I, Tanya Antonini, hereby submit this original work as part of the requirements for the degree of Master of Arts in Psychology.

It is entitled:
The Relationship Between Reaction Time Variability and On-Task Behavior in Children with and without ADHD

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The Relationship Between Reaction Time Variability and On-Task Behavior in Children with and without ADHD

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Abstract

Numerous studies have been conducted to investigate the underlying neuropsychological differences between children with and without ADHD. Studies focused on reaction times have shown that children with ADHD demonstrate greater reaction time (RT) variability across a variety of computerized tasks than children without ADHD. Although several researchers have hypothesized that this RT variability represents lapses in attention, only a few studies have investigated the behavioral correlates of this phenomenon. The results of these studies suggest that RT variability may be more highly correlated with symptoms of inattention than hyperactivity or impulsivity. However, these studies have utilized parent and teacher rating scales, which often take into account behavior across long periods of time (e.g., past week). Observed behavior, coded on a continuous basis, may be more highly associated with RT variability than rating scales and provide us with a better understanding of the behavioral correlates of RT variability. This study examined the relationship between RT variability and attention during two educational tasks. Coefficient of variation (RT SD divided by mean RT) and the Ex-gaussian parameter tau were utilized as indicators of RT variability and mean duration of on-task behavior was used as an indicator of task attention. To explore the specificity of the relationship between RT variability and observed attention, associations between RT variability and hyperactive behavior (fidgeting) and associations between on-task behavior and a different neuropsychological indicator (task accuracy) were also examined. One-hundred, forty-nine participants (96 with ADHD and 53 controls) completed five computerized neuropsychological tasks. Each participant was also video-recorded while completing math problems for twenty minutes and watching an educational video. Behavior was coded in a continuous fashion for each of these videos using Noldus Observer XT® computer software. In terms of group differences, results indicated that children with ADHD had significantly greater RT variability and
significantly lower task accuracy than children without ADHD. Children with ADHD had shorter durations of on-task behavior and longer durations of fidgeting during the math task than the control group. However, there were not significant group-differences for the behavioral variables during the video task. Linear Mixed Models indicated that there were significant associations between RT variability and mean duration of on-task behavior during the math task, but not video task. Specificity analyses showed that although RT variability was not associated with fidgeting, on-task behavior was associated with accuracy. In conclusion, the relationship between RT variability and behavior may be specific to aspects of attention. However, aspects of attention may also be associated with other neuropsychological indicators. These results help to explain the behavioral correlates of RT variability. Future studies should include a variety of different activities settings outside of the laboratory and use psychophysiological outcomes (e.g., EEG) to assess attention.
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Introduction

Attention Deficit Hyperactivity Disorder (ADHD), one of the most commonly diagnosed disorders in childhood, has been estimated to have a prevalence rate of 8.7% in children between the ages of 8 and 15 (Froehlich et al., 2007). As delineated by the DSM-IV, ADHD is characterized by levels of inattention, impulsivity, and hyperactivity that are considered to be atypical for normal development. Depending on the pattern of symptoms within these three categories, children who receive a diagnosis of ADHD are categorized as having one of three subtypes – predominantly inattentive type, predominantly hyperactive-impulsive type or combined type (American Psychiatric Association, 2000).

In an attempt to understand the neuropsychological underpinnings of ADHD, a plethora of research has been conducted to investigate cognitive impairments in children with ADHD, including working memory, attention, and inhibitory control (see Hervey et al., 2004 & Willcutt et al., 2005 for meta-analytic reviews). In addition to documenting deficits in these aspects of cognition, studies utilizing computerized tasks have found that children with ADHD appear to respond more slowly than typically-developing children (e.g., Lijffijt, Kenemans, Verbaten, & van Engeland, 2005). Further, it appears that, intra-individual variability in reaction times is considerably higher in children with ADHD compared with typically-developing children. This increased reaction time variability (RT variability) has been documented across a variety of tasks using different parameters and targeting different cognitive constructs (e.g., sustained attention, inhibitory control, working memory; de Zeeuw et al., 2008; Epstein et al., in press; Klein, Wendling, Huettner, Ruder, & Peper, 2006; Vaurio, Simmonds, & Mostofsky, 2009).

Although RT standard deviation (SD) has been the predominant indicator of RT variability in the literature, other indicators have been able to provide more specific descriptions
of the sources of higher RT variability among individuals with ADHD. For example, ex-Gaussian parameters (mu, sigma, and tau), which describe the normal and exponential components of a reaction time distribution, can be used to model the RT distribution for individuals. Mu and sigma represent the mean and SD, respectively, of the normal component of an individual’s reaction time distribution, while tau describes the exponential component, or positive skew, of the RT distribution. Significantly increased values of tau (positive skew) found in samples of participants with ADHD have demonstrated that the overall increased variability in reaction times among patients with ADHD is largely attributable to the occurrence of infrequent and intermittent long reaction times (Hervey, et al., 2006; Leth-Steensen, et al., 2000; Vaurio, Simmonds, & Mostofsky, 2009). A lack of group differences for mu and sigma values has indicated children with ADHD are not necessarily slower or more variable than typical children over entire tasks. Rather, in the midst of typical responding, children with ADHD have intermittent instances of slow responding within a stream of reaction times (Hervey et al., 2006). Fast Fourier Transform analyses have allowed investigators to examine the predictability of these long reaction times, based on their oscillation frequency (Castellanos et al., 2005; Johnson et al., 2007; Vaurio, Simmonds, & Mostofsky, 2009), and have shown that instances of long reaction times in children with ADHD appear to be consistently fleeting, occurring approximately every 20 seconds (Castellanos et al., 2005).

Currently, it is unclear as to what these intermittent periods of long reaction times represent. Multiple explanations have been suggested. For example, RT variability has been tied to impairments in modulating fluctuations in neuronal activity (Castellanos et al., 2005), motivational deficits (Sergeant, 2000), timing deficits (Castellanos & Tannock, 2002), problems with top-down attentional control (Bellgrove, Hester, & Garavan, 2004), and subcortically
mediated problems in state regulation (Kuntsi, Oosterlaan, & Stevenson, 2001; Scheres, et al., 2001; Sergeant, et al., 2003). Investigators have also posited that the periods of long reaction times are indicative of lapses in attention (Leth-Steensen et al., 2000).

In an attempt to further understand RT variability, researchers have begun to examine behavioral correlates of RT variability. For example, does RT variability relate specifically to either of the ADHD symptom domains (i.e., hyperactivity/impulsivity and inattention)? Studies examining differences between children with ADHD-Combined Type and children with ADHD-Inattentive Type have shown that both groups have slower mean reaction time speed and greater RT variability than control groups. No significant differences between ADHD subtypes on RT variability have been found (Epstein et al., in press; Nigg, Blaskey, Huang-Pollock, & Rappley, 2002; Pasini, Paloscia, Alessandrelli, Porfirio, & Curatolo, 2007, Solanto et al., 2007). However correlational research examining relations between RT variability and the ADHD symptom domains has found that RT variability is related to composite scores of inattention more so than hyperactivity/impulsivity (Nigg, 1999; Wahlstedt, 2009). Looking at ADHD behaviors more discretely, Epstein et al. (2003) examined the relationship between each of the 18 specific DSM-IV ADHD symptoms and RT variability on a go/no-go test. They found that RT variability was significantly related to multiple symptoms of inattention but also related to symptoms of hyperactivity, and impulsivity. To date, it is not clear that RT variability specifically relates to any ADHD symptom domain or to any set of ADHD symptoms in particular.

One limitation of all of these studies is that measurement of behavior has relied on parent interview or parent and teacher ratings. Such behavioral reports provide general summaries of behavior over a long period of time (e.g., last week) and do not provide more temporally-specific, moment by moment, information about behavioral variability. Behavior documented on
a continuous basis, using an observational coding scheme, may better correlate with measures of RT variability, than scores from parent or teacher rating scales.

Indeed, studies that have examined behavior at a minute level in children with ADHD have shown that behavior in children with ADHD is more variable than that of children without ADHD. For example, Abikoff et al. (1977) documented the presence or absence of observed behaviors during structured academic sessions. Each session was divided into consecutive 15-second intervals and within each interval, only off-task behavior was coded if it occurred throughout a full interval. Not only did these authors document a greater frequency of off-task behavior in their group of “hyperactive” children, but they also found greater within-subject variability in off-task behavior within the hyperactive children, compared with the sample of control children (Abikoff, Gittelman-Klein, & Klein, 1977). More recently, Lauth, Heubeck, and Mackowiak (2006) observed children in their natural classrooms utilizing a coding scheme that contained only two behavior categories (negative and positive behaviors). Predetermined 5-second intervals were used for coding a child’s behavior and within each interval, the predominant behavior (of three positive or two negative behaviors) was noted. The authors did not specifically examine differences in off-task behavior variability between groups. However, reported standard deviations were higher for the children with ADHD than the control children, implying that children with ADHD demonstrate greater on and off-task variability than children without ADHD (Lauth, Heubeck, and Mackowiak, 2006).

Although studies in the ADHD literature have utilized a variety of observational methods, most of the observational schemes utilized have not used continuous sampling methods. For example, the majority of observational schemes have used tallies of the number of behavioral occurrences. Other studies have utilized time sampling blocks (i.e., recording if
behaviors occurred within a 15 sec block) or alternating methods where observers switch back and forth between children to collect samplings of observational data. Such methods do not provide information about durations of on-task behavior. Novel computer coding technology designed to allow for continuous sampling of observational behavior allows researchers not only to continuously track the number of times a behavior occurs, but also to record the duration of each behavior. Continuous sampling provides more accurate depictions of moment-to-moment durations of behavior and allows researchers to accurately calculate time on and off-task.

Using continuous sampling to code changes in visual attention during academic assignment completion in the classroom, Rapport, Kofler, Alderson, Timko, and DuPaul (2009) documented greater attentional variability in children with ADHD. Cluster analyses using mean rates of time on-task revealed that the ADHD group was best represented as two subgroups: a high attention (ADHD-H) group and a low attention (ADHD-L) group. Compared with the children in the control group, children in the ADHD-L and ADHD-H groups were off-task 40% and 13% more often, respectively. Analyses revealed that the children in the ADHD-L group had higher average and maximum durations of off-task behavior and lower average and maximum durations of on-task behavior. Analyses examining variability in visual attention over time indicated that the two ADHD groups had greater frequencies of attentional shifts over time than the control group, although there was only a significant difference in intra-individual variability in rates of on-task behavior between the children in the ADHD-L and control groups (Rapport, Kofler, Alderson, Timko, & DuPaul, 2009).

Two studies have examined the relationship between observed ADHD behavior and neuropsychological indicators. Using a behavioral coding scheme similar to those described above, Weis and Totten (2004) found moderate correlations between omission errors on the
Conners’ CPT-II and observed inattentive behavior ($r = .32$) in a school-based normative sample. Solanto et al. (2001) analyzed relations between Stop Signal Reaction Time (SSRT) during a Stop Signal task and off-task behavior and did not find a significant correlation. The mixed results across these studies suggest that established ADHD-related neuropsychological outcomes may not consistently relate to actual ADHD behavior. However, no study has yet examined neuropsychological-behavioral relations using RT variability as a neuropsychological indicator.

The current study examined the relationship between indicators of RT variability on neuropsychological tests and on-task behavior during educational tasks requiring different levels of engagement in children (between seven and eleven years old) with and without ADHD. In order to determine whether relations between RT variability and on-task behavior are specific to these constructs, we also examined whether alternative neuropsychological measures (i.e., task accuracy) similarly relate to on-task behavior and whether RT variability is related to alternative behaviors (i.e., fidgeting). We expected to find significant between-group differences for all neuropsychological and observational variables. Specifically, lower accuracy and greater RT variability were expected in the children with ADHD, as compared with our control participants. Compared with control participants, shorter mean durations of on-task behavior and longer durations of fidgeting behavior during the educational tasks were also expected in the children with ADHD. The central hypothesis of our study was that indicators of RT variability are related to the mean duration of on-task behavior during analog tasks. We did not expect to find a relationship between RT variability and fidgeting behavior or between task accuracy and on-task behavior.

Method

Participants
Participant demographics are summarized in Table 1. One-hundred and forty-nine participants between the ages of seven and eleven (inclusive) were recruited locally in Cincinnati and northern Kentucky. Based on study criteria, ninety-six of these participants were diagnosed with ADHD (51 with Combined Type and 45 with Inattentive Type) and 53 were classified as control participants. ADHD participants were recruited through local schools, as well as the Cincinnati Children’s Hospital Center for ADHD, the Cincinnati Children’s Hospital website, local physicians, and mental health professionals. Control participants were recruited through local schools, and a database of local families interested in participating in research studies. Study participants had no neurological conditions, developmental disabilities, serious medical conditions, or history of brain injury. They received a full scale IQ score of least 80 on the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999) and scored above 80 on the Word Reading, Numerical Operations, and Spelling subtests of the Wechsler Individual Achievement Test (WIAT; Wechsler, 2001). Individuals who had a history of taking any psychiatric medications, including ADHD medications, were excluded from participation.

Participants in the ADHD group all met full diagnostic criteria for ADHD. Similar to the MTA study (Arnold et al., 1997), parent report of ADHD symptoms on the Diagnostic Interview Schedule for Children – Parent Version 4.0 (DISC-P; Shaffer, Fisher, Lucas, Dulcan, Schwab-Stone, 2000) could be supplemented with teacher report of ADHD symptoms. Specifically, if a parent reported at least four symptoms in any ADHD symptom domain on the DISC-P, these symptoms could be supplemented with non-overlapping symptoms on the Vanderbilt Teacher Rating Scale (Wolraich, Feurer, Hannah, Baumgaertel, & Pinnock, 1998) in order to meet ADHD symptom criteria. Children had to have six inattention symptoms identified in this manner to meet ADHD diagnostic criteria. If six or more symptoms were present only in the
inattentive domain, the child met criteria for ADHD-Inattentive Type. If six or more symptoms were present in both the inattentive and hyperactive-impulsive domains, the child met criteria for ADHD-Combined Type. In addition to symptom criteria being met using these supplemental rules, children must also have fulfilled DSM-IV criteria B-E (i.e., age of onset, pervasiveness, impairment, and ruling out other causal conditions) based upon parent responses on the DISC-P. Further, children were required to have more than four symptoms of inattention or hyperactivity/impulsivity coded as occurring *often* or *very often* on the Vanderbilt Teacher Rating Scale.

Participants in the control group met study criteria if their parents endorsed fewer than three ADHD symptoms and no DSM-IV externalizing disorder during the DISC-P (Shaffer, Fisher, Lucas, Dulcan, Schwab-Stone, 2000). Parents and teachers were also required to endorse (as occurring often or very often) no more than four inattentive and hyperactive symptoms on the Vanderbilt scales (Wolraich, Feurer, Hannah, Baumgaertel, & Pinnock, 1998).

**ADHD Screening Measures**

*Wechsler Individual Achievement Test (WIAT).* The WIAT (Wechsler, 2001) is a standardized measure of achievement that provides achievement scores and percentiles for a variety of academic subjects. Three subtests were used in the current study (Word Reading, Spelling, and Numerical Operations) to screen out children with possible learning disabilities. Scores were obtained using grade-based WIAT normative data (as opposed to age-based normative data). As noted above, children with scores below 80 were excluded from participation.

*Wechsler Abbreviated Scale of Intelligence (WASI).* The WASI (Wechsler, 1999) is an abbreviated standardized measure that provides IQ estimates for individuals between the ages of
6 and 89 years. It contains four subtests – Block Design, Similarities, Vocabulary and Matrix Reasoning – that provide estimates for Verbal IQ, Perceptual IQ, and a full-scale IQ. The full-scale IQ was used in the current study to screen out children with borderline intellectual disability. As noted above, children with full-scale IQ scores below 80 were excluded from participation.

*Diagnostic Interview Schedule for Children – Parent Version 4.0 (DISC-P)*. The DISC-P (Shaffer, Fisher, Lucas, Dulcan, Schwab-Stone, 2000) is a computerized structured interview administered to parents. It is commonly utilized in epidemiological and clinical studies to determine which diagnoses a child meets criteria for, using algorithms that were created with rules similar to those published in the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV; American Psychiatric Association, 1994). The DISC-P has demonstrated substantial reliability and validity across a multitude of studies (Shaffer, et al., 2000). This interview takes approximately 1.5 hours to complete and was used in the current study to determine if participants met criteria for ADHD, as well as other childhood psychological/psychiatric diagnoses.

*Vanderbilt ADHD Rating Scales* (VARS; Wolraich, Feurer, Hannah, Baumgaertel, & Pinnock, 1998). The VARS includes a parent report (VADPRS) and teacher report (VADTRS) form. Both forms are derived from DSM-IV symptom criteria for ADHD. Parents and teachers are asked to rate each DSM-IV symptom for ADHD (9 Inattentive symptoms and 9 Hyperactive/Impulsive symptoms) on a four point scale. Each VARS form yields a symptom count score, with symptoms rated as *often* or *very often* counted as present. Each form also includes an impairment scale that assesses the impact of ADHD symptoms on social, behavioral, and academic functioning. Previous studies have demonstrated excellent reliability and
substantial validity for the VARS. This measure was primarily used to assess teacher-report of ADHD symptoms in the current study, although it was also used to supplement the parent-reported symptoms that were gathered using the DISC-P.

*Neuropsychological Assessment Measures*

Each participant completed five computerized neuropsychological tasks that were designed to assess a variety of aspects of neurocognition (working memory, attention, inhibitory control). Tasks were programmed using E-prime 1.2, and were administered on a desktop computer with a 17” monitor and response pad (Cedrus RB-834). Within each task, stimulus presentation was held constant at 500 msecs. Although some of the tasks had varying inter-stimulus events (e.g., warning cues during the Attentional Network Task [ANT]), the inter-stimulus intervals (ISI) were held constant across tasks so that there was either 1 second, 3 seconds, or 5 seconds between stimulus presentations.

Each computer task was divided into six continuous blocks of trials that were divided into two sets of the three event rates. One of these sets included a reward manipulation, in which participants could earn points based on their performance. Points earned on the tasks were traded for prizes. During each task, participants were informed when they were able to earn points for accurate responses through both verbal (“you will earn points for this section”) and visual prompts (i.e., a green border appeared around the screen on reward trials). Participants were informed that they would be able to use their points for rewards (i.e., toys, games, school supplies, etc.) following completion of all tasks. Within the reward and non-reward sets, the order of the three ISIs was randomized and counterbalanced. Both the ISI and reward/non-reward conditions were counterbalanced within each task. Excluding the practice trials, each task
took 21 minutes to complete, except for the Child ANT task which took 14 minutes 48 seconds to complete.

*Go/No-Go Task.* The Go/No-Go task consisted of 20 practice stimuli (letters) and 360 task stimuli that appeared on the computer screen one at a time. Participants were instructed to press a button on the response pad for every letter except the letter X. Target and non-target stimuli appeared individually on the computer screen for 500 msec, followed by presentation of a fixation cross for the duration of the ISI. Across all of the trials, 10% of the stimuli were X’s. After a 20-trial practice block, participants were presented with 360 stimuli (6 blocks of 60 trials). Reaction time was recorded for each non-X trial and measured from the point at which a letter appeared on the screen to the point at which the participant pressed the response pad button. During the reward condition, participants were informed that they would receive 1 point for each accurate response and lose 5 points for each commission error (i.e., pressing the response key in response to the letter ‘X’).

*Stop-Signal Task* (Logan, 1994). During the Stop-Signal Task, a fixation point was presented in the middle of the screen for 500 seconds, followed by an airplane that faced either to the left or right that was presented for up to 500 milliseconds. Participants were instructed to press the left button on the response pad when they saw the plane facing to the left and the right button when they sawing the plane facing to the right. On 25 percent of the trials, a 1 MHz tone was emitted to indicate to the participants that they were to inhibit their responses (stop trials). The delay between presentation of an airplane and the tone began at 250 ms and varied according to the participant’s performance. Successful inhibition resulted in increases of 50 ms and unsuccessful inhibition resulted in decreases of 50 ms so that the rate of inhibition was approximately 50%. Following three practice blocks (one without tones, two with tones) of 20
trials each, 360 trials were administered. Reaction time was recorded on the non-stop trials and measured from the point at which a letter appeared on the screen to the point at which the participant pressed the response pad button. During reward conditions, children were instructed that they would earn 1 point for each successful response to the target stimulus and lose 4 points for each incorrect response (i.e., pushing the wrong directional key).

N-Back Task. The N-Back Task was a 1-Back Task, and required participants to remember the previous letter within a continuous stream of letters, as they appeared one at a time in the middle of the computer screen. Participants were instructed to press a specific button on the response pad every time they saw a letter that was the same as the previous letter they had seen and a different button every time they saw a letter that was different than the previous letter they had seen. Letters were presented on the screen continuously for 500 milliseconds, followed by a fixation cross for the remaining duration of the ISI. The same letter was presented on consecutive trials 30 percent of the time. After a 20-trial practice block, participants were presented with 360 stimuli (6 blocks of 60 trials). Reaction time was measured for all trials, from the point at which a stimulus appeared on the screen to the point at which a response was indicated on the response pad. During the reward condition, participants were instructed that they would earn 1 point for each stimulus they correctly identified (as target/1-back vs. non-target) and lose 1 point for every incorrect response.

Choice-Discrimination Task. The Choice-Discrimination Task consisted of two stimuli (circles and squares) that appeared one at a time, in a continuous stream, in the middle of the computer screen. Each target stimulus was presented, followed by presentation of a fixation cross for the duration of the ISI. Participants were instructed to indicate which shape was presented by pressing either the button on the response pad labeled with a circle or the button on the response
pad labeled with a square. Each block contained an equal proportion of circles and squares, and the order of stimulus presentation within blocks was randomly determined. After a 20-trial practice block, 360 trials (6 blocks of 60 trials) were presented. Reaction time was measured from the point at which a shape appeared to the point at which the participant pressed a response button, for all trials. During reward conditions, participants were notified that they would receive 1 point for each correct response and lose 1 point for each incorrect response.

Child Attentional Network Task (ANT; Rueda et al., 2004). The Child ANT consisted of a single fish stimulus that appeared on the computer screen either by itself or in the middle of a horizontal row of five fish. Participants were told to indicate which way the middle fish was swimming, by either pushing the button with the fish pointing to the left or the button with the fish pointing to the right. In trials that showed a row of five fish, the target (middle) fish could be facing in the same (congruent trials) or opposite (incongruent trials) direction as the other four fish. Neutral trials included the central fish. Each of these three conditions accounted for 33 percent of the trials. Preceding each target, there was one of four different warning conditions that appeared for 150 milliseconds - a no cue condition with no warning cue, a central cue condition which involved an asterisk in the center of the screen, a double cue which involved a two asterisks, or a spatial cue, which involved an asterisk in the location of the target. These four warning conditions each accounted for one quarter of the trials. After a practice block of 20 trials, the task consisted of 360 trials. Reaction time was measured from the point at which the target appeared on the screen to the point at which a response was indicated on the response pad. During the reward condition, participants were instructed that they would receive a point for each correct response and lose a point for each incorrect response.

Naturalistic Tasks
Participants completed two naturalistic analog tasks, modeled after tasks utilized in a classroom, while being videotaped. They differed in levels of engagement and direction. The first naturalistic task required a lower level of engagement, and was not self-directed. It was designed to simulate watching a classroom lecture or observing an educational video that a teacher might show in conjunction with a science lesson. It consisted of watching one of two educational videos (approximately 15 minutes in length). The videos were titled “Solids, Liquids, Gases: A First Look” (Rainbow Educational Media, 2001) and “Plants: A First Look” (Rainbow Educational Media, 2000). Two videos were used, because these tasks were part of a larger study examining the effects of methylphenidate on neuropsychological and observational outcomes. The two videos were counterbalanced across pre and post-medication assessment visits. Participants were told the name of the video, that they would be recorded, and that they should pay attention because they would be given a short quiz afterwards.

The second naturalistic task was designed to simulate self-directed classroom work or homework. This task required a higher level of engagement and had the participants work on a set of math worksheets for twenty minutes (or until all of the problems were finished). The difficulty level of math problems for each child was determined by the Curriculum Based Measurement (Wright, 2010) assessment completed earlier in the study. Based on the participant’s grade level, he or she was administered a math worksheet (e.g., single digit addition, multiple digit addition, single digit multiplication, etc.) and timed for two minutes. After completion, the number of correct digits was tallied. If the participant completed less than 20 digits correctly, then he or she was given the next lowest level sheet to work on for two minutes and if the child completed more than 39 digits correctly, he or she was given the next highest sheet to complete. This continued
until the child completed between 20 and 39 digits correctly on a worksheet or was administered the lowest level of math problems (i.e., single digit addition).

Observational Coding

Behaviors were coded using a continuous second-by-second coding scheme. Computer software (Noldus Observer XT®; Noldus Information Technology, 2008) was used to assist in tracking the frequency and duration of each behavior. This computer program allowed coders to upload participant video recordings and keep track of the onset and offset of each behavioral code for each participant, by pressing a corresponding code key. This provided the number of times and duration for each behavioral occurrence for each participant. This coding scheme also provided the data to demonstrate within-subject patterns for each behavior coding during each of the two tasks. Four coders (TA and three research assistants) coded all of the videos. Coders were trained and calibrated on the coding scheme and Noldus® software using a random set of 20 videos. Further, coders met regularly to code together another random subset of videos (20; 7%), in an attempt to decrease coder drift.

Off-task behavior was coded as a general measure of cognitive attention to each of the educational tasks. For the video task, off-task behavior was defined as visual attention not directed towards the television screen. Off-task behavior during the math task was defined as visual attention not directed towards the math worksheet. During the math task, children often times briefly looked up towards the wall or ceiling before writing an answer during brief periods of thinking, and sometimes looked away while counting to themselves or counting on their fingers. In order to avoid coding these behaviors as off-task, we defined off-task behavior as visual attention away from the worksheet for two or more seconds and did not code behavior as off-task if the child appeared to be counting to him- or herself or counting fingers. Also, if a
child maintained visual attention during the math task, but was doodling, counting problems, or looking ahead to see how many problems were left, this was also coded as off-task behavior.

Fidgeting behavior was coded as a general measure of motor activity. Fidgeting behavior included shifting, rocking, tapping or drumming fingers, playing with hair, face, fingernails, pockets, etc., and was coded for the entire duration that it occurred during the video task. As the math task inherently required more shifting and movement than the video task, fidgeting behavior during this task was coded if the above behaviors lasted for two or more seconds.

Task behaviors were summarized for each participant for each observational task (math and educational video). We calculated a mean duration of time on-task by dividing the total duration of time on-task by the number of times off-task plus one. A duration of fidgeting variable was created by summing the total duration of fidgeting behavior across each task.

Thirty-five percent of the recordings remaining after training and group videos were randomly chosen were double-coded for reliability. Reliability was assessed with intraclass correlation coefficients (ICC) for the three variables used to derive our summary variables: number of times off-task, total duration of off-task behavior, and total duration of fidgeting behavior. Interrater agreement was high for all coded behaviors (see Table 2).

Procedure

This study was approved by the Cincinnati Children's Hospital Institutional Review Board and consisted of three sessions on three separate days, each approximately one week apart. The first session was used to determine whether a participant qualified for an ADHD diagnosis. During this session parents completed the DISC-P and the Parent Vanderbilt Rating Scale, while the child completed the WASI and WIAT screeners, to assess for the presence of intellectual and learning disabilities. Each child also completed the Curriculum Based Measurement assessment (Wright, 2010), as described above, to determine math level proficiency. To ensure the presence
of ADHD symptoms across settings needed for an ADHD diagnosis, teachers of participants completed the Teacher Vanderbilt Rating Scale.

During sessions two and three, participants completed the five neuropsychological computer tasks and the two naturalistic tasks. Tasks were administered in a counterbalanced fashion. Children were all medication naïve and remained so during all three sessions.

Analyses

On the neuropsychological tasks, all reaction times less than 100 ms were excluded before calculating neuropsychological summary statistics, since the non-decision portion of simple RT is approximately 100 milliseconds (Luce, 1986). Further, if the percentage of omission errors exceeded 50% during performance on any of the five tasks, the task was omitted from all analyses.

To ensure that participants with missing/omitted neuropsychological data did not differ from participants with a full complement of data, we utilized t-tests and chi-squared tests to separately compare participants in the control and ADHD groups with missing/omitted data to participants in the control and ADHD groups with a full complement of data on the following variables: age, sex, race, WASI full scale IQ, ODD, conduct disorder, anxiety disorder, mood disorder, and parent- or teacher-rated ADHD symptom scores. No significant differences were found between participants with and without missing data for any of these variables. However, effect sizes indicated that the greatest differences were found between control participants with and without missing data for IQ ($d = 0.56$), age ($d = 0.43$), and sex (OR = 2.14), and between ADHD participants with and without missing data for parent-rated hyperactivity symptoms ($d = 1.5$). It should be noted that these comparisons involved very small numbers of patients with missing data. Of the remaining effect sizes, none were greater than $d = 0.33$ or OR = 1.42.
RT coefficient of variation (CV) for each participant and task was computed by dividing the standard deviation of the reaction times for each block of trials by the mean reaction time, and multiplying by 100. This variable provides a measure of RT variability across a task while controlling for reaction time speed. Percent accuracy was calculated for each participant by dividing the number of correct responses by the number of trials for each block of trials within each task. RTSYS 1.0 (Heathcote, 1996) was used to provide ex-Gaussian estimates. Although the ex-Gaussian distribution has three parameters \([\mu (\mu), \sigma (\sigma), \text{and } \tau (\tau)]\), only \(\tau (\tau)\) was used in our analyses, as a second measure of RT variability. \(\tau\), which represents the exponential component (positive skew) of a reaction time distribution, was calculated for each block of trials within each task. Due to lack of fit between the data and the ex-Gaussian function, a percentage of \(\tau\) values could not be computed for each task (Choice-Discrimination = 3%; ANT = 6%; Go/No Go = 8%; Stop Signal = 8%; and N-Back = 8%). Using \(t\) – tests and chi square tests, children with a full complement of data were compared to children with missing ex-Gaussian indicators on age, IQ, sex, race, ODD, conduct disorder, anxiety disorder, mood disorder, or parent- or teacher-rated ADHD symptom domain scores. Results from these comparisons indicate that participants with missing data had lower IQ scores \((t(149) = 3.00, p < .05, d = .49)\), more parent-rated symptoms of inattention \((t(147) = -3.12, p < .05, d = .51)\) and hyperactivity/impulsivity \((t(144) = -3.89, p < .05, d = .65)\) on the VADPRS, and more teacher-rated symptoms of inattention \((t (146) = -3.01, p < .05, d = .50)\) and hyperactivity/impulsivity on the VADTRS \((t(147) = -2.99, p < .05, d = .49)\), compared with participants who had a full complement of data. To summarize, for each participant, each of the five computer tasks had six CV values, six \(\tau\) values, and six accuracy percentages to take into account performance for each of the three event rates across both reward conditions.
Of the 149 participants who completed the neuropsychological computerized tasks, 9 math observations and 12 video observations were lost due to mechanical errors (e.g., video camera dysfunction). Two behavioral observations (1 video and 1 math) were not included in the analyses because the children fell asleep during the tasks. One math task was also not included due to a participant’s inability to follow task directions. Similar to analyses with the neuropsychological data, we separately compared participants in the ADHD and control groups with missing/omitted data to participants in the ADHD and control groups with a full complement of data on the following variables: age, sex, race, WASI full scale IQ, ODD, conduct disorder, anxiety disorder, mood disorder, and parent- or teacher-rated ADHD symptom scores. There were no significant differences for any of these variables between participants with and without omitted data.

Analyses were conducted to determine whether there were significant differences between the ADHD and control groups for each of the variables. Separate linear mixed models (LMM) were conducted using SAS PROC MIXED for each neuropsychological variable. In each model, group was entered as the independent variable, and event rate, reward status, and task were entered as covariates. The three covariates were not examined specifically, as they were not the primary interests of this study. Detailed results for group, reward and event rate effects for each computerized neuropsychological task are presented elsewhere (Epstein et al., in press). Residuals were examined for each model in order to investigate whether they met normality assumptions. None of the residuals produced from the reaction time models met the normality assumption. A log transformation sufficiently corrected the CV and tau variables. An arcsin transformation was utilized for accuracy, as this variable was represented as a percentage. For each of these variables, models were generated using independence, compound symmetry (with
and without a group variable), and heterogeneous compound symmetry (with and without a group variable) structures. The covariance structure for the final models was chosen based on best fit using the AICC indicator (lower AICC values represent better fit).

Similarly, LMMs were conducted to examine group-differences for each observational variable. Each model included group as an independent variable and no covariates. Residuals produced from the observational models were not normal. Math mean on-task duration and video mean on-task duration were sufficiently transformed using log transformations, as was math total duration of fidgeting behavior. For the video task, the fidgeting variable did not require a transformation. Although these measures were not repeated, LMMs were used to examine group differences, and the [repeated/subject=subject group=group] SAS syntax was included in each model, so that the assumption of homogeneity of variance could be overridden.

Next, Pearson correlations were calculated to examine the general direction and strength of the interrelationships between each of the dependent variables (CV, tau, accuracy, math on-task total duration, math total fidgeting duration, video on-task total duration, and video total fidgeting duration).

LMMs were utilized to examine the relationship between each indicator of RT variability (CV and tau) and attention (math and video mean duration of on-task behavior). Each model utilized a neuropsychological variable as a dependent variable, an observational variable as an independent variable, and event rate, task, and reward status as covariates. Group was also included as a covariate in each model, so that potential significant relationships could not be attributed to group differences for each variable. Each model was generated using the same five covariate structures as those described above and fit was determined using AICC values.
Lastly, LMMs were used to examine whether the relationship between RT variability and attention was specific to CV, tau, and on-task behavior. Percent accuracy and total duration of fidgeting behavior were used as alternate neuropsychological and behavior indicators, respectively. The relationships between percent accuracy and on-task behavior were modeled, as were the relationships between total duration of fidgeting behavior and indicators of RT variability and percent accuracy. The modeling process for each of these analyses was the same as described above.

Each of the models examining the relationship between a neuropsychological and an observational variable originally included a diagnosis by observational variable interaction term. None of the interaction terms were significant, so the results presented reflect all of the models with no interaction terms. All p values were considered significant if less than .05.

Results

Group Differences

Table 3 summarizes results from the models examining between-group differences for each neuropsychological variable. Participants with ADHD had significantly higher CV and tau values and lower percent accuracy than participants without ADHD.

Between-groups differences for both observational tasks are summarized in Table 4. During the math task, participants with ADHD had significantly shorter mean durations of on-task behavior than the participants without ADHD. Although the differences between groups were not significant (p = .13), participants in the ADHD group also had shorter mean durations of on-task behavior than the participants without ADHD during the video task. Results from the models examining fidgeting behavior indicated that the participants with ADHD had significantly longer total durations of fidgeting behavior than the participants with ADHD during
the math task. There was a similar, but marginally non-significant, group difference ($p = .05$) for fidgeting behavior during the video task.

**Intercorrelations**

Table 5 provides the intercorrelations between all of the neuropsychological and observational variables. In terms of our neuropsychological variables, there was a high positive correlation between CV and tau ($r = .55, p < .0001$) and a moderate negative correlation between CV and accuracy ($r = -.21, p < .0001$). Correlations between the observational variables revealed moderate negative relationships between fidgeting and on-task behavior, during the math ($r = -.36, p < .0001$) and video ($r = -.29, p < .0001$) tasks. There was a small positive correlation between math and video fidgeting ($r = .16, p < .0001$); however, there was minimal relationship between math and video on-task behavior ($r = .03, p = .10$).

**Relationship Between Reaction Time Variability and Attention**

Table 6 provides a summary of the models examining the relationship between neuropsychological indicators of RT variability and on-task behavior during the two observational tasks. With regard to the models using CV as a dependent variable, a significant relationship was found for on-task behavior during the math task, such that higher values of CV were associated with lower mean durations of on-task behavior. There was not a significant relationship ($p = .19$) between CV and mean duration of on-task behavior during the video task. The relationship between tau and on-task behavior during the math task was significant. Higher values of tau were associated with lower mean durations of on-task behavior. There was not a significant relationship ($p = .81$) between tau and on-task behavior during the video task.

**Analyses Examining the Specificity of the Relationship Between RT Variability and Attention**
Table 6 also provides a summary of the models that included the alternate neuropsychological (accuracy) and behavioral (fidgeting) indicators. Results from the models examining accuracy and on-task behavior indicated that there was a significant positive relationship between these variables for the math task. Higher percent accuracy values were associated with higher mean durations of on-task behavior. There was not a significant relationship \( (p = .49) \) between accuracy and on-task behavior during the video task. Results from the models examining the indicators of RT variability and fidgeting behavior indicated that there were marginally non-significant relationships between CV and fidgeting behavior during the video \( (p = .07) \) and math \( (p = .06) \) tasks. Higher values of CV were associated with longer durations of fidgeting. There was not a significant relationship between tau and fidgeting behavior during either the math \( (p = .57) \) or video tasks \( (p = .33) \). Lastly, the models examining the relationship between accuracy and fidgeting behavior were significant for both tasks. Lower percent accuracy values were associated with longer durations of fidgeting.

**Discussion**

In order to better understand RT variability, the current study examined the relationship between RT variability on five computerized, neuropsychological tasks and observed ADHD behavior during two educational activities. Neuropsychological results indicated that children with ADHD had greater RT variability and lower accuracy on computerized neuropsychological tasks compared with children without ADHD. Observational results indicated that children with ADHD had shorter mean durations of on-task behavior than children without ADHD during the math task and longer durations of fidgeting behavior during both tasks. Examinations of the relationships between our neuropsychological and observational variables showed that increased RT variability and lower accuracy were related to shorter durations of on-task behavior, while
children were completing a math worksheet. RT variability was not related to on-task behavior while children were watching an educational video.

*Group Differences*

Similar to previous research, children with ADHD demonstrated increased RT variability, as measured by CV and ex-Gaussian tau, and had a lower percentage of correct trials compared with controls (de Zeeuw et al., 2008; Klein, Wendling, Huettner, Ruder, & Peper, 2006; Vaurio, Simmonds, & Mostofsky, 2009; Losier, McGrath, & Klein, 1996; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Effect size calculations indicated that there were greater between-group differences for the measures of RT variability (CV Cohen’s $d = .95$, tau Cohen’s $d = .99$) than accuracy (Cohen’s $d = .84$). Similar effect size patterns have been reported in other studies that have compared group differences for RT variability and accuracy (de Zeeuw et al., 2008, Klein, Wendling, Huettner, Ruder, & Peper, 2006), supporting the notion that RT variability on computerized tasks may better differentiate children with ADHD from those without ADHD than accuracy.

With regard to group differences for the behavioral variables, our results were partially in agreement with our predictions. Specifically, children with ADHD were on-task for significantly shorter periods of time (back transformed mean = 112 sec) than children without ADHD (back transformed mean = 245 sec) during the math task. These results are in line with other studies in the literature that have found greater off-task behavior in children with ADHD than control groups (Abikoff, Gittelman-Klein, & Klein, 1977, Lauth, Heubeck, & Mackowiak, 2006). Further, this finding is consistent with the results of a more recent study by Rapport et al. (2009), which used a continuous coding scheme to document lower rates of on-task behavior during classroom activities in a subsample of children with ADHD with low levels of attention.
Although we predicted that the participants with ADHD would have shorter durations of observed attention during both behavioral tasks, our analyses did not show significant differences for on-task behavior during the video task (back transformed ADHD mean = 47 sec; back transformed Control Mean = 59 sec). There are a few possible explanations for this lack of group differences. First, it is possible that our coding scheme was unable to pick up differences in attention during the video task. Despite the invaluable data observational studies provide, the reliance on observed behavior for behavioral coding does not take into account covert aspects of cognition. In the current study, the operational definition for on-task behavior during the video task relied on overt loss of visual attention as a representation of cognitive inattention. Undoubtedly, there were instances when the children were not cognitively engaged in the task, but were coded as on-task, because they were staring at the video screen. Thus, it is possible that a different methodology for detecting off-task behavior (e.g., EEG; eye-tracking) could have resulted in significant group differences in mean durations of on-task behavior during the video task.

Along with our coding scheme, differences between the two behavioral tasks (difficulty, self-direction, etc.) may have also contributed to the different set of group differences across tasks. Most studies have shown that self-directed tasks and tasks with higher levels of difficulty or engagement produce the greatest inattention, in both children with and without ADHD (Center, Deitz, & Kaufman, 1982; Klein and Young, 1979; Lauth, Heubeck, & Mackowiak, 2006; Roberts, Marshall, Nelson, & Albers, 2001). In contrast, Zentall (1980) found that children exhibit greater instances of off-task behavior while watching educational films than completing self-directed seatwork. The mean durations of on-task behavior found in our study also suggest that longer durations of attention occur during the self-directed math task than the passive video
task. However, contrary to our study’s findings of between-group differences in mean on-task duration during the math task, Zentall (1980) found no differences between the ADHD and control groups in frequency or total duration of off-task behavior during either of these tasks. Mean duration of on-task behavior was utilized in the current study, in an attempt to capture the oscillating nature of attention, which has been hypothesized as an important differentiating characteristic for children with and without ADHD (Johnson et al., 2007; Castellanos et al., 2005). It may be that mean on-task behavior, which is derived by dividing the total duration of off-task behavior by the frequency of off-task behavior, provides a more sensitive measure of ADHD-related attentional deficits than either of these behavioral indicators alone.

A final explanation for the lack of group differences on the video task comes from research investigating attentional processes during television viewing. Indeed, television viewing appears to involve changes in visual attention over time, termed attentional inertia. Attentional inertia has been defined as “a progressive increase in the attentional engagement as a look is sustained” (Richard & Anderson, 2004), and is associated with decreased distractibility and higher comprehension. Perhaps attentional inertia affects on-task behavior of children leading to similar durations of on-task behavior across children with and without ADHD while watching television.

In terms of group differences for fidgeting behavior, the results were consistent with our predictions and showed that children with ADHD exhibited more fidgeting behavior across the math and video tasks ($p = .05$) than children without ADHD. These behavioral results are consistent with numerous studies in the ADHD observational literature documenting greater motor activity during classroom activities in children with ADHD compared with children.
without ADHD (e.g., Abikoff, Gittelman-Klein, & Klein, 1977; Abikoff, Gittelman, & Klein, 1980; Jacob, O’Leary, & Rosenblad, 1978; Klein & Young, 1979).

*Is RT Variability Related to Observed Behavior?*

To date, few studies have examined the relationship between neuropsychological indicators and observed ADHD-related behavior in children. A study by Solanto et al. (2001) examined correlations between observed classroom behavior and Stop Signal Reaction Time (SSRT). These authors, however, did not find significant relationships between SSRT and off-task behavior or gross motor movement. In contrast, Weis and Totten (2004) examined the relationship between aspects of performance accuracy on a CPT and observed classroom behavior. They found significant correlations between observed inattention and omission errors, but little relationship between observed hyperactivity and commission errors. Given the robust between-group (i.e., ADHD vs. controls) differences in RT variability (de Zeeuw et al., 2008; Epstein et al., in press; Klein, Wendling, Huettner, Ruder, Peper, &2006; Vaurio, Simmonds, & Mostofsky, 2009), the current study examined whether RT variability on neuropsychological tasks correlates with behavioral observations. Consistent with interpretations in the literature suggesting that RT variability is indicative of lapses in attention (Leth-Steensen et al., 2000), we expected significant relationships between RT variability indicators and attention during each of our educational tasks. Analyses resulted in significant associations between RT variability and attention during the math task, such that higher values of CV and tau were associated with shorter durations of on-task behavior. However, these associations were not significant for our video task, perhaps due to a lack of group differences, coding scheme sensitivity, and limited attentional variability due to attentional inertia, which have been described above.
Although these results suggest that RT variability may correlate with observed behavioral attention, it is possible that RT variability’s relationship to observed behavior is not specific to attention. To explore the specificity of the relationship between RT variability and attention, we examined the relationship between RT variability and other ADHD-related behavior (i.e., fidgeting), as well as the relationship between on-task behavior and an alternative neuropsychological indicator (i.e., accuracy). Though children with ADHD exhibited increased RT variability on neuropsychological tasks and more fidgeting on the math task than controls, the relationship between RT variability and fidgeting behavior on the math task was not significant, suggesting some specificity to the relationship between RT variability and behavioral attention. Further, the effect size for the relationship between CV and on-task behavior (.64) was relatively larger than the relationship between CV and fidgeting (.36). Of note, Wahlstedt (2009) also found larger correlations between parent-rated symptoms of inattention and RT variability than parent-rated symptoms of hyperactivity and RT variability. Hence, there appears to be some specificity to the relationship between RT variability and attention, at least for the math task.

Our second set of specificity analyses explored the relationship between our observational indicator of attention and neuropsychological task accuracy. Our results showed a significant association between percent accuracy and on-task behavior coded during the math task. Higher accuracy was associated with longer durations of on-task behavior. Similarly, using a school based population, Weis and Totten (2004) also found a significant relationship (r=.32) between omission errors and observed inattentive behavior. Thus, higher rates of behavioral inattention do not appear to be specifically related to RT variability as behavioral inattention also appears to relate to task accuracy. The relationship between task accuracy and observed
attention seems quite logical since individuals can presumably only have high accuracy during neuropsychological tasks if they are visually attending to the tasks.

**Limitations**

There are a few limitations of the current study worth noting. First, despite the educational tasks being designed after those used in classroom settings, both observational tasks were analog tasks completed in a laboratory setting. Many prior observational studies that have documented differences in behavior between children with and without ADHD have used real or simulated classrooms (e.g., Evans et al., 2001; Pelham et al., 2002; Rapport, Kofler, Alderson, Timko, & DuPaul, 2009). In a laboratory setting, participants encounter fewer distractions than would be encountered in a live classroom with other students. This may have led to longer instances of on-task behavior in the children with ADHD and thus underestimated the group differences we found for our behavioral variables, or reduced power to find a relationship between our neuropsychological and behavior variables, particularly for the video task.

Further, even though trial-by-trial data was collected during the neuropsychological tasks and a continuous coding scheme was used for the behavioral data, we were unable to examine temporal patterns in our data, because each neuropsychological task included within-task manipulations of event rates and reward (see Epstein et al., in press for a summary of the effects of these manipulations on RT variability). Using advanced statistical techniques (Fast Fourier Transform Analyses), researchers (Johnson et al., 2007; Castellanos et al., 2005) have found that among children with ADHD, long RTs tend to occur every 13-20 seconds. These RT oscillations have been interpreted as attentional spans or the time between on- and off-task states. Although we were unable to conduct similar analyses using our neuropsychological data, our behavioral results indicated much longer periods between on- and off-task states among children with
ADHD (112 seconds during the video task and 245 seconds during the math task). Such oscillations in attentional states are quite discrepant from those found by Johnson et al. and Castellanos et al. Perhaps due to our use of behavioral observations, subtle, unobserved changes in cognitive attention may have been missed, which may have resulted in longer oscillations in attentional periods than may have been observed with alternative measures (e.g., EEG).

Clinical Implications

Although RT variability is a ubiquitous neuropsychological indicator of ADHD status, the behavioral correlates of RT variability are poorly understood. Better understanding these behavioral correlates can help in interpretation of neuropsychological testing results. In 1991, Barkley wrote “before one can address the question of the ecological validity of particular measures, one must carefully define those behaviors in the natural environment that exemplify that ADHD symptoms of interest that the LM [laboratory or analogue measure] is intended to represent or predict” (pp. 151). Almost a decade later, Rapport, Chung, Shore, Denney, & Issacs (2000) criticized the ability to which laboratory measures of neuropsychological processing predict impairments seen in children with ADHD using direct observation in the classroom. Despite the research cautioning the use of computerized laboratory measures as predictors of impairment or diagnostic tools (e.g., Nichols & Waschbusch, 2004), it is not uncommon to find continuous performance tasks included within sets of measures being used to assess for ADHD. Based on results from the current study, greater RT variability is related to the ADHD phenotype and may specifically indicate attentional span, at least on self-directed tasks.

Future Directions

Given that this is the first study to examine the relationship between RT variability and observed attention, continued investigation is needed to determine the strength, predictability,
and specificity of the relationships between these two variables. Future studies should include a variety of ADHD-related behaviors coded during a variety of activities outside of the laboratory. Further, investigating the relationship between neuropsychological and behavioral variables using advanced statistical techniques (e.g., Fast Fourier Transform analysis) will provide greater insights into whether attentional fluctuations during the behavioral tasks correlate with attentional oscillations during neuropsychological tasks.

In order to understand the relationship between RT variability and ADHD-related behavior, research into physiological indicators of attention is also needed. As explained above, the lack of group differences and relationship between RT variability and attention during the video task may have been due to the inability of our coding scheme to pick up covert aspects of attention. It is possible that physiological indicators of attention during educational tasks may better approximate attentional allocation and thus better correlate with RT variability than the overt, visual indicators of attention utilized in the current study. Research utilizing psychophysiological measures such as EEG, to examine the relationship between ERPs during neuropsychological tasks and ERPs during observational tasks may help us to understand the neural correlates of long reaction times and how they correspond to observed on-task related behavior during different classroom activities.
References


Luce, R. D. (1986). *Response times: Their role in inferring elementary mental organization*. New York: Oxford University Press.


(Available from United Learning, 1560 Sherman Ave., Suite 100, Evanston, IL 60201)


Obtaining systematic teacher reports of disruptive behavior disorders utilizing DSM-IV. *Journal of Abnormal Child Psychology, 26*, 141–152. doi: 10.1023/A:1022673906401


Table 1
**Demographic and Clinical Characteristics of the ADHD and Control Samples**

<table>
<thead>
<tr>
<th></th>
<th>ADHD</th>
<th>Control</th>
<th>Group Comparison</th>
<th>p</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n = 104)</td>
<td>(n = 47)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of males (percentage)</td>
<td>75 (.72)</td>
<td>31 (.66)</td>
<td>$\chi^2(1, N = 151) = 0.40$</td>
<td>0.53</td>
<td>OR = .79</td>
</tr>
<tr>
<td>Number of each ethnicity (percentage)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caucasian</td>
<td>75 (.72)</td>
<td>38 (.80)</td>
<td>$\chi^2(1, N = 145) = 0.85$</td>
<td>0.25</td>
<td>OR = .65</td>
</tr>
<tr>
<td>African American</td>
<td>18 (.17)</td>
<td>7 (.18)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hispanic (non-Black)</td>
<td>2 (.02)</td>
<td>1 (.02)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asian</td>
<td>2 (.02)</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mixed</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>American Indian</td>
<td>2 (.02)</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number with specified comorbid psychological disorder from DISC-P</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oppositional Defiant Disorder</td>
<td>38</td>
<td>0</td>
<td>$\chi^2(1, N = 151) = 22.95$</td>
<td>&lt; .0001</td>
<td>OR = 0</td>
</tr>
<tr>
<td>Conduct Disorder</td>
<td>4</td>
<td>0</td>
<td>$\chi^2(1, N = 151) = 1.86$</td>
<td>0.17</td>
<td>OR = 0</td>
</tr>
<tr>
<td>Any Anxiety Disorder</td>
<td>38</td>
<td>2</td>
<td>$\chi^2(1, N = 151) = 17.33$</td>
<td>&lt; .0001</td>
<td>OR = .07</td>
</tr>
<tr>
<td>Any Mood Disorder</td>
<td>2</td>
<td>0</td>
<td>$\chi^2(1, N = 151) = .92$</td>
<td>0.34</td>
<td>OR = 0</td>
</tr>
<tr>
<td>Mean (SD) age in years</td>
<td>8.13 (1.23)</td>
<td>8.33 (1.35)</td>
<td>t(149) = .79</td>
<td>0.43</td>
<td>d = .15</td>
</tr>
<tr>
<td>WASI full scale IQ (SD)</td>
<td>105.20 (12.55)</td>
<td>116.11 (14.14)</td>
<td>t(149) = 4.75</td>
<td>&lt; .0001</td>
<td>d = .78</td>
</tr>
<tr>
<td>Parent Vanderbilt Scores (SD)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inattention Symptom Count</td>
<td>7.5(1.92)</td>
<td>.07(.25)</td>
<td>t(149) = -25.86</td>
<td>&lt; .0001</td>
<td>d = 4.24</td>
</tr>
<tr>
<td>Hyperactivity/Impulsivity</td>
<td>5.60(2.88)</td>
<td>.02(.15)</td>
<td>t(149) = -13.32</td>
<td>&lt; .0001</td>
<td>d = 2.18</td>
</tr>
<tr>
<td>Teacher Vanderbilt Scores (SD)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inattention Symptom Count</td>
<td>7.24(1.98)</td>
<td>.20(.58)</td>
<td>t(148) = -23.94</td>
<td>&lt; .0001</td>
<td>d = 3.94</td>
</tr>
<tr>
<td>Hyperactivity/Impulsivity</td>
<td>4.63(3.12)</td>
<td>.28(.78)</td>
<td>t(148) = -9.43</td>
<td>&lt; .0001</td>
<td>d = 1.53</td>
</tr>
</tbody>
</table>

*Note: *p<.05; **p<.01; OR = odds ratio; d = Cohen’s d. Group comparisons for ethnicity compared the proportion of White
participants to minority participants for the ADHD and Control groups.

Table 2
_Intraclass Correlation Values for Each Code During the Math and Video Tasks_

<table>
<thead>
<tr>
<th></th>
<th>Video Task</th>
<th>Math Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Off-task Number</td>
<td>0.94</td>
<td>0.89</td>
</tr>
<tr>
<td>Off-task Total Duration</td>
<td>0.89</td>
<td>0.98</td>
</tr>
<tr>
<td>Fidgeting Total Duration</td>
<td>0.97</td>
<td>0.84</td>
</tr>
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</table>
Table 3

*Group Means, Standard Errors, and Group Differences for the Three Neuropsychological Variables*

<table>
<thead>
<tr>
<th></th>
<th>df</th>
<th>Controls</th>
<th>ADHD</th>
<th>$F$</th>
<th>$p$</th>
<th>Cohen’s $d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV</td>
<td>146</td>
<td>3.33(.03)</td>
<td>3.51(.02)</td>
<td>28.31</td>
<td>&lt;.0001</td>
<td>0.95</td>
</tr>
<tr>
<td>Tau</td>
<td>145</td>
<td>5.07(.04)</td>
<td>5.36(.03)</td>
<td>30.66</td>
<td>&lt;.0001</td>
<td>0.99</td>
</tr>
<tr>
<td>Accuracy</td>
<td>143</td>
<td>1.26(.02)</td>
<td>1.16(.02)</td>
<td>21.75</td>
<td>&lt;.0001</td>
<td>0.84</td>
</tr>
</tbody>
</table>

*Note.* Each of the neuropsychological variables least square means and standard error s reflect transformed values. CV and tau were natural log transformed. Accuracy was arcsine transformed.
<table>
<thead>
<tr>
<th>Variable</th>
<th>df</th>
<th>ADHD</th>
<th>Controls</th>
<th>F</th>
<th>p</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Math Task</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean On-task Duration</td>
<td>134</td>
<td>2.05(.05)</td>
<td>2.39(.06)</td>
<td>19.65</td>
<td>&lt;.0001</td>
<td>0.79</td>
</tr>
<tr>
<td>Total Duration of Fidgeting</td>
<td>134</td>
<td>4.98(.07)</td>
<td>4.63(.10)</td>
<td>7.28</td>
<td>0.008</td>
<td>0.48</td>
</tr>
<tr>
<td><strong>Video Task</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean On-task Duration</td>
<td>133</td>
<td>1.67(.04)</td>
<td>1.77(.05)</td>
<td>2.34</td>
<td>0.13</td>
<td>0.27</td>
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<tr>
<td>Total Duration of Fidgeting</td>
<td>134</td>
<td>515.15(23.27)</td>
<td>441.08(28.83)</td>
<td>4.00</td>
<td>0.05</td>
<td>0.36</td>
</tr>
</tbody>
</table>

*Note.* Except for Total Duration of Fidgeting during the video task, each of the observational variables’ least square means and standard errors reflect transformed values. All were natural log transformed.
Table 5
*Intercorrelations Between Three Neuropsychological Variables and Four Observational Variables*

<table>
<thead>
<tr>
<th>Variable</th>
<th>CV</th>
<th>Tau</th>
<th>Accuracy</th>
<th>Math Task</th>
<th>On-task Mean</th>
<th>Fidgeting Duration</th>
<th>Video Task</th>
<th>On-task Mean</th>
<th>Fidgeting Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tau</td>
<td>-0.21****</td>
<td>-0.04**</td>
<td></td>
<td></td>
<td>-0.21****</td>
<td>-0.16***</td>
<td>-0.14****</td>
<td>-0.36****</td>
<td></td>
</tr>
<tr>
<td>Accuracy</td>
<td>-0.21****</td>
<td>-0.16***</td>
<td>0.18****</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Math On-task Mean</td>
<td>0.11****</td>
<td>0.06****</td>
<td>-0.14****</td>
<td>-0.36****</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Math Fidgeting Duration</td>
<td>-0.08****</td>
<td>-0.05**</td>
<td>0.06****</td>
<td>0.03</td>
<td>0.11****</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Video On-task Mean</td>
<td>0.10****</td>
<td>0.08****</td>
<td>-0.13****</td>
<td>-0.13****</td>
<td>0.16****</td>
<td>-0.29****</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Video Fidgeting Duration</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. *p<.05; **p<.01; ***p<.001; ****p<.0001."
### Table 6

**Summary of 12 Linear Mixed Models Examining the Relationship Between Each Neuropsychological and Observational Variable for Each Task**

<table>
<thead>
<tr>
<th>DV</th>
<th>IV</th>
<th>df</th>
<th>$b$</th>
<th>$F$</th>
<th>$p$</th>
<th>Cohen’s $d$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Math Task</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>Mean On-task Duration</td>
<td>133</td>
<td>-0.0002(.0001)</td>
<td>13.55</td>
<td>0.0003</td>
<td>0.64</td>
</tr>
<tr>
<td>CV</td>
<td>Total Duration of Fidgeting</td>
<td>133</td>
<td>0.0002(.0001)</td>
<td>3.58</td>
<td>0.06</td>
<td>0.36</td>
</tr>
<tr>
<td>Tau</td>
<td>Mean On-task Duration</td>
<td>133</td>
<td>-0.0002(.0001)</td>
<td>5.18</td>
<td>0.02</td>
<td>0.41</td>
</tr>
<tr>
<td>Tau</td>
<td>Total Duration of Fidgeting</td>
<td>133</td>
<td>0.0001(.0002)</td>
<td>0.32</td>
<td>0.57</td>
<td>0.10</td>
</tr>
<tr>
<td>Accuracy</td>
<td>Math Mean On-task Duration</td>
<td>132</td>
<td>0.0001(.00005)</td>
<td>7.58</td>
<td>0.007</td>
<td>0.51</td>
</tr>
<tr>
<td>Accuracy</td>
<td>Total Duration of Fidgeting</td>
<td>132</td>
<td>-0.0002(.0001)</td>
<td>5.29</td>
<td>0.02</td>
<td>0.42</td>
</tr>
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<td></td>
<td><strong>Video Task</strong></td>
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</tr>
<tr>
<td>CV</td>
<td>Mean On-task Duration</td>
<td>132</td>
<td>-0.0002(.0002)</td>
<td>1.75</td>
<td>0.19</td>
<td>0.20</td>
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<tr>
<td>CV</td>
<td>Total Duration of Fidgeting</td>
<td>133</td>
<td>0.0001(.0001)</td>
<td>3.42</td>
<td>0.07</td>
<td>0.34</td>
</tr>
<tr>
<td>Tau</td>
<td>Mean On-task Duration</td>
<td>132</td>
<td>-0.0001(.0002)</td>
<td>0.06</td>
<td>0.81</td>
<td>0.05</td>
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<tr>
<td>Tau</td>
<td>Total Duration of Fidgeting</td>
<td>133</td>
<td>0.0001(.0001)</td>
<td>0.97</td>
<td>0.33</td>
<td>0.18</td>
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<tr>
<td>Accuracy</td>
<td>Mean On-task Duration</td>
<td>131</td>
<td>0.0001(.0001)</td>
<td>0.48</td>
<td>0.49</td>
<td>0.13</td>
</tr>
<tr>
<td>Accuracy</td>
<td>Total Duration of Fidgeting</td>
<td>132</td>
<td>-0.0001(.0001)</td>
<td>4.11</td>
<td>0.04</td>
<td>0.37</td>
</tr>
</tbody>
</table>

*Note.* Each of the neuropsychological variables was transformed before it was used in these models (natural log for CV and tau, arcsine for accuracy). Each least square mean and standard error estimate reflects this.