SF were used to calculate an EF Summary score; higher scores on this measure indicated that the individual displays greater deficits in EF. In comparison to the BDEFS-LF questions that measured ADHD-like symptomology, the BDEFS-SF questions allowed us to examine underlying deficits in EF.

Task Switching Paradigm. During the in-lab portion of this study, participants first consented to participate and then began the study by completing a task-switching paradigm. For this paradigm, the stimuli were either presented in number (1, 2, 3, 4, 6, 7, 8, 9) or word form (one, two, three, four, six, seven, eight, nine). Participants were asked to switch between three different number-judgment tasks; parity, magnitude, and form tasks. For the parity task, participants had to decide whether the stimulus displayed was an even or odd number. In the magnitude task, they indicated whether the stimulus was lower or higher than five, and lastly, in the form judgment task they had to decide whether the stimuli were presented in number or word form. The number "5" in both numeric and text form were excluded from the stimuli that were presented to participants because the magnitude number-judgment task could not be performed with these stimuli.

Before each of the trials, participants were provided with a written cue (i.e., "Lower/Higher", "Odd/Even", or "Word/Number") just above the middle of the screen to indicate which task should be performed on the current trial (Figure 1). The cue was displayed for 300 milliseconds (ms) and remained present on the screen until a response was made, or until 3,000 ms had passed. After 300 ms, the stimuli were presented just below the cue, in the middle of the screen. After a response was made, there was a response-cue interval (RCI) of 100, 500, or 1,000 ms before the next cue was displayed.

Figure 1

Example of a task-switching trial



Note. This figure depicts the timeline for presentation of a single trial in the task-switching paradigm.

To make a response, participants used their index fingers to press the "Z" or "M" key. Response key mappings were counterbalanced across participants, such that half the participants pressed the "Z" key for the "Odd", "Lower ", or "Word" responses and the

"M" key for "Even", "Higher", or "Number" responses, while the key mappings were swapped for the other half of the participants. Across all of the blocks, the correct response for half of the trials was the "Z" key, while the correct response for the other half of the trials was the "M" key so that there was no preferential bias towards the "Lower/Odd/Word" or "Higher/Even/Number" responses.

The task was programmed using E-Prime 3.0 software (Psychology Software Tools, Pittsburgh, PA), and was run on a Lenovo ThinkPad. The cues and stimuli were displayed on a white background in bold, black, Arial, size 30 font, while the task instructions were presented in bold, black, Arial, size 24 font.

There were two components to the task-switching paradigm. In the first component, participants completed three N-1 blocks with 72 trials in each block. One-third of the trials were non-switch trials in which the participants completed the same task as the previous trial while two-thirds of the trials were switch trials where the participants completed a task that was different from the immediately preceding trial (N-1). The three N-1 block task sequences were carefully constructed such that for every block of 72 trials, there were an equal number of magnitude, parity, and form tasks (resulting in 24 trials of each task). Additionally, there were an equal number of switch and non-switch trials for each type of task (8 non-switch and 16 switch trials for the magnitude, parity, and form tasks). Three different versions of N-1 trial sequences were designed and each trial sequence was used at each RCI across participants (one of these N-1 trial sequences is shown in Appendix C for clarification purposes).

The second component of the task-switching paradigm consisted of nine N-2 blocks with 48 trials in each block. The purpose of the N-2 blocks was to examine how

inhibition from the previously performed task sets continued to persist across multiple trials by intermixing task sequences of ABA and CBA trials. For every block of 48 trials, there were an equal number of magnitude, parity, and form tasks (16 trials of each task). For the 45 trials that were analyzed within each block (the first three trials were not analyzed as they were used to create the first three-trial sequence, either ABA or CBA), there were approximately an equal number of repetition (ABA) trials and non-repetition (CBA) trials. Across all nine of the switch blocks, 51% of the trials were ABA trials and 49% of the trials were CBA trials. Trials were constructed so that for every ABA trial, the previous "A" task was performed two trials before the current "A" task (N-2), while for the CBA trials the previous "A" task could be performed three, four, or five trials before the current "A" task (i.e., N-3, N-4, or N-5). Within each block, trials were ordered so there could not be more than two ABA or CBA trial sequences in a row. For each individual task (magnitude, parity, form), there were about an equal number of ABA and CBA trials in each block (22 or 23 ABA and CBA trials). In addition, across all of the CBA trials there were also about an equal number of N-3, N-4, or N-5 trials for each task. Three different versions of N-2 trial sequences were designed, and each version was repeated three times, once at each RCI, so that every participant completed each version at each of the RCIs; one of these N-2 blocks can be seen in Appendix D.

In summary, participants completed three N-1 blocks and nine N-2 blocks. In total, six different versions of the entire task-switching paradigm (containing both N-1 and N-2 blocks) were created in order to counterbalance the response key mappings, the order of the RCIs for each block, and the order of the task sequences. Additionally, each of the stimuli (numbers) were presented an equal number of times within each version.

Further, for each of the six versions, no RCIs nor task sequences were repeated across consecutive blocks.

Prior to coming into the lab to participate in the study, participants were randomly assigned to complete one of the six versions of the task-switching paradigm. Participants began the task-switching paradigm by completing a practice block where they performed three trials in a row of each of the three number-judgment tasks (magnitude, parity, and form) at the 500 ms RCI. The goal of this first practice block was to familiarize the participants with the three number-judgment tasks. The participants then completed the set of three N-1 blocks, with one block at each of the RCIs (100, 500, 1,000 ms). At the beginning of each of the three N-1 blocks, participants had four practice trials to adjust to the RCI for that block. Following the N-1 blocks, the participants then carried out the N-2 blocks, which started with a practice block of 24 trials at the 500 ms RCI. The purpose of the practice block was to familiarize the participants with the N-2 blocks and allow them to gain practice in switching tasks on every single trial. Additionally, each of the N-2 blocks began with four practice trials which enabled the participants to adjust to the RCI for that block. For each block, participants were instructed to respond as quickly and as accurately as possible. However, if a participant did not respond within 3,000 ms of the stimuli presentation, the program automatically moved on to the next trial, and the participants' response was not included in the data analysis.

Demographic Information and ADHD Status Questionnaire. Following the task-switching paradigm, participants responded to the Demographic Information and ADHD Status Questionnaire (Appendix E). This questionnaire asked for information such as the participants' age and gender. Similarly to Mass Testing, participants were

also asked to indicate whether they had received an ADHD diagnosis. Individuals who reported a current diagnosis of ADHD were prompted to answer more specific questions regarding their diagnosis (see Appendix E). Furthermore, if participants with ADHD reported taking medication, they were asked to provide more information about their medication status at the time of the study. These questions served to verify the information that the participant previously provided during Mass Testing about their ADHD diagnosis, and provided further insight into the manner in which they were diagnosed, their current treatment approach and the possibility that medication may have impacted their task-switching performance. The Demographic Information and ADHD Status Questionnaire was administered to participants via the online survey software Qualtrics (Qualtrics Lab, Inc., 2020).

Advanced Operation Span (OSPAN). Following the Demographic Information and ADHD Status Questionnaire, participants completed the Advanced OSPAN task (Draheim, Harrison, Embretson, & Engle, 2018), a measure of working memory capacity and EF, in which subjects were asked to solve simple math equations and remember short sequences of letters. This measure was presented to participants using E-Prime 3.0 software (Psychology Software Tools, Pittsburgh, PA).

During the Advanced OSPAN task, participants were first given a simple math equation (e.g., 2+2/1=?) followed by a potential answer to the equation and asked to decide whether the answer was “True” or “False”. Once they responded, they were presented with a letter for 800 ms that they were asked to remember. Participants were presented with anywhere from three equation/letter pairs to nine equation/letter pairs (set sizes). At the end of each set, they were shown a group of letters, some that had been

presented earlier in the trial as part of the equation/letter pairs and others that had not previously been presented and asked to select the letters that had been presented in their order of presentation. If they were unable to recall one of the letters, they had the opportunity to select a "blank" box to skip that letter. After each set, participants received feedback on their accuracy in both solving the math equations and remembering the letters. Prior to starting the experimental trials, participants went through three practice blocks in which they first practiced solving the math equations, then practiced remembering a series of letters, and then practiced performing both tasks together. Following that, they performed two blocks of test trials with one trial at each set size (3-9) per block.

Performance was scored using the "partial score" method, which consisted of the total number of letters correctly recalled, regardless of the set to which the letters belonged. The maximum partial score that participants could achieve was 84. In addition, participants had to achieve an overall math accuracy score of at least 80% in order for their data to be used in the analysis[4]. This allowed us to ensure that participants were complying with the task instructions and trying to alternate between solving the math problems and remembering the letters as instructed.

[4] Typically, the cutoff for math accuracy scores on the OSPAN measure is 85% (e.g., Draheim, Harrison, Embretson, & Engle, 2018), but due to the fact that this was the Advanced OSPAN task, we lowered the cutoff for the math accuracy score to 80% to maximize sample size and participant data. Given that all participants completed the Advanced OSPAN task following the cognitively demanding task-switching paradigm, it was thought that fatigue may have impacted participants' scores on this measure.

RESULTS

EF Index of BDEFS-SF

To test the hypothesis that individuals in the ADHD group experience greater deficits in executive functioning, an independent samples t-test was conducted to compare group means for the BDEFS-SF (Barkley, 2011) Executive Functioning Summary scores. As predicted, individuals in the ADHD group scored significantly higher on this measure and indicated greater self-reported deficits in EF (M = 42.50, SD = 5.82) in comparison to the control group (M = 27.81, SD = 5.82), $t(28) = -3.69$, $p < .001$, one-tailed, $d = 1.28$. These results are consistent with the findings of Sams et al. (2017) and Sams (2018).

Task-Switching

To examine task-switching performance, both participants' RT and accuracy data were analyzed. The RT data consisted of median RTs (ms) obtained from trials in which participants made a correct response while accuracy was scored as the proportion of correct responses. It should be noted that accuracy data tends to yield fewer significant effects and is considered to be a less sensitive method to measure task-switching performance in comparison to RT data due to the simplicity of the number judgement tasks. Therefore, any effects demonstrated by the accuracy data were expected to be similar to the patterns observed with the RT data but smaller or even non-significant. It was thus expected that any differences in task-switching performance between the ADHD and control groups would likely come from the RT data.

N-1 block task-switching performance. Prior to examining the effects of persisting inhibition in the N-2 blocks, it was first necessary to examine task-switching

performance on the N-1 blocks. While the ADHD group may display worse performance on the switch trials due to deficits in inhibitory processing, it was important to demonstrate that the two groups had similar performance on the non-switch trials to show that there were no processing differences between the control and ADHD groups in carrying out the number-judgement tasks. To assess performance on the N-1 blocks, RT and accuracy were averaged across the three number-judgment tasks, and two 2 (group: control vs. ADHD) x 3 (RCI: 100 ms vs. 500 ms vs. 1,000 ms) x 2 (trial type: AA vs. AB) mixed-factors analyses of variances (ANOVAs) were conducted, one for the RT data (Table 2) and one for the accuracy data (Table 3). Consistent with the findings of Kiesel et al. (2010) and Sams et al. (2017), there was a significant main effect of trial type on RT such that all participants had significantly slower RTs on the AB trials in comparison to the AA trials regardless of their group, $F(1,28) = 60.76$, $p < .001$, $\eta^2 = .69$. The main effects of group, $F(1,28) = 2.27$, $p = .143$, $\eta^2 = .08$ and RCI, $F(2,56) = 0.35$, $p = .707$, $\eta^2 = .01$ were non-significant; RTs did not differ significantly between the two groups or across the three RCIs. Contrary to the original prediction that the ADHD group should demonstrate worse inhibition and have slower RTs on the switch trials versus the non-switch trials in comparison to the control group, the trial type by group interaction did not reach significance, $F(1,28) = 0.18$, $p = .677$, $\eta^2 = .01$. The RCI by group interaction, $F(2,56) = 0.10$, $p = .908$, $\eta^2 = .003$, and RCI by trial type interaction, $F(2,56) = 0.92$, $p = .403$, $\eta^2 = .03$ were also non-significant as was the RCI by group by trial type interaction , $F(2,56) = 2.29$, $p = .110$, $\eta^2 = .08$.

In terms of accuracy on the N-1 blocks (Table 3), there was a significant main effect of trial type, $F(1,28) = 11.61$, $p = .002$, $\eta^2 = .29$. Similar to the findings of Sams et

al. (2018), all participants were less accurate in their performance on the AB trials in comparison to the AA trials. The main effect of group was marginally significant such

Table 2

Means and Standard Deviations for Response Time (ms) on N-1 Blocks as a Function of RCI Length and Trial Type by Group with Calculated Switch Costs

Trial Type	Control		ADHD	
	Mean	*SD*	*Mean*	*SD*
100 ms RCI				
AA trials	962.58	190.40	1,201.88	472.04
AB trials	1,391.02	331.43	1,506.38	503.06
500 ms RCI				
AA trials	989.13	255.77	1,134.50	459.72
AB trials	1,230.52	272.20	1,515.88	512.05
1,000 ms RCI				
AA trials	1,018.86	217.49	1,201.50	464.97
AB trials	1,254.02	302.96	1,523.88	648.96
Switch Costs				
100 ms RCI	428.44	248.24	304.50	92.83
500 ms RCI	241.38	160.48	381.38	106.80
1,000 ms RCI	235.16	223.71	322.38	186.81

Note. ADHD = Attention Deficit/Hyperactivity Disorder. RCI = response-cue interval. Switch Cost = Difference in RTs (ms) between the AB and AA trials.
N = 26 for Control and N = 4 for ADHD.

that the ADHD group was less accurate overall in comparison to the control group, $F(1,28) = 3.59$, $p = .068$, $\eta^2 = .11$. However, the group by trial type interaction was not significant, demonstrating that the ADHD group performed less accurately regardless of trial type, $F(1,28) = 0.18$, $p = .677$, $\eta^2 = .01$. In addition, the main effect of RCI was not

significant, $F(2,56) = 1.59$, $p = .213$, $\eta^2 = .05$, nor were the RCI by group, RCI by trial type, or RCI by trial type by group interactions (all $F's \leq 1.41$, all $p's \geq .254$, all η^2's $\leq .05$).

Table 3

Means and Standard Deviations for Accuracy (Proportion Correct) on N-1 Blocks as a Function of RCI Length and Trial Type by Group with Calculated Switch Costs.

Trial Type	Control		ADHD	
	Mean	*SD*	*Mean*	*SD*
100 ms RCI				
AA trials	.936	.062	.840	.173
AB trials	.907	.087	.788	.238
500 ms RCI				
AA trials	.953	.070	.888	.063
AB trials	.912	.090	.818	.176
1,000 ms RCI				
AA trials	.931	.089	.918	.061
AB trials	.912	.010	.830	.140
Switch Costs				
100 ms RCI	.029	.084	.053	.093
500 ms RCI	.041	.072	.070	.159
1,000 ms RCI	.019	.049	.088	.082

Note. ADHD = Attention Deficit/Hyperactivity Disorder. RCI = response-cue interval. Switch Cost = Difference in accuracy between the AA and AB trials.
$N = 26$ for Control and $N = 4$ for ADHD.

N-2 block task-switching performance. Similar to the analysis of the N-1 component of the task-switching paradigm, RT and accuracy were averaged across the number-judgment tasks and two 2 (group: control vs. ADHD) x 3 (RCI: 100 ms vs. 500

ms vs. 1,000 ms) x 2 (trial type: ABA vs. CBA) mixed-factors ANOVAs were conducted, one for RT data (Table 4) and one for accuracy data (Table 5). Consistent with the findings of Mayr and Keele's work (2000), there was a significant main effect of trial type on RT such that participants had slower RTs on the ABA trials compared to the CBA trials, $F(1,28) = 8.32$, $p = .007$, $\eta^2 = .23$, suggesting that persisting inhibition was occurring. There was also a significant main effect of RCI, $F(2, 56) = 4.78$, $p = .012$, $\eta^2 = .15$. Post hoc pairwise comparisons using Bonferroni's correction revealed that RTs were significantly slower at the 100 ms RCI compared to the 500 ms RCI ($p = .004$). Pairwise comparisons between the 100 ms and 1,000 ms RCIs ($p = .368$) and between the 500 ms and 1,000 ms RCIs ($p = .635$) did not reach significance suggesting that RTs were similar when comparing these intervals. However, contrary to the original prediction that differences in RTs between the ABA and CBA trials would get smaller as the length of the RCI increases, the RCI by trial type interaction was not significant, $F(2,56) = 1.36$, $p = .264$, $\eta^2 = .05$. In addition, the main effect of group was not significant, $F(1,28) = 2.47$, $p = .127$, $\eta^2 = .08$, although it is worth noting that the means suggest that the ADHD group demonstrated slower RTs in comparison to the control group regardless of trial type, which may have reached significance with a larger sample size.

More interestingly, the group by trial type interaction was not significant, $F(1,28) = 0.75$, $p = .393$, $\eta^2 = .03$, which contradicts the original hypothesis that there would be a group by trial type interaction whereby deficits in inhibition for the ADHD group would mean faster RTs on the ABA trials, but similar RTs on the CBA trials, compared to the control group. Instead, it appears that the ADHD group, like the control group,

experienced the effects of persisting inhibition as RTs on the ABA trials were significantly slower than RTs on the CBA trials[5]. Lastly, the RCI by group interaction,

Table 4

Means and Standard Deviations for Reaction Time (ms) on N-2 Blocks as a Function of RCI Length and Trial Type by Group with Calculated Repetition Costs.

Trial Type	Control		ADHD	
	Mean	*SD*	*Mean*	*SD*
100 ms RCI				
ABA trials	1,134.98	241.70	1,462.50	592.17
CBA trials	1,090.12	248.53	1,357.38	578.63
500 ms RCI				
ABA trials	1,093.87	264.82	1,316.25	502.76
CBA trials	1,046.60	268.92	1,235.75	516.92
1,000 ms RCI				
ABA trials	1,089.56	288.31	1,347.38	465.85
CBA trials	1,067.31	313.74	1,320.38	502.87
Repetition Costs				
100 ms RCI	44.87	80.52	105.13	111.18
500 ms RCI	47.27	110.37	80.50	136.49
1,000 ms RCI	22.25	96.86	27.00	82.41

Note. ADHD = Attention Deficit/Hyperactivity Disorder. RCI = response-cue interval. Repetition Costs = Difference in RTs between the ABA and CBA trials.
N = 26 for Control and N = 4 for ADHD.

[5] To determine if the results of the current study replicated the findings of Moritz, Hubner, and Kluwe (2004), two 3 (trial type: AA vs. ABA. vs. CBA) x 3 (RCI: 100 ms vs. 100 ms. vs. 1,000 ms) x 2 (group: ADHD vs. control) mixed-factors ANOVAs were conducted for both RT and accuracy data. Similarly to Moritz, Hubner, & Kluwe (2004), the RT analysis yielded a significant main effect of trial type. Post hoc pairwise comparisons using Bonferroni's correction revealed that RTs on the ABA trials were significantly slower than RTs on the AA trials (p = .011) and CBA trials (p = .022). RTs on the AA trials did not differ significantly from the CBA trials (p = .201). All other main effects and interactions were not significant (all $F's \leq 2.55$, all $p's \geq .087$, all η^2's $\leq .08$).

$F(2,56) = 1.27$, $p = .289$, $\eta^2 = .04$ and the expected group by trial type by RCI interaction, $F(2, 56) = 0.38$, $p = .689$, $\eta^2 = .01$, were not significant. These findings suggest that manipulations to the RCI did not differentially impact the difference in RTs between ABA and CBA trials for the control relative to the ADHD group as had been hypothesized.

In terms of accuracy on the N-2 blocks (Table 5), no significant effects emerged as the main effect of trial type, $F(1,28) = 0.03$, $p = .863$, $\eta^2 = .001$, the main effect of RCI, $F(2,56) = 1.01$, $p = .371$, $\eta^2 = .04$, and the main effect of group, $F(1,28) = .320$, $p = .587$, $\eta^2 = .01$ were all not significant. In addition, none of the two way interactions involving trial type, RCI, and group nor the three way interaction yielded significant effects (all $F's \leq 1.47$, all $p's \geq .240$, all η^2's $\leq .05$). These null effects are not surprising as previous researchers have chosen not to report their accuracy data given accuracy on task-switching paradigms is generally high, and does not contradict the effects seen with RT data or provide any additional information about task-switching performance (Mayr & Keele, 2000; Mortiz, Hubner, & Kluwe, 2004).

However, it is important to note that the null accuracy effects found with the N-2 blocks differed from what was found with the N-1 blocks. While the N-1 blocks revealed that the ADHD group was less accurate in their overall performance, accuracy on the N-2 blocks did not differ as a function of group. One reason that the group difference may have trended towards significance in the N-1 blocks is due to the fact that one member of the ADHD group was an outlier and had significantly lower accuracy scores compared to the rest of the ADHD group. Additionally, participants completed the N-1 blocks of the task-switching paradigm first. As a result, accuracy may have been lower for the ADHD group on the N-1 blocks because they may have taken a longer time to become

accustomed to performing each of the number-judgment tasks compared to the control participants.

Table 5

Means and Standard Deviations for Accuracy (Proportion Correct) on N-2 Blocks as a Function of RCI Length and Trial Type by Group with Calculated Repetition Costs.

Trial Type	Control		ADHD	
	Mean	*SD*	*Mean*	*SD*
100 ms RCI				
ABA trials	.916	.074	.870	.082
CBA trials	.909	.084	.888	.067
500 ms RCI				
ABA trials	.910	.078	.903	.029
CBA trials	.909	.078	.920	.065
1,000 ms RCI				
ABA trials	.924	.072	.900	.041
CBA trials	.918	.071	.888	.057
Repetition Costs				
100 ms RCI	-.008	.045	.018	.034
500 ms RCI	-.000	.049	.018	.069
1,000 ms RCI	-.006	.046	-.013	.021

Note. ADHD = Attention Deficit/Hyperactivity Disorder. RCI = response-cue interval. Repetition Costs = Difference in accuracy between the CBA and ABA trials. N = 26 for Control and N = 4 for ADHD.

Advanced Operation Span (OSPAN) Performance

To test the hypothesis that the ADHD group would have lower scores on the Advanced OSPAN task, an independent samples *t*-test was conducted. Contrary to the initial hypothesis, the difference in scores on the Advanced OSPAN task between the

ADHD group (M = 54.00, SD = 14.28) and control group (M = 54.88, SD = 13.80) was not significant, $t(27) = .118$, $p = .938$, one-tailed, $d = 0.06$, as the two groups performed similarly well on this measure.

DISCUSSION

Efficacy of the Task-Switching Paradigm

The purpose of the current study was to use a task-switching paradigm that consisted of N-1 and N-2 blocks to examine differences in task-switching and persisting inhibition between an ADHD and control group across different RCIs. Based on the previous literature, there are several effects that we expected to see in order to verify that the task-switching paradigm being used in the current study was functioning as it should. For the N-1 blocks, we expected to see a significant main effect of trial type (switch vs. non-switch trials) which is a general pattern found across the task-switching literature (Rogers & Monsell, 1995). The current study replicated this finding, as participants had faster RTs and greater accuracy on the non-switch (AA) trials compared to the switch (AB) trials.

In the N-2 blocks, we also expected to find a significant main effect of trial type (ABA vs. CBA trials) as has been demonstrated by Mayr and Keele (2000) along with Philipp and Koch (2006). The main effect of trial type was replicated in the current study as participants had faster RTs on the non-repetition (CBA) trials in comparison to the repetition trials (ABA). While RTs differed between the CBA and ABA trials, accuracy scores were similar between these trials, which is not uncommon with this procedure (Mayr & Keele, 2000; Mortiz, Hubner, & Kluwe, 2004). Further, it was expected that there would be a significant RCI by trial type interaction, such that longer RCIs would allow more time for persisting inhibition to decay, and as a result the difference in RTs between the ABA and CBA trials would decrease as RCI increased (Mayr & Keele, 2000). While the current study found main effects of both trial type and RCI, meaning

that as RCI increased there was more time to prepare for the upcoming task, which reduced RTs regardless of trial type, the RCI by trial type interaction was not significant. Although the current study was unable to replicate this finding, there may be an explanation for this result. Mayr and Keele (2000, Experiment 1A) conducted an N-2 task-switching paradigm in which they manipulated the RCIs such that there were two intervals; a short RCI (50 ms) and long RCI (500 ms). In their analysis they did not see a reduction in the difference in RTs between the ABA and CBA trials across these two intervals. However, in a second experiment (Experiment 1B) the RCI manipulations were changed such that the short RCI was set at 100 ms and the long RCI was set at 900 ms. With the longer RCI (900 ms), which allowed more time for participants to engage their inhibitory processes and for inhibition from previous task sets to decay, the researchers found a reduction in the difference in RTs between the ABA and CBA trials relative to the 100 ms RCI. The results of Mayr and Keele's (2000) experiments thus lead us to believe that the difference in time between the 100 ms and 500 ms RCIs in the current study may not have been sufficient to show a decrease in persisting inhibition, which prevents the RCI by trial type interaction from being significant. To determine if the inclusion of the 500 ms RCI impacted our ability to find a significant RCI by trial type interaction, a 2 (RCI: 100 ms vs. 1,000 ms) x 2 (group: ADHD vs. control) x 2 (trial type: ABA vs. CBA) mixed-factors ANOVA was conducted. When the data from the 500 ms RCI was excluded from the analysis, there was a marginally significant RCI by trial type interaction $F(1, 28) = 3.15$, $p = .087$, $\eta^2 = .101$, showing a decrease in the difference between RTs for the ABA vs. CBA trials at the 1,000 ms RCI compared to the 100 ms RCI. Together these observed patterns demonstrate the efficacy of the task-

switching paradigm implemented here, and as a result the findings from the current study can be based on the knowledge that the task-switching paradigm was properly designed.

Group Differences in Task-Switching and Persisting Inhibition

Given that the N-1 and N-2 blocks produced the expected pattern of results associated with task-switching and persisting inhibition, the next questions to explore were whether there were differences in task-switching performance and persisting inhibition between the ADHD and control groups. The inclusion of the N-1 blocks in the task-switching paradigm provided the opportunity to examine task-switching performance between the two groups at different RCIs, and it was expected that due to their deficits in inhibition, the ADHD group would have slower RTs on the switch trials but similar RTs on the non-switch trials compared to the control group. However, the RTs did not actually differ significantly between the two groups as a function of trial type or across the three RCIs. The N-2 block component of the task-switching paradigm was employed to examine differences in persisting inhibition between the ADHD and control groups and the effect of RCI on that persisting inhibition. It was expected that the ADHD group would have smaller differences in RTs on the ABA trials relative to the CBA trials in comparison to the control group due to their hypothesized lack of inhibition. Furthermore, it was hypothesized that the control group would have a much greater reduction in the difference between RTs on the ABA versus CBA trials due to the longer RCI, as there would be more time for the persisting inhibition of previously performed tasks to decay for this group while the ADHD group would have less inhibition to decay. Surprisingly, the control group did not demonstrate a larger difference in RTs between the ABA and CBA trials compared to the ADHD group. In

fact, both the ADHD and control groups showed the pattern of results one would expect from the effects of persisting inhibition. Moreover, the predicted group by trial type by RCI interaction was not supported. Finally, for the Advanced OSPAN task, it was hypothesized that the ADHD group would recall fewer letters compared to the control group. However, performance on this measure looked very similar between the two groups. Although there were no group differences in task switching, persisting inhibition or working memory though, the individuals with ADHD did report that they experienced significantly greater deficits in EF in their everyday lives on the BDEFS-SF (Barkley, 2011).

Limitations and Future Directions

One of the major limitations of the current study is the fact that the ADHD group has such a small sample size, as there are only four participants with ADHD whose data could be analyzed. As a result, this study lacks statistical power. However, it is probably not the case that we are failing to see the hypothesized group effects in the data due to low power. From the data that we do have, we are seeing that the findings are non-significant because they differ from the original predictions. More specifically, the RT data from the N-2 blocks demonstrates that the ADHD group is experiencing persisting inhibition and that they may even experience persisting inhibition to a greater extent than the control group. Given that the ADHD group sample size is small, the question still remains whether this group is representative of not only the individuals in the Wake Forest University Introductory to Psychology subject pool who have ADHD, but also other young adults diagnosed with ADHD. Wake Forest students come from a fairly homogenous population and thus there may be less variability in task-switching

performance between members of the control and ADHD groups. Also, due to the fact that Wake Forest is a top university, it is possible that these individuals may have a high-functioning form of ADHD and/or they have learned to compensate for their deficits in EF. Evidence to support the claim that students with ADHD at Wake Forest may be high-functioning comes from performance on both the task-switching paradigm and the Advanced OSPAN measure. Performance on the N-1 blocks of the paradigm displayed that the ADHD group did not have significantly greater switch costs, while performance on the N-2 blocks showed that the ADHD group experienced persisting inhibition from the previously performed tasks much like the control group. Furthermore, the ADHD group had similar scores as the control group on the Advanced OSPAN task, which is a measure of working memory performance that contains an element of task-switching. However, even if these individuals in the ADHD group are high-functioning, their EF Summary scores from the BDEFS-LF (Barkley, 2011) demonstrate that there are significant differences in self-reported deficits in EF between the ADHD and control groups, and this finding is consistent with previous studies that have been conducted with individuals who have ADHD at Wake Forest University (Sams et al., 2017; Sams, 2018). It thus seems that the self-reported differences in EF between the control and ADHD group may not stem from issues with inhibition or task-switching based on the ADHD group's performance on the measures in the current study.

Future work in this area should attempt to replicate this study to determine if the findings are maintained with a larger sample, and if the findings of this study are representative of the larger population of students with ADHD at Wake Forest University. This will provide us with a more complete understanding of whether

individuals with ADHD are experiencing persisting inhibition in a manner similar to the control group and how inhibitory skills are impacted in young adults with ADHD. Further, given that the current study suggests that the ADHD group's self-reported deficits in EF do not seem to stem from deficits in inhibition or task-switching, future work should also dive deeper into understanding the mechanisms and components that are driving these differences in EF.

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APPENDIX A

Barkley's Deficits in Executive Functioning Scale (BDEFS)-Long Form

Instructions:
How often do you experience each of these problems? Please circle the number next to each item that best describes your behavior **DURING THE PAST 6 MONTHS**.

	Item	Never or rarely	Some-times	Often	Very Often
1.	Procrastinate or put off doing things until the last minute	1	2	3	4
2.	Have trouble planning ahead or preparing for upcoming events	1	2	3	4
3.	Have difficulty motivating myself to stick with my work and get it done	1	2	3	4
4.	Have trouble completing one activity before starting into a new one	1	2	3	4
5.	I have trouble organizing my thoughts	1	2	3	4
6.	Have difficulty stopping my activities or behavior when I should do so	1	2	3	4
7.	Have difficulty changing my behavior when I am given feedback about my mistakes	1	2	3	4
8.	Not aware of things I say or do	1	2	3	4
9.	More likely to drive a motor vehicle much faster than others (excessive speeding)	1	2	3	4
10.	Likely to take short cuts in my work and not do all that I am supposed to do	1	2	3	4
11.	Have to depend on others to help me get my work done	1	2	3	4

APPENDIX B

Barkley's Deficits in Executive Functioning Scale (BDEFS) – Short Form

Instructions:
How often do you experience each of these problems? Please circle the number next to each item that best describes your behavior **DURING THE PAST 6 MONTHS**.

		Never or rarely	Some-times	Often	Very Often
1.	Procrastinate or put off doing things until the last minute	1	2	3	4
2.	Can't seem to hold in mind things I need to remember to do	1	2	3	4
3.	Not motivated to prepare in advance for things I know I am supposed to do	1	2	3	4
4.	Have trouble doing what I tell myself to do	1	2	3	4
5.	Have trouble learning new or complex activities as well as others	1	2	3	4
6.	Have difficulty explaining things in their proper order or sequence	1	2	3	4
7.	Unable to "think on my feet" or respond as effectively as others to unexpected events	1	2	3	4
8.	I don't seem to process information as quickly or as accurately as others	1	2	3	4
9.	Unable to inhibit my reactions or responses to events or others	1	2	3	4
10.	Make impulsive comments to others	1	2	3	4
11.	Likely to do things without considering the consequences for doing them	1	2	3	4
12.	Fail to consider past relevant events or past personal experiences before responding to situations (I act without thinking)	1	2	3	4

13.	Do not put as much effort into my work as I should or than others are able to do	1	2	3	4
14.	Others tell me I am lazy or unmotivated	1	2	3	4
15.	Inconsistent in the quality or quantity of my work performance	1	2	3	4
16.	Unable to work as well as others without supervision or frequent instruction	1	2	3	4
17.	Have trouble calming myself down once I am emotionally upset	1	2	3	4
18.	Cannot seem to regain emotional control and become more reasonable once I am emotional	1	2	3	4
19.	Cannot seem to distract myself away from whatever is upsetting me emotionally to help me calm down. I can't refocus my mind to a more positive framework	1	2	3	4
20.	I remain emotional or upset longer than others	1	2	3	4

APPENDIX C

Example of one N-1 Block's Design

Below is one version of a 72 trial N-1 block showing which task was presented during each trial (F=Form, P=Parity, M=Magnitude) and where non-switch trials (NS) occurred. Any trial not marked as "NS" served as a switch trial.

F	**F**	**P**	**M**	**M**	**P**	**P**	**F**	**M**
	NS			NS		NS		
F	**M**	**M**	**F**	**F**	**P**	**M**	**P**	**P**
		NS		NS				NS
M	**F**	**F**	**P**	**P**	**F**	**M**	**M**	**P**
		NS		NS			NS	
F	**M**	**M**	**P**	**F**	**F**	**P**	**P**	**M**
	NS				NS		NS	
M	**F**	**F**	**M**	**P**	**F**	**P**	**P**	**M**
NS		NS					NS	
P	**P**	**F**	**M**	**F**	**F**	**P**	**M**	**M**
	NS				NS			NS
F	**F**	**M**	**P**	**P**	**M**	**M**	**F**	**P**
	NS			NS		NS		
P	**M**	**F**	**F**	**M**	**M**	**P**	**F**	**P**
NS			NS		NS			

APPENDIX D

Example of one N-2 Block's Design

Below is one version of a 48 trial N-2 block showing which task was presented during each trial (F=Form, P=Parity, M=Magnitude) and where ABA trials (N-2) and CBA trials (N-3, N-4, N-5) occurred.

M	**P**	**F**	**M** N-3	**P** N-3	**M** N-2	**P** N-2	**F** N-5	**M** N-3
F N-2	**P** N-4	**F** N-2	**M** N-4	**P** N-3	**M** N-2	**F** N-4	**M** N-2	**P** N-4
F N-3	**P** N-2	**F** N-2	**M** N-5	**F** N-2	**P** N-4	**M** N-3	**P** N-2	**M** N-2
F N-5	**M** N-2	**P** N-4	**M** N-2	**F** N-4	**M** N-2	**F** N-2	**P** N-5	**F** N-2
P N-2	**M** N-5	**F** N-3	**M** N-2	**F** N-2	**P** N-5	**F** N-2	**P** N-2	**M** N-5
P N-2	**F** N-4	**P** N-2						

APPENDIX E

Demographic Information and ADHD Status Questionnaire

Do you currently have a diagnosis of ADD/ADHD? (Please circle one)

Yes

No

[If answer "no," does not need to advance further. If answer "yes," continue to subsequent questions.]

At what age were you initially diagnosed with ADD/ADHD?

Please give a numeric response (e.g. 21): _____

When was your last diagnosis/evaluation for ADD/ADHD?

Please respond with the year (e.g. 2015): _____

Who diagnosed you with ADD/ADHD? (e.g., primary care physician, psychologist, etc.)

a. Primary care physician
b. Psychologist or psychiatrist
c. School counsellor or School Learning Assistance Center
d. Other
e. Unsure/don't know

Do you currently take medication for ADD/ADHD? (Please circle one)

Yes

No

[If answer "no," does not need to advance further. If answer "yes," continue to subsequent questions.]

If yes, how many hours ago did you last take your medication?

Please give a numeric response (e.g. 1, 4.5, 6 etc.): _____

How frequently do you typically take your medication on a daily basis? (e.g., 1x daily, 2x, daily, as needed, etc.)

_____

According to your doctor's prescription, how frequently are you supposed to take your medication? (e.g., 1x daily, 2x, daily, as needed, etc.)

_____

Curriculum Vitae

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Master of Science, Neuroscience
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PUBLICATIONS AND RESEARCH PRESENTATIONS

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