Differentiating between Children with and without ADHD Using the Delis-Kaplan Executive Function System and Conners' Continuous Performance Test-II

by

Sarah Nicolette Peden

A dissertation submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Doctor of Philosophy

Auburn, Alabama
December 13, 2010

Keywords: D-KEFS, Executive Functioning, ADHD, CCPT-II

Approved by

Steve Shapiro, Chair, Associate Professor of Psychology
Christopher Correia, Assistant Professor of Psychology
Martha Escobar, PhD, Assistant Professor of Psychology
Jennifer Gillis, Assistant Professor of Psychology

Abstract

The Delis-Kaplan Executive Function System (D-KEFS) is a relatively new measure of executive functioning (EF) that has not been fully evaluated for its potential of differentiating between children with and without ADHD. The Conners' Continuous Peformance Test (CCPT) is a computerized task that has been studied extensively in ADHD populations and been found to have moderate success at predicting diagnostic status. The present study examined diagnostic group differences on the D-KEFS and CCPT between children with ADHD (n = 32) and a control group (n = 37). Results replicate previous findings in both the D-KEFS and general EF literature (Corbett et al., 2009; Frazier et al., 2004; Wodka et al., 2008a; Wilcutt et al., 2005). Specifically, ADHD group performance on several measures of planning, reconstitution, and inhibition was found to be below average or significantly lower than that of the control group. Additionally, performance on most D-KEFS variables, including some less executive tasks, was associated with diagnostic group status. Inattentive and Hyperactive/Impulsive symptoms, as rated by parents on the CPRS, were significantly related to almost all D-KEFS variables. However, higher magnitude correlations between Inattention and the Trailmaking and Color-Word Interference tests were noted. On the CCPT, between-group differences were found for Hit Reaction Time Standard Error, Detectability, and Omission errors. Intercorrelations between the CCPT and CPRS symptom scales revealed Reaction Time variables related to both symptom domains, Omissions related to Inattention, and Detectability and Response Style related to Hyperactivity/Impulsivity. Significant correlations between several CCPT and D-KEFS variables were found, with some planning/inhibition/switching and more basic skill D-KEFS measures being associated with CCPT scores. Moderate predictive utility of diagnostic group was found for both the D-KEFS and CCPT individually. Combined predictive utility of both measures resulted in non-significant models. Recommendations are provided regarding the use of the D-KEFS and CCPT in evaluating ADHD, as well as important future research directions.

Acknowledgments

I wish to thank Steve Shapiro for his unfailing support and guidance throughout the dissertation process. Without the countless meetings, consideration of new ideas, hours of statistical analyses, and lengthy phone conferences, this project would never have seen completion. I also thank Steve for his mentorship and continued interest in my future career as a clinician and researcher. My doctoral committee members Chris Correia, Martha Escobar, Jen Gillis, and Joseph Buckhalt also deserve my appreciation. I appreciate their flexibility and helpful feedback. I also wish to thank Andy Cohen, Bill Ferguson, and Clarissa Mooney for their support in the Shapiro Lab meetings, as well as their assistance with project ideas and data collection. We all survived the Thach basement sauna! The data entry and checking efforts of Laura Coursen and Kristen Hiott are not to go unnoticed, as they diligently helped with the tedious aspects of the project. While on internship, many individuals provided insight and guidance for my project, including David Tupper, Pat McMahon, Andrea Szporn, and my fellow interns. Finally, this project would not have been completed without the financial assistance of the Brown Finch Foundation and the support of Emily Lambeth.

To Mom, Dad, and Luke, your support throughout the dissertation process, as well as all my years of schooling, has been incredible. Through the good times and trying times, you are always there to encourage me, cheer me up, and tell me how proud you are of me. I could not ask for a better family, as I know we can always count on each other. Mom and Dad, thank you for encouraging your children to follow their dreams and for providing guidance along the way.

Table of Contents

List of Tables

Introduction

Reflecting the substantial prevalence of and documented associated functional impairment, Attention-Deficit/Hyperactivity Disorder (ADHD) has been the focus of considerable psychological and medical research. Recent theories proposed by Barkley (1997; 2006) and others (e.g. Nigg, 2006) point to Executive Functioning (EF) as a particular area of interest in ADHD. Specifically, it is postulated that deficits in EF are key features of individuals who meet criteria for the disorder.

However, finding assessment tools to qualitatively and quantitatively measure a construct such as EF can be challenging. The incremental development of EF throughout childhood and adolescence further complicates the measurement of EF, as their skills may be more in flux than those of adults. Executive functioning is biologically based in the sense that the processes have been found to be regulated by the prefrontal cortex, inferior frontal junction, premotor cortex, anterior cingulate, and cerebellum (Davidson, Amso, Anderson, & Diamond, 2006). Thus, some neuroimaging techniques are available to measure brain function. However, most psychologists and neuropsychologists measure EF through a variety of cognitive tests, varying from hands-on manipulative tasks to computerized procedures. The purpose of this study is to explore the utility of a fairly new measure of EF, the Delis-Kaplan Executive Function System (D-KEFS; Delis, Kaplan & Kramer, 2001) in differentiating between children with and without ADHD. In addition, concurrent and incremental validity of a measure commonly used in ADHD evaluations, the Conners' Continuous Performance Test-II (CCPT-II; Conners, 1995), will be assessed.

Attention-Deficit/ Hyperactivity Disorder (ADHD)

ADHD is the most common neurodevelopmental disorder seen in psychology practice around the United States. Its prevalence varies by gender, age, social class, and population density, with 2-18% of children exhibiting clinically significant symptoms (Rowland, Lesene, & Abramowitz, 2002). Furthermore, males are generally more likely than females to meet diagnostic criteria, with a ratio of 3:1 in community samples and a range of 5:1 to 9:1 in clinical samples (American Psychiatric Association, 2000).

The *Diagnostic and Statistical Manual of Mental Disorders* (DSM-IV-TR; American Psychiatric Association [APA], 2000) characterizes ADHD along two symptom domains, inattention-disorganization and hyperactivity-impulsivity, which yields three clinical subtypes: Predominantly Inattentive (PI), Predominantly Hyperactive-Impulsive (HI), and Combined (C). These two symptom domains were derived from empirical studies and factor analysis of parent and teacher ratings in preparation for DSM-IV (Lahey, Applegate, McBurnett, Biederman, Greenhill, et al., 1994). Inattentive symptoms include daydreaming, "spacing out" or being "lost in a fog," staring frequently, and being easily confused, lethargic, and passive. Hyperactive-impulsive symptoms include being "always on the go" (e.g., always out of seat), acting as if driven by a motor (e.g., constantly moving arms and legs while at task), and acting impulsively (e.g., blurting out answers before questions are completed). The Combined subtype includes symptoms of both the Inattentive and Hyperactive-Impulsive variants.

What is Executive Functioning?

Executive functioning (EF) is the ability to maintain an appropriate and efficient problem-solving set for attainment of a future goal (Bianchi, 1922; Lezak, 1985; Luria, 1966). Brown (2006), in describing EF, uses a metaphor of a conductor of a symphony. Just as there are numerous parts of the brain that all function differently, so are there many musicians in a symphony. The role of the conductor is to integrate the functions of these musicians in the execution of a musical composition, from indicating when to start the piece, to keeping time, to modulating dynamics. The frontal lobe of the brain performs a similar function in that it helps to manage cognitive functions that assist in tasks such as programming and planning of goal-oriented motor skill behavior, modulation of behavior in light of expected future consequences, anticipation of events in the regulation of behavior, learning of contingency rules and the ability to use feedback cues, inhibition of response set and flexibility (versus perseveration), abstract reasoning, problem-solving, sustained attention, and concentration (Seguin, Phil, Harden, Tremblay, & Boulerice, 1995).

EF has been found to be a distinct set of cognitive skills when compared to intelligence. Although some skills may overlap, individuals who have sustained damage to areas of the prefrontal cortex show deficits in reasoning tasks related to EF while sustaining normal and intact levels of intelligence (Waltz, Knowlton, & Holyoak, 1999). Some investigators have found specific IQ test profiles that show lower performance by children with ADHD on the Arithmetic, Coding, Information, Digit Span, and Symbol Search subtests of the Wechsler intelligence tests (Dykman, Ackerman, & Oglesby, 1980). The overall IQ scores of these individuals are then lowered because of performance on these specific subtests. Besides the Information subtest, all others are part of the Working Memory or Processing Speed indexes of the WISC-IV (Wechsler Intelligence Scale for Children, Fourth Edition; Wechsler, 2003).

According to the Cattell-Horn-Carroll (CHC) theory of intelligence, general intelligence is a latent structure that includes performance in numerous areas of functioning (fluid reasoning, language knowledge and use, memory and learning, visual and auditory perceptive, retrieval ability, cognitive speed, and reaction time speed) (Carroll, 1993). Therefore, it is possible that children with ADHD have difficulty with some of these skills because they are very similar to those measured by EF tests. However, performance on these tasks is combined with that on verbal and perceptual reasoning tasks for an overall IQ score, which would then dilute the correlation between EF and intelligence. Schuck and Crinella (2005) found minimal correlations between EF measures and all subtests of the Wechsler Intelligence Scale for Children – Third Edition (WISC-III; Wechsler, 1992) in 123 boys with ADHD. Therefore, because intelligence is typically measured combining many factors of the CHC theory, the potential for high correlations with EF is lowered.

EF deficits have also been related to several psychological disorders and developmental delays, such as Attention-Deficit/Hyperactivity Disorder (ADHD) and autism (Pennington & Ozonoff, 1996). Individuals with ADHD, phenylketonuria (PKU), and specific learning disabilities have been found to have impaired levels of EF performance while exhibiting general intelligence within the normal range (Blair, Zelazo & Greenberg, 2005). Thus, measured intelligence can appear unaffected while measured EF can be much lower than expected given intelligence scores, suggesting that multiple cognitive processes are at work.

Theories of ADHD and Executive Functioning

Barkley's Theory of ADHD and EF

Barkley (1997; 2006) articulated an integrative theory of ADHD because he believed that the existing models of ADHD merely described two behavioral deficits (inattention and hyperactivity-impulsivity) and failed to account for many other cognitive and behavioral deficits associated with the disorder. Therefore, he set out to create a more unifying theory of the disorder, proposing that the primary deficit in ADHD is impairment in response inhibition, which leads to disruption in performance of EFs. Barkley (1997; 2006) posited that successful behavioral inhibition sets the stage for four executive functions to occur: nonverbal working memory, verbal working memory, self-regulation of affect/motivation/arousal, and reconstitution. Therefore, once a person successfully inhibits an automatic or ongoing response pattern, that individual may then proceed to the executive function processes. However, a person with ADHD is likely to have poor behavioral inhibition, leading to deficits in these areas of executive functioning which may lead to less overall success in the execution of goal-directed behavior.

Barkley (1997; 2006) defined behavioral inhibition as three interrelated processes: "(a) inhibition of the initial prepotent response to an event; (b) stopping of an ongoing response, which thereby permits a delay in the decision to respond; and (c) the protection of this period of delay and the self-directed responses that occur within it from disruption by competing events and responses" (p. 67). In this light, Barkley characterized the primary underlying mechanism of ADHD as a deficit in behavioral inhibition and executive control of behavior, through which inattention becomes a secondary symptom.

It is believed that behavioral inhibition is the first self-regulatory act in responding, as it allows more time to generate alternate responses, anticipate consequences of various responses, and make an appropriate choice of future behavior. Barkley (1997) asserted that the four executive functions affect two types of sustained attention: contingency-shaped and motor control. Specifically, he argued that immediate contextual factors (e.g., novelty of the task, reinforcement, and delay of reinforcement) govern the attention level demonstrated, which could then affect task performance. It has been found that performance of individuals with ADHD tends to be more easily influenced by these contextual factors (response contingencies) compared to normal control counterparts (Douglas, 1985; Haenlein & Caul, 1987).

Research findings indicate that the cognitive deficit seen in ADHD is at the motor control rather than the attentional or information-processing stage (Sergeant, 2005), which supports Barkley's assertion that inattention in ADHD is secondary to, and results from, deficits in behavioral inhibition. Specifically, in a review of the relationship between behavioral inhibition and ADHD, Nigg (2001) reported that there is more evidence to support the inhibitory deficit when it involves suppression of a pre-potent motor response, such as the Stop or Go/No-go tests, as opposed to secondary response inhibition, such as that measured by the Stroop test. Barkley also included a motor control aspect in which self-regulation, internal representation of motivation and goals, and novel chains of responses all influence the inhibition of impulsive motor behavior.

The first EF implicated in Barkley's theory is nonverbal working memory. Individuals with ADHD tend to have significant difficulties in nonverbal working memory when complex information must be held in mind over lengthy delays (Seidman, Biederman, & Faraone, 1995). Barkley (1997; 2006) suggested that this inability to hold information in mind can lead to impairments in imitating complex, novel, and lengthy behavioral sequences, temporal organization and regulation, and consequently, the disorganization of the syntax of motor planning and execution. Therefore, a deficiency in nonverbal working memory makes it difficult for those with ADHD to determine the times and places for appropriate and adaptive behavior, as well as the steps and sequences required to complete nonverbal tasks and activities.

The second EF proposed by Barkley is verbal working memory, which includes self-directed (internalized) speech, following rules, and moral reasoning (Kochanska, DeVet, & Goldman, 1994). Deficits in the internalization of speech have been seen among children with

ADHD who had difficulty complying with directions and commands, following rules when the rules competed with rewards available for rule violation, and transferring initially learned rules to novel tasks (Conte & Regehr, 1991; Danforth, Barkley, & Stokes, 1991; Hinshaw & Melnick, 1992). Therefore, Barkley (1997; 2006) suggested that people with ADHD show deficits in creating an internalized dialogue of what they *should* be doing and with keeping long sequences of verbal information in mind, especially when required to manipulate the information and use it for a task.

Next, Barkley implicated self-regulation of affect/motivation/arousal as an EF associated with ADHD, with deficits resulting in greater emotional reactivity, fewer anticipatory emotional reactions, less capacity to regulate emotional drive and motivation for future goals, and greater dependence on external sources for drive, motivation, and arousal. Therefore, Barkley argued that the behavior of people with ADHD is primarily under the control of immediate and external sources of reinforcement, rather than internal motivation.

Finally, Barkley included reconstitution as the fourth EF, which he described as the ability to create multiple, novel, complex, alternative response sequences. Researchers have found that people with ADHD perform poorly on verbal and organizational fluency tests (Grodzinsky & Diamond, 1992). Also included in this domain are analysis and synthesis of behavior, in which components or steps toward a response are broken down and reorganized based on the demands of a new task. Furthermore, planning and goal-directed behavior are important in reconstitution. Barkley reasoned that if a person has difficulty with behavioral inhibition, that person consequently may not be able to envision multiple behavioral responses and would have a deficit in the EF of reconstitution.

Nigg's Theory of ADHD and EF

Nigg (2006) set forth a similar theory of ADHD to Barkley's, implicating cognitive control, or EF, as primary deficits in the disorder. However, Nigg eliminates the hierarchy of behavioral inhibition with the other EFs and simply suggests that all aspects of EF are equally important. Nigg breaks down the cognitive control EFs into four areas: control of attention, control of motor response and behavior, working memory, and state regulation.

Nigg (2006) describes "control of attention" as important in selection and working memory, conflict detection, and control of interfering information/responses. Thus, this area of EF serves to filter competing information, suppress this information from working memory, and allow for more appropriate current responses. Nigg suggests that interference control and cognitive inhibition also fall into this category, in which one would put out of mind thoughts that are not relevant to the task and select appropriate cognitions to facilitate task completion. Nigg's *control of attention* category seems to fit most closely with Barkley's (2006) *verbal working memory* EF component in that both require the filtration of interfering cognitions for more task-appropriate thoughts.

Next, Nigg (2006) suggests that *control of motor response and behavior* is critical for the suppression or interruption of a prepared response, as well as the delay of any or all responding. This second area of "control" in Nigg's theory is more motor response and behaviorally oriented, rather than being cognitive and thought-process oriented. One must be able to stop a prepared or previously performed motor response in order to adapt to new task demands. Therefore, Nigg's description of this area maps on most closely to Barkley's (1997) description of behavioral inhibition.

Nigg's (2006) third EF in his theory of ADHD is *working memory*, which includes auditory, spatial, and location working memory. Specifically, Nigg asserts that working memory is distinct from interference control, as it involves additional demands such as the ability to manipulate information over a short period of time and protect it from interfering thoughts and stimuli. In addition, *planning* is included within the working memory domain and is described as the ability to mentally organize the steps for solving a problem and determining the appropriate sequence for these steps. Nigg's description of *working memory* seems to overlap most closely with Barkley's (2006) category of *nonverbal working memory.* However, with the addition of planning in Nigg's category, it may also include some of Barkley's *reconstitution* functions.

Finally, Nigg (2006) suggests state regulation to be the fourth EF in his theory, and it is described as activation, readiness to respond, or motor preparation. Furthermore, Nigg distinguishes activation from attention or vigilance in that it is the preparedness to respond and is not simply the overall alertness to surroundings. Nigg's proposed *state regulation* category of EF is most similar to Barkley's (2006) *self-regulation of affect/motivation/arousal*. Both describe the readiness to respond, where the brain and body have to be active and attentive to the task.

Other theories of ADHD

Some other theories are prominent in the ADHD literature, one of which is the dual pathway model (Sonuga-Barke, 2002, 2005). This model proposes two possible mechanisms toward ADHD: an inhibitory deficit and an altered reward/reinforcement deficit. The pathways are associated with two distinct subtypes of ADHD, one that results from dysregulation of action and poor inhibitory motor control and one that stems from delay aversion (preferring immediate small rewards over larger delayed rewards). The dysregulation of thought and action pathway

(DTAP) is characterized by disinhibition, which results in consequences for both behavioral (impulsiveness, inattention, hyperactivity) and cognitive (quality and quantity of task engagement) processes. This pathway is thought to be more biological and less context-dependent, and individuals with the DTAP form of ADHD are expected to be more generally cognitively impaired. The motivational style pathway (MSP) suggests that delay aversion is an acquired characteristic stemming from shortened dopaminergic reward circuits in the brain, combined with environmental factors. Tendency to be delay aversive is strengthened over time by an individual's experiences in situations where reward is delayed and reinforcement is given to shortening the delay (thus, a form of conditioning). It is suggested that delay aversion leads to both impulsivity and inattention, as an individual is likely to act quickly and impulsively if wanting rewards sooner and may also try to find stimulation in the environment to increase how "rewarding" a task is. Both pathways are proposed to be separate manifestations of ADHD symptoms, and Sonuga-Barke uses this multiple pathway model to possibly explain some of the inconsistencies in research on neuropsychological profiles of ADHD.

The other theory mentioned in ADHD literature is the cognitive-energetic model (Sergeant, 2005). This model includes deficits associated with ADHD on three levels: cognitive response output (encoding, search, decision, and motor organization), energetic activation and effort (effort, arousal, and activation), and EF control (planning, monitoring, detection of errors, and error correction). It is posited that ADHD results from the inability of an individual to modulate physiological state to meet task demands, with problems occurring at one or more of the three levels. Specifically, Sergeant posits that information processing is likely intact in individuals with ADHD, but that the failure of inhibition (or other EFs) might be a failure of the activation of the inhibitory mechanism (activation and effort factors) rather than a deficit in the inhibitory skill itself. Therefore, his theory combines factors from the more pure EF theories and the dual pathway model.

Developmental Considerations of Executive Functioning

EF skills, as noted earlier, have been found to be associated with brain activity in the prefrontal cortex, inferior frontal junction, premotor cortex, anterior cingulate, and cerebellum. With normal brain development, EF skills develop and become more fine-tuned throughout childhood and adolescence. Some researchers consider EF as a multi-faceted cognitive component in which different developmental trajectories occur and maturation is reached in stages (Anderson, Anderson & Lajoie, 1996). It has been found that the brain develops and fine-tunes itself in a back-to-front direction, beginning in the primary motor cortex, moving forward with the prefrontal cortex developing last (Gogtay, Giedd, Lusk, Hayashi, Greenstein, et al., 2004). Therefore, cognitive development follows the sequence of functional developmental milestones, such as primary motor and sensory development, then spatial orientation, speech, and language development. Finally, the executive function and attention areas seem to be the last to develop. Evolutionarily, this order makes sense because the least important skills for survival (EF) develop last, preceded by more basic human functions.

Barkley's and Nigg's theories provide a framework to examine the literature to-date that explores links between ADHD and EF, specifically in children. Developmental considerations are particularly important in examining the reliability and validity of using EF tasks because of the wide variety of measures used. Additionally, some EF tasks seem to measure abilities that are not yet formed in younger children. Therefore, it is critical to understand the applicability of such tests within a developmental framework before using them for research or diagnostic purposes.

ADHD is described as a disorder of developmental deficits of EF, such that children may not perform comparably to their same-age counterparts on various measures of EF. This is not to say that individuals with ADHD will never have the EF skills, but rather, that they will likely fall behind their peers in EF development. Furthermore, deficits of EF implicated in children with ADHD may vary across the age groups, and distinct deficits may manifest themselves at different ages or developmental stages. For example, Brocki and Bohlin (2006) found that younger children's (ages 6.0 to 9.7) ADHD symptoms were related to their performance on tasks of inhibition; whereas, these tasks did not predict ADHD symptoms in the older age group (9.8 to 13.0 years). The older group's ADHD symptoms were significantly related to verbal working memory, fluency, and speed/arousal, while these EFs did not predict ADHD symptoms in the younger group.

Associations between EF Measures of Behavioral Inhibition and Planning/Reconstitution and ADHD in Children

An underlying EF deficit in ADHD that spans across both Barkley's (2006) and Nigg's (2006) models is that of inhibiting prepotent, automatic responses for more appropriate, planned responses. Barkley describes this construct as behavioral inhibition whereas Nigg terms it "control of motor response and behavior." When approaching goal-directed behavior, a person is required to inhibit inappropriate responses while at the same time keeping in mind the rules of the task and planning more accurate, situation-specific responses. Therefore, reconstitution and planning are also an important part of goal-directed behavior. A number of research studies suggest EF deficits in both behavioral inhibition and reconstitution/planning in individuals with ADHD, and these will be described below. Because of the natural link between these two aspects of EF, they have been chosen to be the main focus of this current study.

One difficulty with studying EF is that many tasks overlap by measuring several EFs. Due to the focus of the current study, EF measures have been chosen based on their historical and theoretical association with behavioral inhibition or reconstitution/planning. Specifically, the D-KEFS (Delis, et al., 2001) incorporates a standardized scoring procedure across various well-established tasks of EF that will be reviewed below. Furthermore, the D-KEFS produces scores for separate tasks within subtests, which allows for description of both EFs, as well as the more basic non-EF cognitive processes. Therefore, separate processes within subtests and their relationship to ADHD can be explored. Given significant results from research with older measures of EF and ADHD, the next logical step is to explore the relationship between the D-

KEFS and ADHD, since the subtests on the D-KEFS are derived from established EF tasks.

Two extensive meta-analyses were recently conducted with a variety of EF measures and their relationship to ADHD (Frazier, Demaree, & Youngstrom, 2004; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Frazier et al. (2004) analyzed 123 studies that each included a control group and an ADHD group (diagnosed by DSM-III, III-R, or IV criteria). Effects were combined for all ADHD subtypes, and weighted mean effect sizes for the 11 reported measures of EF ranged from small to medium, with only one from the CPT falling in the large range. Willcutt et al. (2005) analyzed a total of 83 studies that included 13 measures of EF. Standardized effect sizes were calculated for a group of all ADHD subtypes (diagnosed by DSM-III, III-R, or IV criteria, ICD-10 criteria, or rating scales) versus a control group, and all effect sizes fell within the medium range. Weighted mean effect sizes for all EF variables from both meta-analyses are included in Table A1, and individual results will be discussed within each section below as the evaluation measure is presented. The predictive utility of several EF variables are included in Table A2.

Behavioral Inhibition (Control of Motor Response and Behavior)

Continuous Performance Tasks. Several studies have examined behavioral inhibition in children with ADHD using continuous performance, go/no-go, and stop tasks that require motor inhibition and the ability to control response perseveration. Continuous performance tasks (CPT), typically administered on a computer, examine motor inhibition, perseveration, and attention. There are several variations of the task, including the Stop signal and Go/No-go measures. The Stop Signal Task (Logan, Schachar, & Tannock, 1997) requires participants to press a key when the letter X or O appears on the screen (go trial) and inhibit responding when a tone is presented immediately prior to the letter (stop trial). Another example of one of these measures is the Conners' Continuous Performance Test-II (CCPT-II; Conners, 1995) in which examinees are required to respond to all letters that appear on the screen except for the letter "X," for which a response should be inhibited. The Go/No-go task requires motor responses to red and blue colored squares appearing on the screen, such that the participant must determine a rule for responding (i.e. response to red squares, no response to blue squares) (Drewe, 1975).

In an epidemiological study, 816 children completed the CCPT (Conners et al., 2003). Twenty-one children met criteria for diagnosis of ADHD, and their performance was compared to that of nondiagnosed children. Results revealed significantly worse performance by the ADHD group on Hit Reaction Time Standard Error (RT SE), errors of commission, errors of omission, and detectability (d'). Reaction Time (RT) and Response Style (B) were also reported, as they were considered by the authors as primary response measures; however, no differences in group performance were noted on these two variables. Explanation of the CCPT variables can be found in Table 4, where they are outlined for use in the current study. Relationship between CCPT variables and specific ADHD symptoms was explored for the same sample by Epstein et al. (2003), with Hit RT SE, commission, omission, detectability, and response style demonstrating relationships across the ADHD symptom domains (inattention, hyperactivity, and impulsivity). Detectability and response style showed the strongest relationship with ADHD symptoms.

In a rare study that included all female participants (Hinshaw, Carte, Sami, Treuting, & Zupan, 2002), the CCPT was administered to girls ages 6 to 12 years with ADHD-C (n=93), ADHD-PI (n=47), and an age- and ethnicity-matched control group (n=88). Results indicated that the ADHD-C and ADHD-PI groups performed significantly worse than controls on CPT commission errors. Furthermore, the ADHD-C group had significantly more commission errors than the ADHD-PI group.

Wodka and colleagues (2007) administered three variations of go/no-go tests to children with ADHD (n=58; CT=35, HI=3, PI=20; 52.4% male) and controls (n=84; 62.1% male). One task was the typical "motor" go/no-go task, whereas the other two required either more cognitive effort (refrain from pressing the button when the red spaceship was preceded by an odd number of green spaceships) or was motivation-linked (a screen indicated whether points were gained or lost based on accuracy and speed). Covarying age, children with ADHD had more commission errors and had greater reaction time variability than controls on the basic go/no-go task. However, no differences were found for omissions or response time, and no gender differences were noted. The cognitive go/no-go task produced a significant difference in commission errors for the ADHD group, and no effects for omissions, response time, and reaction time variability were noted. Furthermore, gender differences were noted such that boys made significantly more commission errors and had greater reaction time variability than girls. On the motivational go/no-go task, ADHD children made more omissions and commissions and showed greater reaction time than controls. No significant differences were noted for any of the measures between ADHD subtypes.

Meta-analyses have been conducted on a variety of inhibition measures. CPT commission errors (responding to the stimulus when inappropriate) and omission errors (not responding to the stimulus when response is required) indicated moderate effect sizes in differentiating between ADHD and non-ADHD groups (Frazier et al., 2004; Willcutt et al., 2005; see Table 1). CPT hits (number of hits recorded) received the largest weighted mean effect size of all EF measures evaluated (Frazier et al., 2004). However, all CPT variables analyzed by Frazier et al. (2004) had heterogeneous effect sizes, indicating that the results were inconsistent across studies. Stop-signal task reaction times produced medium effect sizes across studies, with homogeneous distribution (see Table 1). Therefore, according to these meta-analyses, stop-signal tasks may be more efficient and accurate in differentiating between ADHD and control groups than the CPT, as the effects were more homogeneous across studies.

A different, non-computerized, continuous performance task was used in a study comparing 6 girls and 19 boys with ADHD CT to age and sex matched controls (Klimkeit, Mattingley, Sheppard, Lee, & Bradshaw, 2005). This selective reaching task required responding as rapidly as possible to a target, which could appear to the left or right of fixation, while at times having to ignore a simultaneous distractor. Scoring procedures allowed for parsing out of reaction and movement times as control measures. Results indicated that unmedicated children with ADHD showed significantly slower reaction times than controls but were not impaired in movement execution time. They also made more inattentive (misses) and impulsive (premature responses) errors. In all of these measures, medicated ADHD participants performed similarly to control participants, indicating that stimulant medication proved beneficial to task performance. However, the medicated group was composed of only 7 children, possibly limiting the significance of this finding.

Stroop Color-Word Test. The Stroop Color-Word Test has been described as a measure of selective attention and response inhibition (Stroop, 1935). Scoring is typically calculated based on the time required to complete the task. Often, three tasks are administered in the Stroop Test: naming colors of printed squares, reading names of colors written in black ink, and the interference task (which assesses color-word interference skills by presenting a subject with a series of names of colors written in ink of non-congruent colors). In the latter task, the participant is required to name the color of the printed ink and inhibit the more automatic response of reading the word.

A meta-analysis of seventeen independent studies that implemented the Stroop Color-Word Test was conducted to determine the overall evidence for deficits in interference control in individuals with ADHD aged 6-27 years (van Mourik, Oosterlaan, & Sergeant, 2005). The analysis took into account only studies that used an interference score calculated in one of two ways: subtracting the color-word card score from the score on the color card (C – CW) and the Golden method in which correction for color naming and word reading is taken into account (CW score – [(W score * C score) ÷ (W score + C score)] (Golden, 1978). Participants in each study included at least one ADHD group and a comparison group of normal controls. Results of the meta-analysis indicate a small (.35) but significant effect size for interference scores and a heterogeneous distribution of effect sizes across studies, with eight studies having an effect size of zero. Therefore, the authors conclude that the Stroop Test may not be a valid measure of interference or inhibitory control deficits in ADHD.

Van Mourik et al. (2005) attribute the lack of consistency in findings comparing Stroop performance in individuals with and without ADHD to the method used to calculate interference scores. They found the effect size for C – CW non-significant and heterogeneous (.26; $p = .04$) and the effect size for the Golden method as significant but also heterogeneous (.40; $p = .01$). In terms of ADHD subtypes, three studies compared children with ADHD PI and ADHD CT (Houghton, Douglas, West, Whiting, Wall, et al., 1999; Nigg, Blaskey, Huang-Pollock, & Rappley, 2002; Scheres, Oosterlaan, Geurts, Morein-Zamir, Meiran, et al., 2004), all finding no differences. However, results of the meta-analysis indicate a small but significant and homogeneous effect size, suggesting that children with ADHD PI perform worse on measured interference than children with the CT. Thus, the Stroop test may be beneficial in distinguishing between ADHD subtypes even though it does not seem to be able to accurately differentiate between ADHD children and controls. It is possible that individuals with PI have a more pronounced deficit associated with this task, and, since many of the studies combine ADHD subtypes into one group, this effect may have been lost. Further research comparing ADHD subtypes on the Stroop task could help illuminate the conflicting results.

Reconstitution/Planning

Tower Tests. Several tests are typically used to examine reconstitution or planning, such as tower tests, mazes, trailmaking, and card sorting tasks. The Tower of Hanoi or Tower of London tasks (TOH; Borys, Spitz, & Dorans, 1982; TOL; Culbertson & Zillmer, 1999; Shallice, 1982) measure planning, problem-solving, inhibition, and working memory using three colored beads that can be placed on pegs of three different heights. Participants are required to match a prescribed pattern of beads on the pegs by following set rules, and they are graded on number of moves, difficulty of problem, and time taken to make the first move (initial planning time). Meta-analyses of the tower tests indicated medium effect sizes (.51 and .69) for distinguishing between ADHD and control groups (Willcutt et al., 2005).

A computerized version of the Tower of London (TOL) task, which measures planning, problem-solving, inhibition, and working memory, was used to assess 103 children aged 7 to 15 years with only ADHD and ADHD with comorbid disorders. Sixty-nine boys and 26 girls were included in the study, and results indicated a gradual decrease in initiation time as children got older. Furthermore, boys were found to have a shorter total initiation time than girls, indicating that boys' EFs of planning and inhibition might mature at a slower rate than girls. No significant effects in performance on the TOL were noted for comorbid disruptive behavior, anxiety, or mood disorders (Sarkis, Sarkis, Marshall, & Archer, 2005).

Trail Making Tests. Trail Making tests are part of the Halstead-Reitan Neuropsychological Test Battery (Reitan & Wolfson, 1985), and they are often used to examine set-shifting, sequencing, and mental flexibility. Two tasks are typically presented, one in which the individual is required to use a pencil to connect numbers (part A) and one in which the requirement is to connect a series of numbers and letters in ascending order, alternating between numbers and letters (part B). The task demands of the Trail Making Test necessitate visual search and motor skills as well. Since the typical scoring procedure is based on time taken for task completion, true measurement of the EFs versus fine motor skills and speed of responding is questionable.

Meta-analyses of the Trail Making Test indicated a small effect size for Trails A (.40) and medium effect sizes for Trails B (.59 and .55) when comparing ADHD children to normal controls (Frazier et al., 2004; Willcutt et al., 2005). In an independent study looking at ADHD and control twin pairs (ages 8-18 years), results indicated a significant difference between controls and ADHD children on Trails B (d=.69) (Bidwell et al., 2007). Additionally, a small effect size (.39) was noted between non-ADHD co-twins and their ADHD siblings.

Controlled Oral Word Association Test. The Controlled Oral Word Association Test (COWAT; Benton & Hamsher, 1976) examines verbal working memory and fluency skills by requiring the individual to generate as many words as possible beginning with certain letters (F, A, S) in one minute, a measure of effortful phonemic word fluency. Since the original task, versions measuring semantic fluency have also been developed, in which the individual is required to generate items from overlearned concepts, such as animals or things to eat (category) (Newcombe, 1969). In addition, a condition requiring simultaneous switching between two semantic (overlearned) categories was included on some versions (Newcombe, 1969). The EF assessment measure being used in the current study (D-KEFS) includes the category switching component of the Verbal Fluency subtest, in which an individual is required to switch back and forth between naming fruits and pieces of furniture. This additional trial requires the EF of reconstitution and planning, as the new rules must be kept in mind and responses are planned accordingly. Thus, a review of the COWAT tests as a measure of EF deficits in individuals with ADHD is being included, despite the lack of the switching aspect on the most commonly used versions of the test.

Brocki and Bohlin (2006) combined Digit Span and COWAT z-scores from their sample to form a verbal working memory/fluency composite score, and this composite significantly predicted ADHD inattentive (but not hyperactive/impulsive) symptoms. Separate regression analyses were performed for each age group, which were formed by median split of age distribution. Results revealed that verbal working memory/fluency was only predictive of these symptoms in the older age group (9.8 to 13 year olds) and not in the younger age group (6 to 9.7 year olds). The authors give two hypotheses that could account for these results: 1) the abilities are not yet fully formed in the younger children, and there may be little or no variation in scores (i.e. tasks are too difficult) or 2) verbal working memory deficits are only apparent in older children with ADHD compared to normal controls because their development in this area of EF is significantly delayed.

Delis-Kaplan Executive Function System (D-KEFS)

A recently developed measure of EF is the Delis-Kaplan Executive Function System (D-KEFS). The D-KEFS (Delis et al., 2001) is a nine-test battery that assesses key components of executive functions, including flexibility of thinking, inhibition, problem solving, planning, impulse control, concept formation, abstract thinking, and creativity in both verbal and spatial modalities. Several of the tests are similar to existing and well-established measures of executive functioning described above. The standardization on a contemporary stratified sample of children, adolescents, and adults (n = 1,750) is one of several practical and empirical advantages of this instrument. Standard scores are available for individuals between the ages of 8 and 89 years, thus reflecting developmental trends and the applicability of tasks for children under 8 years of age. Norms were developed specifically for each age year from 8 years to 15 years, which allows for more age-specific information on EF and reflects rapid developmental changes in EF for this age group.

The D-KEFS manual provides some evidence of reliability and validity (Delis et al., 2001). Internal consistency values included split-half reliability estimates within each subtest that ranged from moderate to high for the tasks being used in the current study. Test-retest reliability estimates range from low to high (.20 to .90), suggesting the relative stability of most of the constructs being measured over time. See Table A3 for a summary of scores presented throughout the D-KEFS manual. The authors also noted that practice effects were observed across measures, as performance improved from the first to the second testing session for virtually all variables. Alternate forms are available in order to minimize the effects of readministration.

Minimal evidence for convergent and discriminant validity was presented in the D-KEFS manual. The authors presented correlations between an early version of the D-KEFS sorting test (*California Card Sorting Test*; CCST) and the Wisconsin Card Sorting Test (WCST) with a small sample (n = 23), and they found moderate correlations. The CCST was also used in several other validity studies, described in the D-KEFS manual, in which patients with frontal lobe lesions, Korsakoff syndrome, Parkinson's disease, chronic alcoholism, and schizophrenia all exhibited lower levels of performance on the task than healthy adults. In addition, D-KEFS performance was compared to that on the California Verbal Learning Test – 2nd Edition (CVLT-II) in a sample of 292 adults, with generally non-significant correlations suggestive of discriminant validity.

Since the D-KEFS is a relatively new measure, limited independent research is available on its reliability and validity in measuring EF in children and adolescents. A study comparing the Woodcock Johnson III Tests of Cognitive Abilities (WJ COG-III; Woodcock, McGrew, & Mather, 2001) and the D-KEFS suggested moderate correlations between measures (Floyd, McCormack, Ingram, Davis, Bergeron, et al., 2006). The Color-Word Interference, Design Fluency, Verbal Fluency, and Trail Making tests were administered to 12 high-functioning adults and adolescents with autistic disorder or Asperger's disorder (Kleinhans, Akshoomoff, & Delis, 2005). Results indicated significantly lower performance on an aggregated EF score than the normative sample. Children with prenatal alcohol exposure have also been found to perform lower than normative controls on the Trail Making, Color-Word, Tower, Word Context, Verbal Fluency, and Design Fluency subtests of the D-KEFS (Mattson, Goodman, Caine, Delis, & Riley, 1999; Schonfield, Mattson, Lang, Delis, & Riley, 2001). In addition, children ages 8 to 16 years who met criteria for a fetal alcohol spectrum disorder, performed significantly lower than the normative mean on the Trail Making letter sequencing and number-letter switching tests, the Verbal Fluency letter fluency and category switching tasks, and all conditions of the Color-Word Interference test (Rasmussen & Bisanz, 2009).

A recent study used four subtests of the D-KEFS (Color-Word Interference, Trail Making, Tower, and Verbal Fluency) to predict ADHD in boys and girls aged 8-16 years (Wodka, Loftis, Mostofsky, Prahme, Larson, et al., 2008a). Comparison of ADHD (n = 54; 59% boys) versus control (n = 69; 51% boys) groups revealed poorer performance by the ADHD group on only the Color-Word Interference (Color Naming, Word Reading, Inhibition, and Inhibition Switching) and Tower (total achievement) tests. However, even though ADHD participants performed worse on these subtests, all scores were still within average range for both control and ADHD participants. Furthermore, prediction of ADHD in girls resulted in 67.3% being accurately classified based on contribution from scores on the Tower test and Trail Making test. Boys with ADHD were accurately classified at 58.5%, solely based on the Combined Color Naming + Reading Composite score on Color-Word Interference.

Another study analyzed the ‘process’ scores from the same participants’ performance on the D-KEFS (Wodka, Mostofsky, Prahme, Larson, Loftis, et al, 2008b). They found no significant group, sex, or ADHD subtype effects; however, a significant interaction for Verbal Fluency Total Repetition Errors emerged. Specifically, boys with ADHD-HI performed better than girls with ADHD-C. On the other hand, girls with ADHD-PI performed better than boys with ADHD-PI. Overall, the authors concluded that these subtests of the D-KEFS did not provide sufficient predictive power to be used alone in identifying ADHD. Furthermore, the process scores did not prove useful in distinguishing between ADHD and control groups. Several limitations to their sample included the use of a “pure ADHD” sample, thus ruling out participants with all other often comorbid disorders except Specific Phobias and Oppositional Defiant Disorder. Additionally, the majority of participants were Caucasian, limiting the generalizability of findings across ethnic groups. Finally, both groups had above-average IQ scores, and the authors cited literature suggesting lower sensitivity of EF measures in individuals with higher IQs.

Another study examined EF performance (which included some D-KEFS subtests) between typically developing children, those with ADHD, and those with Autism Spectrum Disorders (ASD) (Corbett, Constantine, Hendren, Rocke, & Ozonoff, 2009). MANCOVAs were conducted using IQ as a covariate. Children with ASD performed significantly worse than controls on the Color-Word Interference Inhibition and Letter Fluency tasks. The ASD group also performed significantly worse than ADHD participants on the Verbal Fluency Category Switching condition. No differences between ADHD and control groups were noted on the above measures, nor on the Category Fluency condition.

Based on the standardization across EF tasks that are similar to older, more widely used EF measures, the use of the D-KEFS to study EF deficits in ADHD seems warranted. The D-KEFS allows for intra- and inter-individual comparisons across tasks that tap into distinct EFs, hopefully providing a clearer picture of the relationship between EF and ADHD. 'Contrast' and process scores are generated by the D-KEFS scoring software, which describe various aspects of performance on each D-KEFS test. Therefore, the utility of the D-KEFS should be higher than that of previous measures of EF that did not separate the tasks into specific components. However, further research is warranted to establish the utility of the D-KEFS in examining EF, particularly in a sample of children with ADHD. Independent research, as well as evidence from the D-KEFS manual, suggests adequate psychometric properties of the variables to be used from this measure. Therefore, the current study built upon these findings to further explore the utility of the D-KEFS.

Rationale for the Current Study

Several limitations in the current literature linking ADHD and EF deficits should be noted in order to focus future research in a direction that will be most beneficial to the field. First, measures of EF seem to have adequate positive predictive power (i.e. probability of having the disorder if exhibiting the symptoms). However, they also have poor negative predictive power, suggesting that individuals with ADHD may not exhibit all of the associated symptoms. In this case, EF performance is expected to be lower in people who are diagnosed with ADHD. In addition, many of the EF tests exhibit low sensitivity, indicating that ADHD diagnosis does not always predict abnormal EF scores. Finally, specificity seems to be good in that individuals with normal test scores typically do not meet criteria for diagnosis.

Table A2 highlights these predictive statistics for several EF tasks in which cutoff criteria were based on ADHD scores that were 1.5 SD above or below the mean of controls (Doyle, Biederman, Seidman, Weber, & Faraone, 2000; Grodzinsky & Barkley, 1999). Grodzinsky and Barkley's study (1999) had a sample of 66 boys with ADHD and 64 control boys, all aged 6-11 years. The Doyle et al. (2000) study included boys ages 6 to 17 years with ADHD (n=113) and without ADHD (n=103). Neither study specified ADHD groups by subtype. Judging by these results, EF deficits do not seem to be necessary nor sufficient in order to render a diagnosis of ADHD, given the current EF testing measures' poor discriminative validity (Seidman, 2006). Whereas 5-10% of controls typically exhibit abnormal EF scores across measures, 30-50% of individuals with ADHD have been found to display some type of EF deficit (Doyle et al., 2000). Further research is necessary to determine if there is a subtype of ADHD that includes EF deficits or if the current tasks designed to measure EFs are not tapping into the areas that are most specifically impaired in individuals with ADHD. The D-KEFS will hopefully shed some light onto this matter, as it generates scores for individual components of each subtest that might allow for better discrimination between ADHD and control groups, suggesting that components rather than broad processes are contributing factors.

Many of the instruments used to measure EF in children pose potential problems for research in this area. A significant conceptual issue with EF tasks is that some of them require the use of several skills, such as the EFs of planning, organization, or inhibition but also other skills like reading, visual and auditory processing, and motor responding. Furthermore, numerous measures and tasks are available to test EFs (as evident by the review above), which poses a problem for consistency and consensus across researchers. Some newer measures, such as the D-KEFS (Delis et al., 2001), include scores on separate tasks within subtests, such as reading, speed of processing, and similar concepts that can be taken into account for analyses to better differentiate between more basic processes or higher order EF processes.

Another limitation with research in this area is that, across studies, identical EF measures (e.g. the Stroop test) may be scored using various techniques, or scores may be aggregated or manipulated in some other way prior to analyses that makes comparison of results difficult. Use of measures with standardized scoring procedures and multi-domain scores that can be compared intra-individual would alleviate this issue. Thus, the D-KEFS is a logical choice to address previous scoring irregularities in the literature.

Furthermore, most EF assessment tools used with children were originally designed for adults. Developmental considerations are critical in this area because of the research cited earlier that clearly shows that EF capabilities become more refined and efficient throughout childhood and adolescence. Therefore, measures originally created to assess adult levels of EF may not be sensitive to the more subtle differences that develop between age groups in children. In addition, some tasks, such as the Stroop test, require non-EF abilities like reading, which eliminates any utility this test would provide in examining EFs in children who are too young to read. The D-KEFS standardization sample included children of each age level from 8 years to 15 years, thus establishing individual age-based norms. Age-based norms are critical in understanding developmentally appropriate performance on a measure, and the D-KEFS aptly takes this into account. Previous literature suggests that skills for some tests of EF, such as the Stroop test, do not develop until age 7 or 8 years. Thus, the developers of the D-KEFS did not norm their measure on children younger than 8 years.

The current study takes into account the limitations of EF and ADHD research to-date, exploring EF performance in children with and without ADHD. Specifically, the D-KEFS, a relatively new assessment battery, was used. The D-KEFS incorporates well-established measures of EF, has standardized scoring, and has been normed on an age-stratified sample. Furthermore, performance on a basic test of behavioral inhibition (CCPT-II) was compared with that on a measure of more complex EFs (D-KEFS) to determine concurrent as well as incremental validity in predicting ADHD. The measures used in this study have been normed on children as young as 8 years old, which suggests that children of that age are able to comprehend and complete the tasks. Finally, the D-KEFS provides scores for the more basic tasks (e.g. motor speed, reading) within subtests that can help parse out the influence of basic skills on the more complex EF tasks.

Hypotheses for the Current Study

Several hypotheses were tested in this study. First, the relationship between diagnostic group and performance on EF measures was explored. Specifically, it was expected that individuals with ADHD would perform significantly worse than controls on measured variables of complex EF (inhibition/switching), but not on measures of the less executive aspects of a task (reading, number sequencing, etc.). Furthermore, more severe ADHD symptoms, as measured by the CPRS, were expected to be associated with more deficient EF performance. CCPT-II performance on all variables measured was expected to be worse for the ADHD group, as various research groups have found CPT performance deficits across variables (Conners et al., 2003; Frazier et al., 2004).

Next, concurrent validity between D-KEFS 'inhibition' measures and the CCPT-II was evaluated. It was hypothesized that scores measuring inhibition on the D-KEFS and scores on the CCPT-II would be moderately correlated.

In addition, utility of all study measures in predicting ADHD versus control group membership was explored. It was expected that the D-KEFS variables that include inhibition and planning components would significantly contribute to group prediction. Specifically, results from Wodka et al. (2008a) suggest that scores from the Tower Test and Color-Word Interference subtests would significantly predict groups. It was also expected that CCPT-II scores would accurately predict group membership based on previous research that found omission errors, commission errors, and hits to significantly differentiate between ADHD and controls (Frazier et al., 2004; Willcutt et al., 2005). Additionally, it was hypothesized that combining D-KEFS and CCPT-II scores would increase the utility of predicting ADHD versus control group membership.

Finally, analyses were conducted to explore the prediction of ADHD symptoms based on age. Given Brocki and Bohlin's (2006) research, it was expected that younger children's ADHD symptoms would be more related to performance on inhibition measures; whereas older children's ADHD symptoms would be predicted by verbal working memory, fluency, and speed/arousal scores.

Method

Participants

Participants included children with and without ADHD ranging in age from 8 years to 14 years. The use of this age range was to facilitate a sample that might allow for age group comparisons and sufficient distribution characteristics. Eight years was selected as the lowest end of the spectrum due to D-KEFS norms beginning at that age. Fourteen years was selected at the highest end of the spectrum as the sample would then extend through elementary and middle-school age groups, and would exclude individuals in junior high and high school. Typically, adolescents begin high school around the age of 15 years, and recruitment of the high school population is difficult due to increased independence and higher levels of involvement in extracurricular activities. Therefore, in expectation of possible recruitment difficulties with older adolescents, it was decided to stop recruitment at age 14 years.

Recruitment occurred via flyers distributed to local agencies, including physicians' offices, gyms, recreation centers, daycare centers, elementary schools, and mental health professionals. Furthermore, participants in the study were given flyers to pass on to friends or family members who might be interested. Approval was obtained from the Auburn University Institutional Review Board.

Parents or guardians who were interested in their children participating in the study completed a screening packet, which included a demographic questionnaire (see Appendix B) and the CPRS-R:L (Conners, 2000). Inclusion criteria for the ADHD group required endorsement of a prior ADHD diagnosis and scores 1.5 or more standard deviations above the mean on the CPRS-R:L *DSM-IV Inattentive Symptoms Scale* and/or *DSM-IV Hyperactive/Impulsive Symptoms Scale.* Children who were currently taking short-acting psychostimulant medication for ADHD were eligible for the study, and their parents/guardians were instructed to complete the CPRS-R:L based on the child's behavior while unmedicated. Membership in the control group required a child to have no prior diagnosis of ADHD and scores no more than 1 standard deviation above the mean on the CPRS-R subscales noted above. Exclusion criteria for both groups included current use of any long-acting psychotropic medication, uncorrected vision, history of seizures, brain damage, or psychosis.

Of note, ADHD assessment practices typically include a comprehensive evaluation for clinical purposes but have focused on a DSM-based norm-referenced scale for research purposes (Pelham, Fabiano, & Massetti, 2005). In addition, previous research using ADHD rating scales for diagnostic purposes has primarily been validated with maternal parent report, and no incremental utility has been found when combining parent ratings with structured interviews (Pelham, et al., 2005). Therefore, the current study used previously validated rating scale procedures in verifying ADHD symptom criteria and attempted to garner maternal report unless the child was not in the mother's custody.

Thirty-two children with ADHD and thirty-seven children without ADHD met study criteria and completed the laboratory portion of the study. One Caucasian female ADHD participant was excluded from analyses because her full-scale IQ (standard score = 134)resulted in violating the assumption of homogeneity of variance of IQ scores across diagnosis and sex defined groups. All statistical analyses were run with and without her in them, and no significant changes were noted in the results.

Table 1 presents diagnostic and sex group descriptive statistics. Of the 32 children with

ADHD, scores on the CPRS indicated 5 displaying significant level of symptoms consistent with meeting criteria for ADHD-H, 4 for ADHD-I, and 23 for ADHD-C. MANOVA produced significant diagnostic group differences on mean CPRS scores for the Inattentive symptoms and the Hyperactive/Impulsive symptoms subscales, with parents of children with ADHD reporting higher symptom levels, $F(2, 66) = 201.7$, $p < .001$ (Table 2).

Control participants were matched as best as possible for age and sex. The ADHD group included 27 males and 5 females, with a mean age of 10.8 years (SD = 1.97). The control group included 28 males and 9 females, with a mean age of 11.1 years (SD = 1.98). No diagnostic group differences were found for age, $t(67) = -0.60$, $p > .05$, and proportion of sex, $\chi^2(1, N = 69) = 0.80$, $p > .05$. The ADHD group included 18 Caucasian and 14 African-American participants; whereas, the control group included 31 Caucasian and 6 African-American participants. This resulted in a significant between-group difference in the proportion of race, $\chi^2(1, N = 69) = 6.32$, $p < .05$.

Full-scale IQ, as measured by the WASI, produced significant diagnostic group differences, $t(67) = -3.53$, $p = .001$, with the ADHD group mean of 99.1 (SD = 15.8) and the control group mean of 112.9 (SD = 16.6). In addition, significant IQ differences by race were noted, $t(67) = 4.96$, $p <.001$, as the mean IQ for Caucasian participants was 112.2 (SD = 16.0) and African American participants was 92.4 (SD = 12.6). However, the interaction between diagnostic group and race for IQ was not significant, $F(3,65) = .388$, $p = .762$.

Table 1. Diagnostic Group Descriptives

	ADHD Group (n =32) *Mean (SD)*		Control Group (n = 37) *Mean (SD)*	
Sex	Male (n=27)	Female (n=5)	Male (n=28)	Female (n=9)
Age in years	10.8 (0.40)	9.9 (0.90)	11.2 (0.38)	10.5 (0.67)
Verbal IQ	102.2 (16.2)	85.0 (8.1)	111.9 (18.5)	115.7 (13.2)
Performance IQ	100.8(16.0)	88.2 (13.3)	109.7 (14.4)	112.3 (15.4)
Full Scale IQ	101.7 (15.4)	85.0 (10.2)	111.9 (17.2)	115.9 (15.1)
CPRS – Inattention T-score	72.0 (6.8)	77.6 (14.7)	46.3 (5.6)	46.3 (4.2)
CPRS – Hyperactivity-Impulsivity T-score	76.6 (11.3)	85.2 (9.1)	47.0 (4.3)	47.7 (4.3)

Table 2. CPRS Group Comparison

CPRS Scale	ADHD Group *Mean (SD)*	Control Group *Mean (SD)*	Univariate F
Inattention T-score	72.9 (8.4)	46.3 (5.3)	254.7***
Hyperactivity-Impulsivity T-score	78.0 (11.3)	47.2 (4.2)	237.4***

*** $p < .001$

Measures

Conners' Parent Rating Scales-Revised, Long Form. (CPRS-R:L). The CPRS-R:L (Conners, 2000) is a norm-referenced questionnaire that assesses for core DSM-IV symptoms of ADHD and related problem areas. Reviews of evidence-based ADHD assessment indicate that the CPRS-R:L is one of the most widely used rating scales for this purpose and has the benefits of a large standardization sample (2,482 children and adolescents; 3 to 17 years), ease of administration and interpretation, and sound psychometric properties (Collett, Ohan, & Myers, 2003; Conners, 2000). Specifically, test-retest reliability coefficients after 6 to 8 weeks ranged from .73 to .94, and internal consistency Cronbach's alpha coefficients ranged from .47 to .85 (Collett et al., 2003). In addition, the CPRS-R technical manual reports on acceptable levels of internal, convergent, and divergent validity, as well as discriminative validity between children with and without ADHD (Conners, 2000). Subscales used in this study included *DSM-IV*

Inattentive Symptoms Scale, the *DSM-IV Hyperactive/Impulsive Symptoms Scale*, and the *DSM-IV Total ADHD Symptoms Scale.*

Conners' Continuous Performance Test-II (CCPT-II). The CCPT-II (Conners, 1995) is a computerized task that was administered on a Windows desktop computer (17 in (43.18 cm) monitor, 1,024 x 768 resolution, 75 Hz refresh rate). Three-hundred and sixty letters (approximately 1 inch high) appear on the screen, one at a time, for approximately 250 ms. The participant is required to press the spacebar for each letter as it appears on the screen and to refrain from pressing the spacebar when an 'X' appears. The 360 letter trials are divided into 18 blocks, each consisting of 20 trials. Each block is randomly assigned to one of three interstimulus interval (ISI) conditions (1, 2, or 4 s), and all three ISI conditions occur every three blocks. Across all blocks, the percentage of trials in which letters other than X appear is 90%. The test administration duration was 14 minutes. Variables used are those outlined by the task authors as the "standard set of performance measures" calculated in most continuous performance tasks (Conners, Epstein, Angold, & Klaric, 2003). These include variables of accuracy: commission errors (responding to a non-target stimulus), omission errors (failing to respond to target stimulus), detectability (d', signal detection or perceptual sensitivity to targets), and response style (B, tendency to respond too little or too much relative to the actual distribution of the signal). Descriptions of variables are presented in Table 3. T-scores ≥ 65 indicate markedly impaired functioning (Conners, 1995).

Table 3. CCPT-II Variables

Score	Measures	Feature
Omissions	Not responding to target (non-X) stimuli	Accuracy/Inattention
Commissions	Responding to non-target (X) stimuli	Accuracy/Inattention & Impulsivity
Detectability (d')	Derived from distance between target distribution and non-target distribution (greater distance = better detection of targets). Is dependent upon frequency of target and sensitivity of respondent, and reflects the ability to discriminate among stimuli.	Accuracy/Inattention
Response Style (B)	Derived from response frequency compared to actual target vs. non-target distribution. Calculated by comparing if the participant responds too little or too much versus the actual distribution of target stimuli. Reflects the degree to which respondent is being conservative or impulsive in responding, which affects likelihood that the correct response will be made.	Accuracy/Impulsivity
Hit Reaction Time (RT)	Mean time taken to respond to all targets	Reaction Time/Inattention & Impulsivity
Hit Reaction Time Standard Error (RT SE)	Variability/consistency of response time for all targets	Variability/Inattention & Impulsivity

Delis-Kaplan Executive Function System (D-KEFS). The D-KEFS (Delis, Kaplan, & Kramer, 2001) is a nine-test battery that assesses key components of executive functions, including flexibility of thinking, inhibition, problem solving, planning, impulse control, concept formation, abstract thinking, and creativity in both verbal and spatial modalities. Several of the tests are similar to existing and well-established measures of executive functioning, and the standardization on a contemporary stratified national sample of ages 8 to 89 years is a practical and empirical advantage of this instrument. In addition, subtest scores have all been normed to a mean of 10 and standard deviation of 3 to enable comparison across measures. Subtests used in this study include: Trail Making Test, Verbal Fluency Test, Color-Word Interference Test, and Tower Test. Test-retest reliability coefficients range across tests from low to high, suggesting that the constructs most tasks are measuring remain consistent over time (Delis et al., 2001). Evidence of sufficient convergent and discriminant validity was described previously and is provided in the D-KEFS manual, and scores across the subtests are correlated appropriately based on similarity in construct being assessed (Table 3). Primary measure scores across all components of the subtests will be generated by the D-KEFS computer scoring assistant.

Wechsler Abbreviated Scale of Intelligence (WASI). The WASI (The Psychological Corporation, 1999) is a brief, individually administered test of intelligence designed for individuals from age 6 to 89. Standardized on a stratified national sample according to 1997 U.S. Census figures, the WASI yields a Verbal Scale IQ (VIQ), Performance Scale IQ (PIQ), and a Full Scale IQ (FSIQ). Excellent internal consistency and test-retest reliability have been found, and scores on the WASI correlate highly with other ability tests (Sattler, 2001; The Psychological Corporation, 1999).

Independent Measures

Between-Group. For both the CCPT-II and D-KEFS, diagnostic group (ADHD versus control group) serves as a between-group independent measure.

Dependent Measures

CCPT-II. Based on prior research with the CCPT-II, several scores on the instrument have been found to be associated with ADHD symptoms. For the current study, analyses focus on previously established diagnostically significant variables, which are also identified as the main performance by the authors of the task (Conners et al., 2003).

D-KEFS. All primary measure scores will be included in the D-KEFS analyses for the subtests that were administered. This includes individual scores for each task within a subtest. Contrast and process scores were not included in the analyses because of the limited reliability of these types of scores as found in Wodka et al.'s (2008) research. Refer to Table 4 for a list of the D-KEFS variables analyzed. Ingredient scores refer to the tasks being basic skills that are combined with others in the more "executive" condition of the task.

Table 4. D-KEFS Variables

D-KEFS test/variable	**Type of Measure**
Trail Making Test	
Primary Measures: Completion Times	
Condition 1: Visual Scanning	Total – Ingredient
Condition 2: Number Sequencing	Total – Ingredient
Condition 3: Letter Sequencing	Total – Ingredient
Condition 4: Number-Letter Switching	Total - Reconstitution/Inhibition
Condition 5: Motor Speed	Total – Ingredient
Verbal Fluency	
Primary Measures	
Letter Fluency	Total - Reconstitution/Working Memory
Category Fluency	Total – Reconstitution/Working Memory
Category Switching	Total - Reconstitution/Inhibition
Category Switching: Total switching accuracy	Total - Reconstitution/Inhibition
Color Word Interference	
Primary Measures: Completion Times	
Condition 1: Color Naming	Total - Ingredient
Condition 2: Word Reading	Total - Ingredient
Condition 3: Inhibition	Total - Inhibition
Condition 4: Inhibition/Switching	Total - Reconstitution/Inhibition
Tower Test	
Primary Measure	
Total Achievement Score	Total - Reconstitution/Inhibition

Procedure

Prior to participation, parents/guardians (preferably maternal) completed a screening packet that included a consent form, demographic questionnaire, and CPRS-R:L. Children signed the consent form as well, giving their assent to participate. After the forms were received, they were scored by a research assistant to determine participant eligibility. Children for the control group were selected with age and gender corresponding as closely as possible to the ADHD participant characteristics. Parents/guardians of children deemed eligible were contacted to schedule a laboratory research session.

The D-KEFS, WASI, and CCPT-II were administered in a counterbalanced order with two other computerized tasks not analyzed in the current study. Specifically, either the two paper and pencil tasks or the three computer tasks were administered together first, so children did not switch back and forth between mode of testing. Within each mode of testing (computer or paper and pencil), measures were completed in a counterbalanced order. The one-time research session was approximately 2 ½ hours in duration, and 5-minute breaks between each task were implemented. Testing took place in a well-lighted room, free from distractions. A graduate student or research assistant remained in the room with the child at all times during testing, and parents were not allowed to be in the room or to observe the research session to maintain control of surroundings. For children currently taking psychostimulant medication for ADHD, parents consented for them to abstain from their medication on the day of the research session. Prior to beginning the research session, parents and children verbally confirmed adherence to this procedure.

For the CCPT-II, a practice administration was administered prior to the test administration. On-screen instructions were read out-loud to the participant, instructing him/her to press the spacebar for every letter presented except the letter X. The participant was then required to paraphrase the instructions prior to beginning the task. During the practice phase, for each commission error the participant made (pressed the spacebar for the X), the following prompt was given: "Remember, don't press for the X." This prompt was not given during the test phase.

The WASI and the four selected subtests from the D-KEFS were administered at a table, with the examiner seated directly across from the participant. Standardized administration procedures as outlined in each test's manual were followed.

Upon completion of the laboratory phase, parents of participants were compensated $50. In addition, children received gift certificates (worth $10 in total) for free pizza, ice cream, movies, kids' meals, or bowling. No compensation was given for solely completing and returning the research packet, and this was indicated clearly on the consent form.

Results

Statistical Considerations

A review of literature regarding appropriate statistical analyses in neuropsychological research revealed several key points. Specifically, Tupper and Rosenblood (1984) discuss the issues of using attribute variables (sex, age, education, socioeconomic status, diagnosis) in research. Attribute variables are not randomly assigned, as subjects are likely self-selected. In addition, attribute variables are characteristics that the participant brings to the study, and these variables cannot be manipulated. Therefore, statistical procedures used in true experimental design may not be appropriate for studies that do not manipulate a condition experimentally and have random assignment of participants to groups. Most attribute variables are conceptually related in the real world, which makes it difficult to make clear or succinct conclusions regarding group differences due to possible confounding variables. Attempts to match groups post-hoc on some variables are undesirable because it risks un-matching the groups on a potential confounding or unconsidered variable, may create a sub-sample that differs from the population of interest, and creates confusion in the ability to conclude causation (Meehl, 1970).

Next, use of ANOVAs, despite their prolific use in neuropsychological research in peer-reviewed journals (e.g. Epstein et al., 2003; Wodka et al., 2008a; Wodka et al., 2008b), is discouraged because of the strong relationship between attribute variables and neuropsychological status, which violates one of the basic assumptions of the ANOVA model (Miller & Chapman, 2001; Tupper & Rosenblood, 1984). Analysis of covariance (ANCOVA) is often used to "statistically control" for effects of a nuisance variable. However, ANCOVA should only be used when the nuisance variable is statistically independent of the outcome variable (Tabachnik & Fidell, 2007). In the current study, this rationale was used to determine that analyses which likely included impact from nuisance variables would not be appropriate for ANCOVA. However, analyses where no nuisance variables were evident reverted to using traditional ANOVA.

Relationship between attribute variables is common. For example, males are generally more likely than females to meet diagnostic criteria for ADHD, with a ratio of 3:1 in community samples and a range of 5:1 to 9:1 in clinical samples (American Psychiatric Association, 2000). When individuals self-select to participate in a study, the number of males versus females may not match the naturally occurring ratio. Furthermore, cell sizes in analyses are likely to be unequal, which can lead to low statistical power. Some researchers attempt to solve this problem by over-sampling the less prevalent individuals to create equal cell sizes for analysis. However, this method is discouraged because it ignores the conceptual problem that the independent variables are related (Tupper & Rosenblood, 1984). Since MANOVA and MANCOVA are based on comparison between groups (cells), these methods are discouraged when using attribute variables.

After review of the relevant literature, several options were explored for the most appropriate statistical analyses in the present study. Due to race and diagnostic group differences, consideration was given to using IQ as a covariate in a MANCOVA. However, the high correlation between IQ and D-KEFS variable scores violates an assumption regarding this type of analysis – that the covariate should not be moderately or highly correlated with the independent variables (Tabachnik & Fidell, 2007). Race was also considered as a covariate, but no theoretical rationale linking race and EF could be established, thus precluding a decision to covary race solely based on the diagnostic group difference in proportion of race. Another option was to re-match the groups so that each had an equal proportion of African American and Caucasian participants. This would produce a smaller sample size but may eliminate the potential of the race/IQ interaction confounding subsequent analyses. However, as noted above, post-hoc matching can result in unmatching on other variables; thus, this option was not chosen.

Finally, the literature suggests that the most appropriate analyses in neuropsychological research are those of correlations and regressions (Tupper & Rosenblood, 1984). Given that these statistical models emphasize the relationship between variables, it is not required for the variables to be independent of each other or to be "controlled for." Therefore, the approach taken in this study was based on what seemed most appropriate in this line of research. IQ was used as a predictor, rather than a covariate, which eliminated the problem of moderate to high correlations with the D-KEFS variables.

Diagnostic Group Performance

D-KEFS. Data were evaluated for outliers by performing frequency counts and viewing histogram plots of all participants. Outliers would be those scores more than 3 standard deviations from the mean, and no outliers were noted in any of the D-KEFS variables analyzed. Scaled scores for all dependent variables, divided by diagnostic group, are presented in Table 5. For the ADHD group, variables that had means below the average range were Trailmaking Letter-Number Switching and Tower total achievement. All control group variables were within the average range of performance.

Given statistical considerations previously outlined, a MANCOVA was not performed to discern diagnostic group differences. Point biserial correlations were calculated between diagnostic group and D-KEFS variables, with the diagnostic variable being coded 1 for ADHD and 0 for control (Table 6). Results indicate low to moderate significant relationship between diagnosis and all D-KEFS variables except Trailmaking Visual Scan, Verbal Fluency-Letter Fluency total correct, and Color Word Interference-Word Reading. Specifically, as negative correlations suggest, better performance tended to be associated with control group status.

Chi square analyses were performed to determine the difference between ADHD and control performance on D-KEFS scores, with scaled scores of 6 or lower being below average (8^{th} percentile) and, for consistency in comparisons, matching the percentile of clinically significant T-scores from the CCPT. Scores of 7 and up on the D-KEFS are considered average and above. Scaled score values were divided into two groups: below average (6 and under) and average or above (7 and up). Results indicated significant group differences on Trailmaking Letter Sequencing, $\chi^2(1, N = 69) = 6.01$, $p < .05$, Verbal Fluency Category Switching Total Switching Accuracy, $\chi^2(1, N = 69) = 4.85$, $p < .05$, and Tower total achievement, $\chi^2(1, N = 69) = 9.42$, $p < .01$. ADHD group scores were more likely to be in the below average range than were those for controls.

Table 5. Group Performance on D-KEFS

D-KEFS Variable	ADHD Group *Mean Scaled Score (SD)*	Control Group *Mean Scaled Score (SD)*
Trailmaking Visual Scan	9.7 (3.2)	10.2 (2.9)
Trailmaking Number Sequencing	9.7 (3.0)	11.2 (2.6)
Trailmaking Letter Sequencing	8.1 (4.2)	10.3 (2.6)
Trailmaking Letter-Number Switching	7.0 (3.9)	10.0 (3.8)
Trailmaking Motor Speed	9.5 (2.7)	11.3 (1.7)
Verbal – Letter Fluency total correct	9.6 (2.8)	10.3 (3.1)
Verbal – Category Fluency total correct	9.8 (2.4)	12.2 (2.7)
Verbal – Category Switching total correct	8.3 (2.8)	10.8 (3.0)
Verbal – Category Switching Accuracy	8.5 (2.9)	11.0 (2.7)
Color Word – Color Naming	8.9 (2.5)	10.4 (3.1)
Color Word – Word Reading	10.5 (2.2)	11.2 (2.2)
Color Word – Inhibition	8.2 (3.2)	10.8 (3.0)
Color Word – Inhibition/Switching	9.3 (3.0)	10.9 (2.7)
Tower – Total Achievement	7.5 (3.2)	10.2 (2.4)

Table 6. Point Biserial Correlations between Diagnostic Group and D-KEFS Variables

D-KEFS Variable	Correlation Coefficient
Trailmaking Visual Scan	-.098
Trailmaking Number Seq.	-.263*
Trailmaking Letter Seq.	-.306*
Trailmaking L-N Switching	-.363**
Trailmaking Motor Speed	-.375**
Verbal – Letter Fluency total correct	-.120
Verbal – Category Fluency total correct	-.427***
Verbal – Category Switching total correct	-.407**
Verbal – Category Switching Accuracy	-.410***
Color Word – Color Naming	-.251*
Color Word – Word Reading	-.164
Color Word – Inhibition	-.384**
Color Word – Inhibition/Switching	-.289*
Tower – Total Achievement	-.438***

(Control = 0, ADHD = 1) * p <.05 ** p <.01 *** p <.001

Correlations among D-KEFS variables are presented in Table 7, which shows low to moderate correlations across numerous variables. Specifically, correlations among all tasks within each subtest were all significant, with magnitude of low to moderate. Table A15 presents intercorrelations from the D-KEFS manual. Magnitude of intercorrelations within each subtest were generally consistent with those reported in the manual.

Correlations across subtests in the current study revealed low to moderate relationships between most variables. Compared to the magnitudes reported in the D-KEFS manual, those in the current study revealed higher degrees of relationship between subtests. Most notably, the manual indicates Tower total achievement score as a low negative correlation with most other measures (range of -.03 to -.13). The current study found significant positive correlations between Tower and most other measures in the low to moderate magnitude (range of .24 to .54). In addition, relationships between Trailmaking and the Color-Word Interference and Verbal Fluency tasks were higher than those in the manual. It is possible that the current study produced higher intercorrelations because it is a more homogeneous sample than that used in the D-KEFS normative research. Specifically, a relative restriction of range in scores in the current study differs from the range of scores in the normative sample, which included individuals with severe EF deficits as well as those in the normal range of functioning.

A high correlation ($r = .92$, $p < .001$) was noted between Verbal Fluency Category Switching total correct responses and Verbal Fluency Category Switching total switching accuracy. Since these variables were so highly related, a decision was made to include only the total switching accuracy variable in subsequent analyses on inhibition/switching variables to hopefully eliminate a problem of multicolinearity. This variable was chosen given that it is a measure of the ability of a participant to change between categories; whereas, the total correct responses does not take into account switching responses. Since the current study goal is to examine the executive skills, the switching accuracy score is a better estimation of the more complex skill.

Table 7. Intercorrelations among D-KEFS Variables and IQ

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.
1. Full Scale IQ	-													
2. TM Visual Scan	.124	-												
3. TM Number Seq.	.309**	.305*	-											
4. TM Letter Seq.	.521***	.354**	.434***	-										
5. TM L-N Switching	.607***	.449***	.496***	.587***	-									
6. TM Motor Speed	.297*	.321**	.312**	.351**	.407**	-								
7. VF – Letter Fluency total correct	.420***	.247*	.109	.294*	.388**	.111	-							
8. VF – Category Fluency total correct	.464***	.233	.263*	.169	.304*	.020	.400**	-						
9. VF – Category Switch total correct	.658***	.250*	.331**	.497***	.477***	.379**	.413**	.432***	-					
10. VF – Category Switching Accuracy	.689***	.205	.336**	.527***	.493***	.377**	.389**	.410***	.921***	-				
11. CW –Color Name	.254*	.165	.242*	.322**	.448***	.163	.284*	.054	.282*	.228	-			
12. CW – Word Read	.224	.352**	.202	.277*	.376**	.175	.265*	.186	.316**	.243*	.679***	-		
13. CW – Inhibition	.543***	.236	.443***	.595***	.670***	.222	.287*	.252*	.515***	.505***	.685***	.508***	-	
14. CW – Inhibition/Switching	.340**	.136	.283*	.372**	.461***	.250*	.225	.181	.247*	.223	.558***	.406**	.650***	-
15. Tower – Total Achievement	.546***	.148	.220	.417***	.442***	.289*	.328**	.229	.320**	.377**	.129	.125	.288*	.124

TM=Trailmaking; VF=Verbal Fluency; CW=Color Word Interference * p <.05 ** p <.01 *** p <.001

CCPT. Across all CCPT variables analyzed, three outliers were identified. Two of these were for omissions T-score (1 ADHD and 1 control participant), and one was for detectability (control participant). To address these outliers, mean T-score for the diagnostic group was calculated for each variable, and the outlier results were recoded as the T-score three standard deviations from the mean of the corresponding dependent variable. T-scores for all CCPT dependent variables are presented in Table 8. Correlations across CCPT variables indicate modest to moderate relationship between measures, which is expected given that some of the scores are derived from performance on the other variables. Correlations between CCPT performance and IQ revealed significant modest results only for Hit Reaction Time Standard Error ($r = -.328$, $p < .01$) and Omissions ($r = -.284$, $p < .05$), as shown in Table 9. Therefore, unlike the significant relationship between IQ and D-KEFS variables, CCPT performance was largely unrelated to IQ. No sex differences were evident in CCPT scores, $F(6,60) = .72$, $p = .64$.

Table 8. Group Performance on CCPT Variables

CCPT Variable	**ADHD Group** *T-score Mean (SD)*	**Control Group** *T-score Mean (SD)*	**F (1,66)**
Omissions	55.6 (13.9)	48.9 (10.6)	5.01*
Commissions	49.6 (12.1)	44.5 (12.2)	2.27
Hit RT	54.8 (12.7)	49.9 (10.6)	3.60
Hit RT SE	57.3 (9.9)	49.4 (7.8)	13.48***
Detectability (d')	52.9 (12.3)	46.2 (12.0)	4.76*
Response Style (B)	58.2 (15.4)	52.7 (14.7)	2.26

* p<.05 **p<.01 ***p<.001

Table 9. CCPT and IQ Intercorrelations

CPT T-score	Full Scale IQ (FSIQ)	Omissions	Commissions	Hit RT	Hit RT SE	Detectability
Omissions	-.284*					
Commissions	-.184	.171				
Hit RT	-.109	.176	-.600***			
Hit RT SE	-.334**	.729***	.124	.531***		
Detectability (d')	-.210	.254*	.868***	-.465***	.154	
Response Style (B)	-.200	.306*	-.088	.373**	.349**	.025

Hit RT= Hit Reaction Time; Hit RT SE=Hit Reaction Time Standard Error * p<.05 **p<.01 ***p<.001

A MANOVA was conducted to test mean group differences across CCPT variables (Table 8). There was a significant main effect of diagnostic group, $F(6,61) = 3.19$, $p < .01$. Specifically, the ADHD group produced more omission errors, with $F(1,66) = 5.01$, $p < .05$. In addition, the ADHD group also produced more variability in their hit reaction time, as evidenced by Hit Reaction Time Standard Error scores, $F(1,66) = 13.48$, $p < .001$. Finally, the ADHD group had more difficulty with Detectability (d'), $F(1,66) = 4.76$, $p < .05$. However, mean T-scores for both the ADHD and control group across all variables were in the non-clinical range.

Chi square analyses were performed to determine if CCPT scores were clinically significant (T-score ≥ 65) for more ADHD than control participants. Results indicated significant group differences, with ADHD participants producing a higher number of clinically significant scores than controls on Hit RT, $\chi^2(1, N = 68) = 7.04$, $p < .01$, and Hit RT SE, $\chi^2(1, N = 68) = 4.15$, $p < .05$. No significant group differences were found for Omissions, $\chi^2(1, N = 68) = 2.82$, $p > .05$, Commissions, $\chi^2(1, N = 68) = .56$, $p > .05$, Detectability, $\chi^2(1, N = 68) = 1.48$, $p > .05$, and Response Style, $\chi^2(1, N = 68) = 3.62$, $p > .05$.

Correlations between D-KEFS, CCPT, and CPRS Scores

Bivariate correlations between the D-KEFS and CCPT dependent variables were calculated (Table 10). Given the large number of correlations calculated, discussion in this section will focus on those with a coefficient of .01 or better. CCPT variables that measure accuracy were related to several D-KEFS variables. CCPT omission errors were significantly correlated with D-KEFS Verbal Fluency – Category Switching total switching accuracy. CCPT commission errors were correlated with Verbal Fluency – Category Switching total switching accuracy. CCPT Detectability was significantly related to Trailmaking Number Sequencing.

CCPT Response style was not significantly correlated at the .01 level with any D-KEFS variables.

The CCPT score that is a measure of variability in response times, Hit Reaction Time SE, was significantly correlated with the most D-KEFS variables: Trailmaking Letter Sequencing and Letter-Number Switching, Color Word Interference Color Naming, and Inhibition. CCPT Hit Reaction Time was not significantly correlated at the .01 level with any D-KEFS variables.

D-KEFS variables that were unrelated to any CCPT variables at the .05 level or better include Trailmaking Visual Scan and Motor Speed, Verbal Fluency – Letter and Category Fluency total correct, and Color Word Interference Word Reading. These results were somewhat surprising, given that the CCPT is a visual attention (visual scan) task that requires speed (motor speed) in responding to letters. However, due to several of the D-KEFS inhibition/switching variables being significantly correlated with multiple CCPT variables, it appears as though both measures may be tapping into a more complex construct than simple motor speed, visual scanning, and letter/word identification.

Table 10. Correlations between CCPT and D-KEFS Variables

CCPT	Omissions	Commissions	Hit RT	Hit RT SE	Detectability	Response Style
D-KEFS						
TM Visual Scan	.125	-.018	-.031	-.023	.046	.066
TM Number Seq.	-.155	-.285*	.030	-.202	-.382**	-.105
TM Letter Seq.	-.256*	-.173	-.219	-.394**	-.180	-.188
TM L-N Switching	-.194	-.257*	-.157	-.323**	-.301*	-.267*
TM Motor Speed	-.103	-.219	.010	-.185	-.204	.006
VF – Letter Fluency total correct	-.064	-.209	.036	-.132	-.075	.026
VF – Category Fluency total correct	-.192	.002	-.119	-.200	.006	-.196
VF – Category Switch total correct	-.294*	-.311*	.031	-.271*	-.247*	-.175
VF – Category Switching Accuracy	-.330**	-.316**	-.039	-.301*	-.303*	-.180
CW –Color Name	-.085	-.309*	-.137	-.362**	-.233	-.150
CW – Word Read	.047	-.104	-.177	-.231	.005	-.080
CW – Inhibition	-.201	-.223	-.312*	-.446***	-.238	-.310*
CW – Inhibition/Switching	-.288*	-.143	-.133	-.280*	-.107	-.202
Tower – Total Achievement	-.128	-.197	-.145	-.281*	-.243*	-.028

* p<.05 **p<.01 ***p<.001

Bivariate correlations between D-KEFS and CCPT dependent variables and the CPRS Inattentive Symptoms, Hyperactive/Impulsive Symptoms, and Total ADHD Symptoms scales were calculated (Table 11). Virtually all D-KEFS scores were modestly to moderately correlated with all three CPRS scores. The only D-KEFS variables that were not correlated with any of the CPRS scores were Trailmaking Visual Scan, Verbal Fluency-Letter Fluency total correct, and Color Word Interference Word Reading. Trailmaking Number Sequencing was only significantly correlated with CPRS Inattentive and Total Symptoms scores, and not with CPRS Hyperactive-Impulsive, suggesting that symptoms of hyperactivity-impulsivity may not affect performance on this task.

CCPT variables had a much lower incidence of significant correlations. Hit Reaction Time and Hit Reaction Time Standard Error produced low to moderate correlations with all three

CPRS scores. This suggests that the average *speed* of all target responses for the entire test (Hit RT) and the *variability* of response time across the 18 time blocks (Hit RT SE) are affected by both symptoms of hyperactivity/impulsivity and inattention. Detectability (d') and Response Style (B) had a significant low correlation with only the CPRS Hyperactive/Impulsive score, indicating that *accuracy*, or the power to differentiate between signal and noise (d') and response tendency to be overly or less concerned about mistakenly responding to non-targets (B), is affected by symptoms of hyperactivity/impulsivity but not inattention. Overall, it appears that CCPT performance is not highly related to symptoms of ADHD, as measured by the CPRS.

Taken together, these results indicate that, when either a D-KEFS or CCPT measure is significantly correlated with CPRS scores, it is typically related to both symptom domains of ADHD as measured by the CPRS. Only a few subscales (2 on each measure) were related to only hyperactivity/impulsivity or inattention, indicating that the D-KEFS and CCPT do not have many aspects that are differentially related to only one type of symptom cluster.

Table 11. Correlations between D-KEFS, CCPT, and CPRS Scores

	CPRS Inattentive T-score	CPRS Hyperactive-Impulsive T-score	CPRS Total ADHD T-score
D-KEFS			
Trailmaking Visual Scan	-.127	-.019	-.069
Trailmaking Number Seq.	-.351**	-.237	-.300**
Trailmaking Letter Seq.	-.374**	-.284*	-.332**
Trailmaking L-N Switching	-.487***	-.351**	-.434***
Trailmaking Motor Speed	-.412***	-.310**	-.375**
Verbal – Letter Fluency total correct	-.108	-.054	-.082
Verbal – Category Fluency total correct	-.420***	-.434***	-.443***
Verbal – Category Switching total correct	-.350**	-.390**	-.383**
Verbal – Category Switching Accuracy	-.381**	-.456***	-.433**
Color Word – Color Naming	-.297*	-.263*	-.290*
Color Word – Word Reading	-.185	-.204	-.200
Color Word – Inhibition	-.443***	-.403**	-.437***
Color Word – Inhibition/Switching	-.375**	-.292*	-.348**
Tower – Total Achievement	-.423**	-.435***	-.441***
CCPT			
Omissions	.250*	.226	.242*
Commissions	.168	.187	.187
Hit Reaction Time (RT)	.264*	.269*	.266*
Hit Reaction Time Standard Error (RT SE)	.424***	.398**	.415***
Detectability (d’)	.227	.257*	.255*
Response Style (B)	.203	.267*	.238

* p<.05 **p<.01 ***p<.001

Predictive Utility

D-KEFS. To test the hypothesis that the planning/inhibition/switching variables of the D-KEFS would be predictive of diagnostic group membership, a logistic regression was performed (Table 12). Sex and IQ were entered in the first block of the analysis, and then the planning/inhibition/switching D-KEFS variables (Trailmaking Letter Number Switching, Verbal Fluency-Category Switching total switching accuracy, Color Word Interference Inhibition and Inhibition/Switching, and Tower total achievement) were entered in the second block using a forward stepwise LR method. An alpha level of .05 was used as the basis of inclusion of dependent variables in the final model. The likelihood ratio test was significant, meaning the overall model can be interpreted, and the Hosmer & Lemeshow goodness-of-fit test (with a nonsignificant chi-square) indicated that the data fit the model well. Tower total achievement score was the only significant predictor in the model, and the model predicted 22.9% of the total variance (Cox and Snell R^2). Full scale IQ and sex were not significant in the final model

The resulting classification matrix correctly identified 21 of 32 members of the ADHD group, producing a sensitivity coefficient of 65.6%; and 28 of 36 members of the control group, producing a specificity coefficient of 77.8%. The overall correct classification rate was 72.1%. Positive and negative predictive power was 72.4% and 71.8%, respectively.

Table 12. Logistic regression for D-KEFS planning/inhibition/switching variables

Predictor	β	SE β	Wald's χ^2	df	*p*	Odds ratio
Constant	6.866	2.30	8.325	1	.004	959.33
Sex	-.796	.771	1.067	1	.302	.451
Full Scale IQ	-.035	.020	3.169	1	.075	.965
Tower Total Achievement	-.260	.114	5.151	1	.023	.771
Test			χ^2	df	*p*	
Overall Model Evaluation						
Likelihood ratio test			17.665	3	.001	
Goodness-of-fit test			χ^2	df	*p*	
Hosmer & Lemeshow			8.298	8	.405	

Cox and Snell R^2 = .229. Nagelkerke R^2 = .305

An exploratory logistic regression analysis was conducted using all of the D-KEFS variables to determine if prediction of diagnostic group improved when allowing variables of both the basic tasks and the planning/inhibition/switching variables to enter into the statistical model (Table 13). Sex and IQ were entered in the first block of the analysis, then all D-KEFS variables were entered into second block using a forward stepwise LR method. An alpha level of .05 was used as the basis of inclusion of dependent variables in the final model. The likelihood ratio test was significant, meaning the overall model can be interpreted, and the Hosmer & Lemeshow goodness-of-fit test (with a nonsignificant chi-square) indicated that the data fit the model well. The Tower total achievement, Trailmaking Motor Speed, and Verbal Fluency-Category Fluency total correct scores were the only significant predictors in the final model, and the model predicted 39.0% of the total variance (Cox and Snell R^2). Full scale IQ and sex were not significant in the final model.

The resulting classification matrix correctly identified 24 of 32 members of the ADHD group, producing a sensitivity coefficient of 75.0%; and 30 of 36 members of the control group, producing a specificity coefficient of 83.3%. The overall correct classification rate was 79.4%. Positive and negative predictive power was 80.0% and 78.9%, respectively.

Table 13. Logistic regression for all D-KEFS variables

Predictor	β	SE β	Wald's χ^2	df	*p*	Odds ratio
Constant	13.845	3.990	12.043	1	.001	1.03E6
Sex	-.530	.918	.334	1	.563	.588
Full Scale IQ	-.005	.025	.040	1	.841	.995
Trailmaking Motor Speed	-.509	.196	6.763	1	.009	.601
Verbal Fluency-Category Fluency	-.401	.143	7.877	1	.005	.670
Tower Total Achievment	-.341	.149	5.267	1	.022	.711
Test						
Overall Model Evaluation			χ^2	df	*p*	
Likelihood ratio test			33.586	5	.000	
Goodness-of-fit test			χ^2	df	*p*	
Hosmer & Lemeshow			8.159	8	.418	

Cox and Snell R^2 = .390. Nagelkerke R^2 = .520

CCPT. To examine the diagnostic utility of the CCPT, variables that demonstrated significant between-group differences (Omissions, Hit RT SE, and detectability) were entered in a forward stepwise logistic regression (Table 14). An alpha level of .05 was used as the basis of inclusion of dependent variables in the final model. The likelihood ratio test was significant, meaning the overall model can be interpreted, and the Hosmer & Lemeshow goodness-of-fit test (with a nonsignificant chi-square) indicated that the data fit the model well. Hit RT SE remained in the final model, and the model predicted 16.7% of the total variance (Cox and Snell R^2). The resulting classification matrix correctly identified 19 of 31 members of the ADHD group, producing a sensitivity coefficient of 61.3%; and 31 of 37 members of the control group, producing a specificity coefficient of 83.8%. The overall correct classification rate was 73.5%.

Positive and negative predictive power was 76.0% and 72.1%, respectively.

Table 14. Logistic regression for CCPT variables

Predictor	β	SE β	Wald's χ^2	df	*p*	Odds ratio
Constant	-5.583	1.751	10.171	1	.001	.004
Hit RT SE	.102	.033	9.723	1	.002	1.107
Test						
Overall Model Evaluation			χ^2	df	*p*	
Likelihood ratio test			12.428	1	.000	
Goodness-of-fit test			χ^2	df	*p*	
Hosmer & Lemeshow			5.771	8	.673	

Cox and Snell R^2 = .167. Nagelkerke R^2 = .223

Combined Tasks. To determine the predictive utility of diagnostic group by both the D-KEFS and CCPT, variables that were significant in the logistic regressions described above were included in analysis (Table 15). Specifically, D-KEFS Tower total achievement was the only significant predictor in the analyses of planning/inhibition/switching variables. Results indicated only Hit RT SE as a significant predictor in the CCPT. Sex and full scale IQ were entered in the first block of the equation. The CCPT and D-KEFS variables were entered in a forward stepwise logistic regression. The only variables that remained in the final model were CCPT Hit RT SE and Full Scale IQ, and the model predicted 25.4% of the total variance (Cox and Snell R^2). Sex was not significant in the final model. The resulting classification matrix correctly identified 19 of 31 members of the ADHD group, producing a sensitivity coefficient of 61.3%; and 28 of 37 members of the control group, producing a specificity coefficient of 75.7%. The overall correct classification rate was 69.1%. Positive and negative predictive power was 67.9% and 70.0%, respectively.

Table 15. Logistic regression for combined D-KEFS planning/inhibition/switching and CCPT variables

Predictor	β	SE β	Wald's χ^2	df	*p*	Odds ratio
Constant	1.112	3.023	.135	1	.713	3.041
Sex	-1.061	.789	1.807	1	.179	.346
Full Scale IQ	-.043	.019	5.235	1	.022	.958
Hit RT SE	.085	.034	6.230	1	.013	1.089
Test						
Overall Model Evaluation			χ^2	df	*p*	
Likelihood ratio test			19.965	3	.000	
Goodness-of-fit test			χ^2	df	*p*	
Hosmer & Lemeshow			4.655	8	.794	

Cox and Snell R^2 = .254. Nagelkerke R^2 = .340

Given that only the CCPT Hit RT SE variable entered into the final model that combined D-KEFS planning/inhibition/switching variables and CCPT variables, another logistic regression was run using all of the D-KEFS variables that were significant in the exploratory analysis (Tower total achievement, Trailmaking Motor Speed, and Verbal Fluency-Category Fluency total correct) and CCPT Hit RT SE (Table 16). This was to determine whether the additional information across more basic EF tasks would improve the diagnostic utility of combining the D-KEFS and CCPT measures. Sex and full scale IQ were entered in the first block of the equation. The CCPT and D-KEFS variables were entered in a forward stepwise logistic regression. The variables that remained in the final model were Trailmaking Motor Speed, and Verbal Fluency-Category Fluency total correct, and the model predicted 38.1% of the total variance (Cox and Snell R^2). Sex and full scale IQ were not significant in the final model. The resulting classification matrix correctly identified 23 of 31 members of the ADHD group, producing a sensitivity coefficient of 74.2%; and 29 of 37 members of the control group, producing a specificity coefficient of 78.4%. The overall correct classification rate was 76.5%. Positive and negative predictive power was 74.2% and 78.4%, respectively.

Table 16. Logistic regression for combined CCPT and exploratory D-KEFS variables

Predictor	β	SE β	Wald's χ^2	df	*p*	Odds ratio
Constant	14.644	4.107	12.710	1	.000	2.29E6
Sex	-1.378	1.002	1.890	1	.169	.252
Full Scale IQ	-.018	.002	.651	1	.420	.982
Trailmaking Motor Speed	-.584	.200	8.523	1	.004	.558
Verbal Fluency-Category Fluency	-.481	.154	9.812	1	.002	.618
Test			χ^2	df	*p*	
Overall Model Evaluation						
Likelihood ratio test			32.630	4	.000	
Goodness-of-fit test			χ^2	df	*p*	
Hosmer & Lemeshow			1.894	8	.984	

Cox and Snell R^2 = .381. Nagelkerke R^2 = .509

D-KEFS Prediction of ADHD Symptoms by Age Group

To determine whether specific D-KEFS variables were more predictive of ADHD diagnostic status and ADHD symptoms at different ages, two age groups were formed based on cognitive developmental theory of Piaget (1963), which divides children 7 to 11 years into the concrete operational period and those 11 years and up in the formal operational period. In addition, children in the city where the study was conducted are typically entering middle school (6^{th} grade) while they are still 11 years old and remain in middle school through age 14. Research suggests that ADHD symptoms decline over time; however, the transition to middle school disrupts this decline with an exacerbation of symptoms (Langberg, Epstein, Altaye, Molina, Arnold, et al., 2008). Therefore, the cut point of 11 years was decided upon based on cognitive theory and research regarding school transitions and possible changes in ADHD symptomatology. Children 8 years to 10 years 11 months were included in the younger age group, and children 11 years to 14 years were included in the older age group.

Other methods, such as a median split based on the data or EF developmental models were considered; however, potential problems are found in all options for creating age groups.

Median split does not give a theoretical rationale to age group division, as it focuses on creating equal group sizes for analyses. Brocki & Bohlin (2006) appear to have utilized a median split method in their study, as the age groups have the same number in participants in each and age cutoffs were not explained as theoretically driven. For the current study, median split was not chosen as an appropriate method, as it does not take into account what might be occurring developmentally at different ages. EF developmental models are not yet fully elucidated, as there appear to be different trajectories for development of each of the different facets of EF, which makes it difficult to choose age cutoffs when several tasks of EF are being studied. Recognizing the potential pitfalls to using any age cutoff rationale, the following analyses were conducted for exploratory purposes. In the future, other analyses based on different age cutoffs could be conducted.

The logistic regressions for the D-KEFS described above were re-run separately for each age group. Sex and full scale IQ were entered in the first step, and D-KEFS planning/inhibition/switching variables were entered in the second step in a forward stepwise method.

For the younger age group, the only significant predictor in the final model was Full Scale IQ (Table 17). When D-KEFS variables were entered in the second block in a stepwise manner, Tower total achievement was the only variable that entered the step, with the overall model being significant. However, the Tower coefficient was non-significant, with $p > .05$. Therefore, the previous step that only included sex and IQ was deemed more appropriate, and the model predicted 41.1% of the total variance (Cox and Snell R^2). Sex was not significant in the final model. The resulting classification matrix correctly identified 14 of 17 members of the ADHD group, producing a sensitivity coefficient of 82.4%; and 15 of 17 members of the control group, producing a specificity coefficient of 88.2%. The overall correct classification rate was 85.3%. Positive and negative predictive power was 87.5% and 83.3%, respectively.

Table 17. D-KEFS logistic regression for younger age group

Predictor	β	SE β	Wald's χ^2	df	*p*	Odds ratio
Constant	10.644	3.866	7.582	1	.006	4.19E4
Full Scale IQ	-.093	.032	8.417	1	.004	.911
Sex	-.497	1.021	.237	1	.626	.608
Test						
Overall Model Evaluation			χ^2	df	*p*	
n/a (block 1)						
Goodness-of-fit test			χ^2	df	*p*	
Hosmer & Lemeshow			7.516	8	.482	

Cox and Snell R^2 = .411. Nagelkerke R^2 = .548

For the older age group, no models were found to be predictive of diagnostic group. For the first step, in which sex and Full Scale IQ were entered, the model was non-significant, as indicated by the likelihood ratio test (p > .05). In the second step, Color Word Interference Inhibition entered into the model, with the likelihood ratio test being significant (p < .05), but the Homer and Lemeshow test revealed that the model was not a good fit for the data (p < .05). Therefore, none of the variables were significant predictors of diagnostic category in the older age group.

Using the dimensional CPRS variables, stepwise hierarchical regressions were run for each age group. Sex and IQ entered in the first step, followed by all D-KEFS variables entered in a forward stepwise manner. Two regressions were run for each age group, with the dependent variable being the CPRS Inattentive scale in the first analysis and the Hyperactive/Impulsive scale in the second.

For the younger group, the significant predictors of CPRS Inattentive symptoms in the final model were Verbal Fluency – Category Fluency total correct (β = -.606, $t(27) = -4.54$, $p <$ .001), Tower total achievement (β = -.454, $t(27) = -3.13$, $p < .01$), Verbal Fluency – Letter Fluency total correct (β = .300, $t(27) = 2.35$, $p < .05$), and Trailmaking Motor Speed (β = -.255,

$t(27) = -2.28$, $p < .05$) . These variables explained a significant proportion of variance in Inattentive scores, $R^2 = .71$, $F(6, 27) = 11.41$, $p < .001$. Sex and full scale IQ were non-significant in the model.

The only significant predictors of CPRS Hyperactive/Impulsive symptoms in the final model for the younger age group were Verbal Fluency – Category Fluency total correct ($\beta = -.34$, $t(30) = -2.16$, $p < .05$) and full scale IQ ($\beta = -.45$, $t(30) = -2.78$, $p < .01$). These variables also explained a significant proportion of variance in Hyperactivity scores, $R^2 = .49$, $F(3, 30) = 9.55$, $p < .001$.

For the older group, the only significant predictor of CPRS Inattentive symptoms in the final model was Color Word Interference Inhibition ($\beta = -.58$, $t(30) = -2.98$, $p < .01$). Sex and full scale IQ were not significant in the final model. Color Word Interference Inhibition also explained a significant proportion of variance in Inattentive scores, $R^2 = .29$, $F(3, 30) = 4.06$, $p < .05$.

The final model for CPRS Hyperactive/Impulsive symptoms was non-significant, $F(3,30) = 2.64$, $p > .05$. Therefore no D-KEFS scores, nor sex or full scale IQ were significant predictors of Hyperactivity symptoms in the older group.

Discussion

Prominent current theories of ADHD implicate EF deficits in individuals with ADHD compared to their normally developing peers. Extensive research has found significant performance deficits by ADHD participants on classic measures of EF (Frazier et al., 2004; Willcutt et al., 2005). The D-KEFS is a relatively new neuropsychological measure of EF and has been minimally studied with an ADHD population, with only some diagnostic group differences noted. Furthermore, research examining D-KEFS performance in other psychiatric populations is limited, which suggests that relatively little is known about its clinical utility. In addition, deficient performance by ADHD groups on CPTs has been noted (Conners et al., 2003; Frazier et al., 2004; Willcutt et al., 2005). The primary aim of this study was to determine whether performance on the D-KEFS and CCPT-II differentiated ADHD children from non-ADHD children. In addition, concurrent and incremental validity between the measures was examined.

D-KEFS Between-Group Performance

Several analytic strategies revealed ADHD diagnosis being associated with below average performance on several D-KEFS tasks that measure inhibition/switching and planning (Trailmaking Letter-Number Switching and Tower total achievement), as well as more deficient performance than controls on most of the D-KEFS measures (including all EF measures as well as some ingredient skill subtests). These results are consistent with previous literature, in that individuals with ADHD have significant difficulty (below average performance) with traditional trailmaking, verbal fluency, and tower tasks (Frazier et al., 2004; Willcutt et al., 2005). These tasks all include components of reconstitution and planning, inhibition of more automatic responding, working memory, and fine motor control and speed. Therefore, these results fit with aspects of both Barkley's (2006) and Nigg's (2006) theories of ADHD and EF, as they both articulate inhibition and planning/reconstitution (part of Nigg's working memory component) as deficits in individuals with ADHD.

Using the D-KEFS, Wodka et al. (2008a) found significant differences between ADHD and control performance on all tasks of the Color-Word Interference subtest and on Tower Total Achievement scores. The only other study using the D-KEFS found no significant differences between ADHD and control participants on the two D-KEFS subtests examined (Color-Word Interference and Verbal Fluency subtests), and ADHD participants' scores on these subtests were all within average range (Corbett et al., 2009). Therefore, previous findings of ADHD performance on the D-KEFS are mixed, some indicating deficits in individuals with ADHD on planning/reconstitution and inhibition tasks, while others not finding these differences.

It should be noted that the ADHD group means on the D-KEFS in Wodka et al.'s (2008a) study were all within the average range, even though there was a significant difference compared to controls. Discrepancy between their results and those of the current study might be due to the effects of a more heterogeneous sample and larger range of IQ scores in our study, as our standard deviations for IQ scores were larger than those of Wodka et al.'s (SDs all 14 and below). The authors indicate that measures of EF tend to be less sensitive in children with above average IQ (Mahone, Hagelthorn, Cutting, Schuerholz, Pelletier, Rawlins, et al., 2002). Therefore, our sample characteristics likely allowed for the more distinct between-group performance on the D-KEFS.

D-KEFS subtest performance was found to be associated with both inattention and hyperactivity/impulsivity, as rated by parents on the CPRS, for all executive measures and many ingredient skills. The only variables that were not significant in these analyses are associated with more basic tasks of the subtests, rather than the executive components. Therefore, it appears that visual scanning skills, phonological fluency, and reading skills likely do not differ between diagnostic groups in the current study. Verbal Fluency Letter Fluency has been found to be deficient in children with ADHD by some researchers (e.g. Grodzinsky & Diamond, 1992) but not others (e.g. Carte, Nigg, & Hinshaw, 1996). The weighted mean effect size from a meta-analysis examining reading difficulties in children with ADHD was found to be 0.64, suggesting moderate reading deficits associated with the diagnosis of ADHD (Frazier et al., 2004). Though previous research suggests a relationship between phonological fluency and reading and ADHD diagnosis, our results did not support this. Current sample characteristics (e.g. IQ, demographics) may be influencing these findings.

Several other ingredient skills (number sequencing, letter sequencing, motor speed, and color naming) produced significant correlations with diagnosis and inattention/hyperactivity/impulsivity, though they were all lower in magnitude compared to the executive tasks. It is possible that these skills are more critical to overall performance in the inhibition/switching conditions of the D-KEFS subtests, thus accounting for the relationship with diagnostic group.

Some more specific patterns in the relationship between D-KEFS and CPRS scores were noted. Scores on the Inattentive Symptoms scale produced roughly 0.1 higher magnitude of correlations with the Trailmaking and Color Word Interference tasks than did the Hyperactive/Impulsive Symptoms scale. Wodka et al. (2008a) found that children with ADHD-PI performed significantly worse than ADHD-C on Trailmaking Number Sequencing and Letter

Sequencing. Better performance has also been noted on traditional trailmaking tasks for ADHD-C compared to the ADHD-PI group (Chhabildas, Pennington, & Wilcutt, 2001; Nigg, Blaskey, Huang-Pollock, & Rappley, 2002). However, symptom ratings of inattention and hyperactivity/impulsivity predicted total time on Trailmaking *equally* as well (Chhabildas et al., 2001). Though our sample did not categorize participants by ADHD subtype, results are comparable that symptoms of inattention are more related to Trailmaking tasks than are symptoms of hyperactivity/impulsivity. On the Stroop Color-Word Interference test, performance between ADHD-C and ADHD-PI subtypes did not differ significantly from each other but were both lower than that of controls (Nigg et al., 2002). Our study found symptoms of inattention to have a higher correlation with Color Word Interference performance.

Both the Trailmaking and Color-Word Interference subtests require persistent attention on a timed test, while following along visually on a sheet of paper (reading and/or writing). Any inattention or stoppage in the task would require significant time to reorient to the task. Therefore, it follows that inattention might be more detrimental to task performance than possible fidgeting, impulsivity, or general hyperactivity. However, both symptom domains were significantly associated with these tasks, so it is possible that inattention might be more critical to performance, as individuals with ADHD-C also exhibit symptoms of inattention. Parsing out the inattentive component by comparing individuals with ADHD-HI type to those with ADHD-PI would help clarify this relationship.

CCPT Between-Group Performance

Performance on the CCPT revealed diagnostic group differences on Omissions, Hit RT SE, and Detectability (d'). Since mean scores on these measures were within the average range for both diagnostic groups, further analysis indicated only Hit RT and Hit RT SE scores in the clinical range for ADHD participants. Conners et al.'s (2003) research on the CCPT revealed significantly worse performance by the ADHD group on Hit RT SE, errors of commission, errors of omission, and Detectability (d'). Meta-analysis of CPTs indicated moderate but heterogeneous effect sizes across CPT variables, with CPT hits (number of hits recorded) producing the largest effect sizes of all EF measures examined (Frazier et al., 2004). This points to results being somewhat inconsistent across studies; however, our results are commensurate with some of them.

Current study results indicate that response time and variability of response times are more deficient in our sample of ADHD participants compared to their control counterparts. Sergeant's (2005) theory suggests that activation and arousal are problematic for children with ADHD, and thus gives rise to more variable reaction times (both faster and slower). Conners et al.'s (2003) research on the CCPT revealed significantly worse performance by the ADHD group on Hit RT SE. Wodka et al. (2007) found ADHD children with greater reaction time variability than controls on a basic go/no-go task. Reaction time variability has been found to differentiate between children with ADHD and controls on the go/no-go continuous performance test (Rubia, Russell, Overmeyer, Brammer, Bullmore, et al., 2001; Van der Meere, Marzocchi, & De Meo, 2005; Wahlstedt, Thorell, & Bohlin, 2009; Wodka et al, 2007).

In addition, ability to detect targets versus non-targets (d') and not responding to target stimuli (omissions) distinguished between ADHD and control groups in our study, though at a lower magnitude than the reaction time variables. Conners et al. (2003) also found group differences research on CCPT omissions and Detectability (d'). Meta-analyses revealed mean effect sizes in the moderate range (.64 to .66) for CPT omissions (Frazier et al., 2004; Wilcutt et al., 2005). Thus, our results are consistent with prior literature that found individuals with

ADHD to have difficulty with accuracy on CPT tasks. Specifically, detectability and omissions are conceptually related, as they both assess the ability of the individual to discriminate targets from non-targets and then respond appropriately.

Comparison of CCPT variables and CPRS Inattentive and Hyperactive/Impulsive scales found significant correlations with the reaction time variables. Specifically, Hit RT SE was moderately correlated with both CPRS Inattentive and Hyperactive/Impulsive subscales, while Hit RT was modestly correlated with both subscales. This is consistent with most theories of ADHD, that control of motor behavior (and consequently time taken to perform motor behavior) is associated with the disorder (e.g. Barkley, 1997; Nigg, 2001; Sergeant, 2005; Sonuga-Barke, 2002).

In regards to CCPT accuracy variables, omissions were modestly correlated with CPRS Inattention, while commission errors showed no significant correlations. A previous study found no significant correlations between CCPT omissions and neither parent nor teacher ratings of inattentive and hyperactive-impulsive behaviors in children with ADHD, and a negative relationship between commissions and teacher reported hyperactive-impulsive behaviors was noted (Edwards, Gardner, Chelonis, Schulz, Flake, & Diaz, 2007). Another study found commission errors related to both ADHD symptom domains (Brocki, Tillman, & Bohlin, 2010). Prior research has suggested that omission errors are suggestive of inattention because responses to target stimuli are not being generated (Barkley, 1991). Since stimuli are being presented relatively frequently, omissions mean that the individual is likely off-task, bored, or not engaged in the task. Therefore, our results modestly support this hypothesis that inattention is related to omissions.

Detectability (d’) and response style (B) were modestly correlated with CPRS

Hyperactivity/Impulsivity. Significant weaknesses in CCPT detectability have been found for both the ADHD-C and ADHD-PI subtypes (Huang-Pollock, Nigg, & Halperin, 2006; Losier, McGrath, & Klein, 1996). Huang-Pollock et al. (2006) also found children with ADHD-C to have more deficient response style (B) scores than those with ADHD-PI, suggesting that the hyperactive/impulsive component of ADHD-C is associated with difficulty in "activation" on the CCPT, which is consistent with our results. Detectability measures perceptual sensitivity to targets, and response style measures if a participant responds too little or too much based on the actual distribution of target stimuli. More risky or impulsive ("too much") responding would result in clinically significant scores. Sergeant et al. (1999) posit that deficits in ADHD are associated with activation and alertness/arousal, both of which influence detectability and response style scores.

Epstein et al. (2003) compared CCPT performance with symptom report on a parent diagnostic interview, and found Hit RT SE, Commissions, Omissions, Detectability, and Response Style demonstrating relationships across both ADHD symptom domains. Other research has found no significant correlations between Conners' Parent and Teacher rating scale ADHD symptoms and any of the CCPT detectability, response style, hits, omission, and commission variables (Naglieri, Goldstein, Delauder, & Schwebach, 2005). Therefore, our results differ somewhat in that we did not find consistent relationships across CCPT variables and both symptom domains. A difference could lie in the way ADHD symptoms were measured, as Epstein's study utilized a face-to-face parent interview, and while our study and Naglieri et al. used a rating scale.

Predictive Utility of Diagnostic Group

D-KEFS. Prediction of diagnostic group membership by the D-KEFS was evaluated with

D-KEFS planning/inhibition/switching variables, and only Tower Total Achievement score emerged as a significant predictor of diagnostic group (overall correct classification rate 72.1%). An exploratory analysis was conducted with all D-KEFS variables entered, and Tower Total Achievement, Trailmaking Motor Speed, and Verbal Fluency- Category Fluency Total Correct were the only significant predictors in the model (overall correct classification rate 79.4%). Thus, including more basic tasks in the equation allowed for more accurate classification than provided by the Tower Total Achievement score alone.

Prior research found Tower Total Achievement and Trailmaking (Switching vs. Number Sequencing contrast score) to predict diagnostic status in girls, with overall correct classification being 67.3% (Wodka et al., 2007). For boys, the Color Word Interference combined Color Naming+Word Reading optional score was the only significant predictor, with overall correct classification being 58.5%. Therefore, the current study's discriminative utility was slightly better than that of Wodka and colleagues, and also included Tower Total Achievement as a significant predictor. However, Wodka et al. only found Tower to be a significant predictor for females. As our sample included very few females, and sex was not significant in any analysis, it appears that the Tower test may, in fact, differentiate males with ADHD as well. Weighted mean effect sizes found traditional tower tests to have moderate effects between diagnostic group (.51 to .69) (Wilcutt et al., 2005). This is compared to mean effect sizes of trailmaking, Stroop-like color-word, and verbal fluency tests averaging .40 to .56. Thus, there is evidence from prior research that tower tests are slightly better at discriminating between groups than other EF tests.

Two additional variables were significant in the current study – Trailmaking Motor Speed and Verbal Fluency – Category Fluency. Though Wodka et al. found a Trailmaking variable to be predictive of diagnostic group in females, it was not the motor speed condition. Traditional trailmaking tests have been found to have a total predictive power of 54% (Grodzinsky et al., 1999). As our final model combined the Trailmaking variable with others, it is not surprising that the discriminative utility was improved. It is possible that motor speed might be what is deficient in individuals with ADHD, rather than the more complex tasks of sequencing and switching. Sergeant's (2005) cognitive-energetic model posits that failure of activation of response is a defining factor of ADHD. Greater sluggishness and variability in motor preparation, as well as difficulty in execution of complex motor movements have been found to be deficient in children with ADHD (McMahon & Greenberg, 1977; Oosterlaan & Sergeant, 1995). Our results point to this as more critical to predicting diagnostic status than the more complex aspects of the Trailmaking subtest.

Traditional category fluency tests have a mean effect size of .41 (Frazier et al., 2004), with mixed results indicating that individuals with ADHD have difficulty with both the letter fluency and category fluency tests (e.g. Grodzinsky & Barkley, 1999; Grodzinksy & Diamond, 1992), and others indicating only difficulty with letter fluency (Sergeant, Geurtz, & Oosterlaan, 2002). Our study found only Category Fluency to be a significant predictor of diagnostic group, and the more complex task of Category Switching did not predict diagnostic group status. It is unclear why only Category Fluency and neither Category Switching nor Letter Fluency were predictive of diagnostic group. Given the results that showed ADHD group performance was not below average on either Category Fluency or Letter Fluency, it is possible that the control group just performed particularly well, resulting in the significant prediction of diagnostic group status.

CCPT. Analyses revealed Hit RT SE being the only predictor of diagnostic status (overall correct classification 73.5%). Meta-analyses of CPTs have reported low sensitivity (15-38%), good specificity (91%), moderate positive predictive power (68-87%), and low negative predictive power (47-61%) (Grodzinsky et al., 1999; Doyle et al., 2000). Overall correct classification ranged 50-67%. These numbers were based on measures of number correct, omissions, and commissions.

As the current study's discriminative utility was based on only one significant predictor, Hit Reaction Time SE (variability), direct comparison with previous research is limited. However, some trends can be noted. Sensitivity was significantly higher than that reported in previous studies, suggesting that ADHD children are more likely to have abnormal scores on the test than controls. In addition, positive predictive power (76%), which shows moderate likelihood that an abnormal test result predicts ADHD status, was similar to that in the meta-analyses. Specificity was slightly lower than previous research, indicating that control participants were less likely to have normal scores in our study than in previous research. However, this rate was still 83% in the current study, which was the highest out of all predictive rates. Finally, negative predictive power (72.1%) in the current study was quite a bit higher than previous research, indicating that individuals with normal test scores were more likely to be correctly classified as non-ADHD.

It is possible that Hit RT SE is a better predictor of ADHD group status than the CPT variables used in the meta-analyses, as research on motor responding has found both greater sluggishness and greater variability in motor preparation in individuals with ADHD (Oosterlaan & Sergeant, 1995). Our overall results point to the CPT as being better able to classify non-ADHD individuals than those with ADHD, which is consistent with the literature.

D-KEFS and CCPT. Using the planning/inhibition/switching D-KEFS variable (Tower Total Achievement) with the CCPT variable (Hit RT SE), the final model only retained CCPT Hit RT SE and Full Scale IQ as significant predictors. Therefore, incremental utility of diagnostic prediction by the tasks was not found. Sensitivity of this model was 61.3%, specificity was 75.7%, and the overall correct classification rate was 69.1%. Positive and negative predictive power was 67.9% and 70.0%, respectively. All of these values were lower than the model described above that used only CCPT variables as predictors (and not IQ). However, the combined model included IQ as a predictor given the relation to D-KEFS scores. Though IQ was a significant predictor in the combined analysis, it actually reduced the predictive utility of the CCPT. These results also suggest that Hit Reaction Time SE on the CCPT was more important to predicting diagnostic group than the Tower Total Achievement score, pointing to a possible more pronounced deficit in motor speed variability ("erraticness") than planning in individuals with ADHD.

When entering the CCPT Hit RT SE and D-KEFS variables that were significant in the exploratory analysis that included all D-KEFS variables, the final model of combined predictive utility only included Trailmaking Motor Speed and Verbal Fluency – Category Fluency. Again, the hypothesis of combined predictive utility of the tasks was not supported, as only D-KEFS variables entered into the final model, while CCPT variables did not. Interestingly, no D-KEFS planning/inhibition/switching variables were significant predictors when the model attempted to include the CCPT Hit RT SE score. The addition of CCPT Hit RT SE as a possible predictor "forced" the Tower variable out of the model. Predictive utility of the D-KEFS-only model was better than that of the current model that attempted to combine CCPT and D-KEFS, suggesting that combining tasks is actually detrimental to prediction of diagnostic group.

Concurrent Validity Between the D-KEFS and CCPT

Patterns of intercorrelations between the D-KEFS and CCPT were examined with the hypothesis that the D-KEFS inhibition/switching variables would be related to CCPT scores, as the CCPT measures relatively basic inhibition skills. Interpretation was based on those at the $p < .01$ level or better. CCPT accuracy (omission and commission errors) were both significantly correlated with D-KEFS Verbal Fluency – Category Switching total switching accuracy, which assesses the ability to keep two concepts in mind while responding to both. Though the CCPT requires motor responses and category switching requires verbal responses, both tasks include an aspect of keeping two rules in mind at the same time, which taps into the EFs of working memory and reconstitution.

CCPT Detectability (discrimination between X and non-X) was significantly related to Trailmaking Number Sequencing, which is somewhat surprising, given that the CCPT requires the participant to discriminate between letters, not numbers. It is possible that this result is due to the Number Sequencing being the first task presented on the D-KEFS Trailmaking test that requires the individual to view an array of letters and numbers and only pay attention to one modality (numbers), and practice effects might be in place when completing Letter Sequencing. However, both ADHD and control group means for Letter Sequencing were actually lower than for Number Sequencing. Therefore, some other variable might be affecting the non-significant relationship between CCPT detectability and Trailmaking Leter Sequencing.

Variability in reaction time on the CCPT was related to two D-KEFS inhibition/switching measures (Letter-Number Switching and with Color Word Interference Inhibition, which partially supports our hypothesis. In addition, D-KEFS Letter Sequencing and Color Word Interference Color Naming, two more basic tasks, were also significantly correlated with CCPT Hit RT SE. Though it would follow more naturally for the Trailmaking subtest to be related to an accuracy measure of the CCPT (because of discrimination between letters), it was related to a measure of reaction time variability. Both Trailmaking and Color Word Interference subtests are time-sensitive, with better scores being associated with faster response times. Thus, more variable reaction time in responding would predict difficulty with any task that requires speed of responding combined with accuracy.

No previous research has compared performance between these two measures; therefore, this study provides exploratory findings. Overall, a clear pattern of significance between inhibition/switching D-KEFS variables and CCPT variables was not noted. The tasks of each measure are inherently very different, with the CCPT likely requiring fewer complex cognitive and motor processes than some of the tasks of the D-KEFS. However, since several of the variables were related to each other, it is also possible that the CCPT is actually tapping into more complex EFs. Some researchers found the CCPT unable to distinguish between children with ADHD and those with reading disorders (McGee, Clark, & Symons, 2000). They suggest that the CCPT's use of letters as stimuli confounds phonological skills with inhibition, and this may confound the measurement of more basic continuous responding and behavioral inhibition. Given the lack of significant correlations across all measures of both tasks, it may be that the CCPT and the D-KEFS offer potentially useful clinical information on different aspects of EF.

Predictive Utility of the D-KEFS by Age Group

Two age groups (8-10.11 years and 11.0 to 14 years) were formed, based on cognitive and developmental theory, to assess whether ADHD diagnosis or symptoms were predicted by different D-KEFS tasks at different ages. For the younger age group, Full Scale IQ was the only significant predictor of diagnostic status. The older group produced no significant models as predictors of diagnostic group. Possible non-significant results could be due to statistical power issues, since the total sample was divided into two groups. Full scale IQ was not significantly different between age group. However, diagnosis by age group analyses produced a significant interaction, with the younger control group participants having significantly higher IQ (M=120) than the older control group participants (M=105) and both older (M=101) and younger (M=97) ADHD participants. This interaction might have affected the predictive utility of the D-KEFS, given the strong relationship between D-KEFS performance and IQ in our sample.

CPRS Inattentive symptoms in the younger age group were predicted by Verbal Fluency – Category Fluency and Letter Fluency total correct, Tower Total Achievement, and Trailmaking Motor Speed, with 71% of variance explained by these variables. Hyperactive/Impulsive symptoms for the younger group were predicted by Verbal Fluency – Category Fluency and Full Scale IQ, with 49% of variance explained by these variables. For the older age group, Inattentive symptoms were predicted only by Color Word Interference Inhibition, accounting for 29% of the variance. No variables were found to be significant predictors of Hyperactive/Impulsive scores for this group.

Brocki and Bohlin (2006) found that younger children's (ages 6.0 to 9.7) ADHD Inattentive and Hyperactive/Impulsive symptoms were related to their performance on tasks of disinhibition, while the older age group's (9.8 to 13.0 years) ADHD Inattentive symptoms were significantly related to verbal working memory and fluency and speed/arousal. No relationship with Hyperactive/Impulsive symptoms in the older age group was noted. Though age range in the groups was different than in the current study (due to Brocki and Bohlin's median split method of creating groups), current results are not commensurate with their findings for the younger age group, as none of the tasks that were significant predictors of inattention or hyperactivity/impulsivity in our study were direct measures of inhibition. The older group in the current study did replicate a portion of Brocki and Bohlin's findings, as Color Word Interference Inhibition was predictive of inattentive symptoms. Additionally, no measures predicted hyperactive/impulsive symptoms in the older age group in either study.

Regarding the developmental progression of EFs, research is not consistent across age groups and measures, thus making it difficult to establish an accurate picture of the relationship between ADHD symptoms and EF at different ages. EEG studies show central nervous system changed through childhood, with growth periods appearing between birth and 2 years, another from 7 to 9 years, and a final spurt at 16 to 19 years (Thatcher, 1991). Hudspeth and Pribram (1990) found frontal regions of the brain to have accelerated development from 7 to 10 years. Given these biologically-based changes, it would be expected that neuropsychologically measured cognitive changes would be evident around these periods of time. Several researchers have examined the development of EF in normally developing children and have found a steady stage-like progression of skills from 6 to 12 years of age (Chelune & Baer, 1986; Levin, Culhane, Hartmann, Evankovich, Mattson, Harward, et al., 1991; Passler, Isaac, & Hynd, 1985).

Results from the current study found Verbal Fluency, Trailmaking, and Tower Test predictive of ADHD symptoms in children under age 11. Both Tower Test and Verbal Fluency task performance have been found to continue development past age 12 (Welsh, Pennington, & Groisser, 1991), which may indicate that skills are much more variable at younger ages. Thus, these tests may be more predictive of ADHD symptoms in the younger age group because they are still in flux, and children with ADHD may be further behind in development than their same-age peers. In regards to Trailmaking, prior research found possible stabilization around age 12 years (Anderson, 1998). Since the current study's age cut point was 11 years, it is difficult to assess the consistency of these results. However, Trailmaking skills are reportedly continuing to develop past age 11. Our youngest age group's ADHD symptoms were predicted by a basic motor speed aspect of the task, which suggests the possibility that, though task skills in general are continuing to develop, children with ADHD might show difficulty with Trailmaking due to a motor speed deficit at younger ages.

Limitations

Several limitations should be noted regarding the current study. First, inclusion criteria for the study did not rule out comorbid psychological disorders; therefore, the sample may have been more heterogeneous than those of other studies of children with ADHD, which often have more stringent inclusion criteria that rules out comorbidities. Additionally, ADHD diagnosis was confirmed by rating scale scores and prior diagnosis by a professional. This method was used given Pelham et al.'s (2005) findings that rating scales are sufficient to document ADHD symptomatology in research studies. However, more strict inclusion criteria might have produced different outcomes. In addition, lack of a comprehensive ADHD evaluation precluded the use of ADHD subtypes in analyses, as all children with ADHD were combined into one group. Though the CPRS symptom scales do not necessarily classify subtypes, use of this measure would have resulted in most participants being labeled the Combined subtype. Therefore, differences in performance between subtypes could not be assessed.

Recruitment resulted in a small number of females in the ADHD group, which is consistent with national prevalence rates. Some studies have oversampled females in order to conduct gender comparisons (e.g. Wodka et al., 2008a); however, this method was not used for the current study. Wodka and colleagues noted sex differences on a few subscales of the D-KEFS, but our sample did not allow for specific sex comparisons. It should be noted that sex was used as a predictor in all D-KEFS analyses in the current study, and it was a non-significant factor in all analyses.

Sample size was relatively small for the number of variables studied, which could have influenced the detectability of performance differences in the measures to be detected. Recruitment difficulties in a small town likely influenced sample size, as data collection spanned the course of almost one year. Furthermore, many research packets were completed and returned for children who did not have a prior diagnosis of ADHD, but scores on the CPRS were clinically significant. These potential participants did not meet criteria for either the ADHD group or control group. It is possible that parents thought the study would assess their children for ADHD, even though it was clearly stated in the packet that this was not the case. Regardless, many fewer packets were returned in which the child did not have an ADHD diagnosis and had non-significant CPRS scores.

This response pattern resulted in difficulty with recruitment of control participants, specifically since each ADHD participant was matched to a control participant by age and sex. Midway through the data collection period, recruitment focused solely on control participants in order to obtain relatively equal numbers in each group. Flyers continued to be posted at schools, daycares, doctor's offices, and psychological clinics. However, the snowball effect was the most successful method for recruiting control participants. This could have influenced the sample characteristics, though, because families that were affiliated with the university (professors, friends of professors, etc.) were most likely to respond to a call for research participation. Demographics of the university faculty indicate a majority of Caucasian individuals, which resulted in a large number of Caucasian participants in the control group. Racial makeup of the control group might have differed if all participants had been from the initial recruitment phase.

Recruitment difficulties likely affected the confounding issues of IQ differences by race (African American participants had lower mean IQ than Caucasian participants). There was a non-significant interaction between race and diagnostic group on IQ. However, the disproportionate number of African American participants in the ADHD group compared to the control group make conclusions from the results complicated in regards to race. An attempt to statistically address this issue was made by including IQ as a predictor in analyses. Nevertheless, results would have been clearer if groups had been matched by race (perhaps thereby controlling for IQ in this sample) as well as sex and age.

Evaluation of the developmental relationship between EF and ADHD was difficult to complete with any certainty. The lack of consistent literature giving age-specific cutpoints in development of EFs complicated the matter of selecting age groups for analyses. The choice of using Piaget's cognitive developmental theory and theories related to progression of ADHD symptoms upon entering middle school was made for exploratory purposes. However, future analyses could be done with each D-KEFS subtest using age cut points indicated in the literature as reaching adult levels for each task that is similar to its D-KEFS counterpart.

Conclusions and Future Directions

The predictive utility of ADHD diagnostic status by the D-KEFS was found to be moderate and largely unrelated to the more EF task components of the test battery, with the exception of the Tower test. Combined predictive utility with a more basic measure of behavioral inhibition, the CCPT, did not result in better diagnostic group classification rates. In fact, statistical attempts at combining the tasks actually resulted in worse prediction rates. This could be due to sample size and the number of variables used in the analyses, or to true lack of utility in combination of tasks. Some diagnostic group performance trends were noted, with ADHD individuals' performance on the planning/inhibition/switching tasks of Trailmaking, Verbal Fluency, Color Word Interference, and Tower tests more likely to be below average than performance by control participants. In addition, CPRS ratings of inattention and hyperactivity/impulsivity were significantly related to almost all of the D-KEFS variables. These results point to the possible clinical utility of the D-KEFS in ADHD diagnosis. However, clinicians should be cautious in using either of these measures when evaluating individuals for ADHD, and should, rather, combine information from more clinically established sources of information. Current assessment practices point to diagnostic interviews and rating scales as the most valid forms of assessment for ADHD (Barkley, 2006), given the unreliability of many neuropsychological tests to accurately predict diagnosis. However, there is no gold standard for ADHD evaluation, and information from neuropsychological tests can be helpful collateral information in some circumstances. Future research needs to focus on the ecological validity of laboratory measures, and the creation of tests that can be administered or evaluated in a "real world" setting could prove better at discriminating between individuals with ADHD and those without the disorder.

In addition, findings in the current study are consistent with previous research that not all individuals with ADHD will demonstrate deficits in EF on laboratory measures (Bernstein & Waber, 1990). Researchers posit that some individuals with ADHD might recruit other "compensatory" cognitive resources to perform in lab settings but still have difficulties when subject to more distractions in the real world (Doyle et al., 200). It remains unclear why EF deficits are found in some individuals with ADHD but not others, but dual-pathway models such as Sonuga-Barke's (2002) might explain this. As suggested, there might be two different etiologies toward ADHD, with different neuropsychological deficits as a result. The only ways to clarify this relationship would be to either differentiate ADHD groups by symptom presentation instead of grouping them all together into one combined ADHD group, or determine a way to differentiate individuals by etiology based on Sonuga-Barke's theory.

Developmentally, results did not reveal any clear patterns regarding the predictive utility of the D-KEFS at different age groups. However, some age group patterns were noted with the relationship between inattentive and hyperactive/impulsive symptoms and D-KEFS performance. As these analyses were exploratory, and choice of age group cut points was subject to the inherent lack of consensus in the literature, further research is needed to clarify age patterns.

Future research is necessary to evaluate the usefulness of the D-KEFS in ADHD diagnostic assessments, given that only two published research groups have used the measure with ADHD populations, with mixed results. Critical in the process of establishing reliability and validity is evaluating a wide range of well-defined clinical samples. Future studies should be very specific in looking at and describing their sample's demographics and comorbid characteristics, as these factors could affect group performance. In addition, since IQ scores were very significantly related to most D-KEFS variables, research clarifying the relationship or distinction between the constructs of intelligence and EF (as measured by the D-KEFS) are critical. Comparison between ADHD subtypes could also elucidate possible different EF profiles for each subtype, as it is often the case that all ADHD subtypes are combined into one group for analyses. Along similar lines, further study of possible sex differences in D-KEFS performance is important, given that research has pointed to differences in ADHD symptom presentation in girls versus boys. Longitudinal studies with retests on the D-KEFS every few years would provide useful information regarding the trajectory of EF development in individuals with ADHD. In addition, further clarification of age-related development of EFs would be useful to give researchers a comparison of how abnormal or delayed EF development is in ADHD children. Previous research has pointed to the lack of reliability of the process and contrast scores generated by the D-KEFS scoring software. Though it was beyond the scope of this study to include analyses of these variables, further evaluation of these measures might be useful. Finally, the high number of intercorrelations between D-KEFS variables could have reduced the significance of findings in the regression analyses. A large-scale study of D-KEFS performance by individuals with ADHD would allow for factor analysis, which may illuminate clusters of skills that may better explain possible EF difficulties.

References

American Psychiatric Association. (2000). *Diagnostic and statistical manual of mental disorders* (4th ed., rev.). Washington, DC: Author.

Anderson, V. (1998). Assessing executive functions in children: Biological, psychological, and developmental considerations. *Neuropsychological Rehabilitation, 8*, 319-349.

Anderson. V., Anderson, P., & Lajoie, G. (1996). The Tower of London Test: Validation and standardization for pediatric populations. *The Clinical Neuropsychologist, 10,* 54-65.

Barkley, R. A. (1991). The ecological validity of laboratory and analogue assessment methods of ADHD symptoms. *Journal of Abnormal Child Psychology*, *19,* 149–178.

Barkley, R. A. (1997). Behavioral inhibition, sustained attention, and executive function: Constructing a unified theory of ADHD. *Psychological Bulletin, 121*, 65-94.

Barkley, R. A. (2006). *Attention-Deficit Hyperactivity Disorder : A handbook for diagnosis and treatment* (3rd ed.). New York: Guilford Press.

Benton, A. L., & Hamsher, K. deS. (1976). *Multilingual Aphasia Examination Manual* (Rev. ed.). Iowa City: University of Iowa.

Bernstein, J., & Waber, D. (1990). Developmental neuropsychological assessment: The systemic approach. In A. Boulton, G. Baker, & M. Hiscock (Eds.), *Neuromethods: Neuropsychology* (pp. 311-371). Clifteon, NJ: Humana Press.

Bianchi, L. (1922). *The mechanism of the brain and the function of the frontal lobes*. Edinburgh: Livingston.

Bidwell, L. C., Willcutt, E. G., DeFries, J. C., & Pennington, B. F. (2007). Testing for neuropsychological endophenotypes in siblings discordant for Attention-Deficit/Hyperactivity Disorder. *Biological Psychiatry, 62*, 991-998.

Blair, C., Zelazo, P. D., & Greenberg, M. T. (2005). The measurement of executive function in early childhood. *Developmental Neuropsychology, 28*, 561-571.

Borys, S. V., Spitz, H. H., & Dorans, B. A. (1982). Tower of Hanoi performance of retarded young adults and nonretarded children as a function of solution length and goal state. *Journal of Experimental Child Psychology, 33*, 87-110.

Brocki, K. C., & Bohlin, G. (2006). Developmental change in the relation between executive functions and symptoms of ADHD and co-occurring behaviour problems. *Infant and Child Development, 15*, 19-40.

Brown, T. E. (2006). Executive functions and attention deficit hyperactivity disorder: Implications of two conflicting views. *International Journal of Disability, Development, and Education, 53*, 35-46.

Carroll, J. B. (1993) *Human cognitive abilities: A survey of factor analytic studies*. New York: Cambridge University Press.

Carte, E. T., Nigg, J. T., & Hinshaw, S. P. (1996). Neuropsychological functioning, motor speed, and language processing in boys with and without ADHD. Journal of Abnormal Child Psychology, 24, 481-498.

Chhabildas, N., Pennington, B. F., & Wilcutt, E. G. (2001). A comparison of neuropsychological profiles of the DSM-IV subtypes of ADHD. *Journal of Abnormal Child Psychology, 29*, 529-540.

Chelune, G. J., & Baer, R. A. (1986). Developmental norms for the Wisconsin Card Sorting Test. *Journal of Clinical and Experimental Neuropsychology, 8*, 219-228.

Collett, B. R., Ohan, J. L., & Myers, K. M. (2003). Ten-year review of rating scales. VI: Scales assessing externalizing behaviors. *Journal of American Academy of Child and Adolescent Psychiatry, 42*, 1143-1170.

Conners, C. K. (1995). *Conners' Continuous Performance Test*. North Tonawanda, NY: Multi-Health Systems, Inc.

Conners, C. K. (2000). *Conners' Rating Scales – Revised*. North Tonawanda, NY: Multi-Health Systems, Inc.

Conners, C. K., Epstein, J. N., Angold, A., & Klaric, J. (2003). Continuous performance test performance in a normative epidemiological sample. *Journal of Abnormal Child Psychology, 31*, 555-562.

Conte, R., & Regehr, S. M. (1991). Learning and transfer of inductive reasoning rules in overactive children. *Cognitive Therapy and Research, 15*, 129-139.

Corbett, B., Constantine, L., Hendren, R., Rocke, D., & Ozonoff, S. (2009). Examining executive functioning in children with autism spectrum disorder, attention deficit hyperactivity disorder, and typical development. *Psychiatry Research, 166*, 210-222.

Culbertson, W. C., & Zillmer, E. A. (1999). *Tower of London: Examiner's manual*. North Towanda, NY: Multi-Health Systems.

Danforth, J. S., Barkley, R. A., & Stokes, T. F. (1991). Observations of parent-child interactions with hyperactive children: Research and clinical implications. *Clinical Psychology Review, 11*, 703-727.

Davidson, M. C., Amso, D., Anderson, L. C., & Diamond, A. (2006). Development of cognitive control and executive functions from 4 to 13 years: Evidence from manipulations of memory, inhibition, and task switching. *Neuropsychologia, 44*, 2037-2078.

Delis, D. C., Kaplan, E., & Kramer, J. H. (2001). *Delis-Kaplan Executive Function System*. San Antonio, Texas: The Psychological Corporation.

Delis, D. C., Lansing, A., Houston, W. S., Wetter, S., Han, S. D., et al. (2007). Creativity lost: The importance of testing higher-level executive functions in school-age children and adolescents. *Journal of Psychoeducational Assessment, 25*, 29-40.

Douglas, V. I. (1985). The response of ADD children to reinforcement. In L. M. Bloomingdale (Ed), *Attention deficit disorder: diagnostic, cognitive, and therapeutic understanding* (pp. 147-162). New York: Spectrum.

Doyle, A. E., Biederman, J., Seidman, L. J., Weber, W., & Faraone, S. V. (2000). Diagnostic efficiency of neuropsychological test scores for discriminating boys with and without attention deficit-hyperactivity disorder. *Journal of Consulting and Clinical Psychology, 68*, 477-488.

Drewe, E. A. (1975). Go-no go learning after frontal lobe lesions in humans. *Cortex, 11*, 8-16.

Dykman, R. A., Ackerman, M. A., & Oglesby, B. A. (1980). Correlates of problem solving in hyperactive, learning disabled, and control boys. *Journal of Learning Disabilities, 13*, 23-32.

Edwards, M. C., Gardner, E. S., Chelonis, J. J., Schulz, E. G., Flake, R. A., & Diaz, P. F. (2007). Estimates of the validity and utility of the Conners' continuous performance test in the assessment of inattentive and/or hyperactive-impulsive behaviors in children. *Journal of Abnormal Child Psychology, 35*, 393-404.

Epstein, J. N., Alaatin, E., Conners, C. K., Klaric, J., Costello, J. E., et al. (2003). Relations between continuous performance test performance measures and ADHD behaviors. *Journal of Abnormal Child Psychology, 31*, 543-554.

Floyd, R. G., McCormack, A. C., Ingram, E. L., Davis, A. E., Bergeron, R., & Hamilton, G. (2006). Relations between the Woodcock-Johnson III clinical clusters and executive functions from the Delis-Kaplan Executive Function System. *Journal of Psychoeducational Assessment, 24*, 303-317.

Frazier, T. W., Demaree, H. A., & Youngstrom, E. A. (2004). Meta-analysis of intellectual and neuropsychological test performance in attention-deficit/hyperactivity disorder. *Neuropsychology, 18*, 543-555.

Gogtay, N., Giedd, J. N., Lusk, L., Hayashi, K. M., Greenstein, D., et al. (2004). Dynamic mapping of human cortical development during childhood through early adulthood. *Proceedings of the National Academy of Sciences of the United States of America, 101*, 8174-8179.

Golden, C. J. (1978). *The Stroop color and word test*. Chicago: Stoelting Company.

Grant, D. A., & Berg, E. A. (1948). A behavioral analysis of degree of reinforcement and ease of shifting to new response in a Weigl type card sorting problem. *Journal of Experimental Psychology, 38*, 404-411.

Grodzinsky, G. M., & Barkley, R. A. (1999). Predictive power of frontal lobe tests in the diagnosis of attention deficit hyperactivity disorder. *The Clinical Neuropsychologist, 13*, 12-21.

Grodzinsky, G. M., & Diamond, R. (1992). Frontal lobe functioning in boys with attention-deficit

hyperactivity disorder. *Developmental Neuropsychology, 8*, 427-445.

Haenlein, M., & Caul, W. F. (1987). Attention deficit disorder with hyperactivity: A specific hypothesis of reward dysfunction. *Journal of American Academy of Child and Adolescent*

Psychiatry, 26, 356-362.

Hinshaw, S. P., & Melnick, S. (1992). Self-management therapies and attention-deficit hyperactivity disorder: Reinforced self-evaluation and anger control interventions. *Behavior Modification, 16*, 253-273.

Hinshaw, S. P., Carte, E. T., Sami, N., Treuting, J. J., & Zupan, B. A. (2002). Preadolescent girls with attention-deficit/hyperactivity disorder: II, Neuropsychological performance in relation to subtypes and individual classification. *Journal of Consulting and Clinical Psychology, 70*, 1099-1111.

Houghton, S., Douglas, G., West, J., Whiting, K., Wall, M., et al. (1999). Differential patterns of executive function in children with attention-deficit hyperactivity disorder according to gender and subtype. *Journal of Child Neurology, 14*, 801-805.

Hudspeth, W., & Pribram, K. (1990). Stages of brain and cognitive maturation. *Journal of Educational Psychology, 82*, 881-884.

Kleinhans, N., Akshoomoff, N., & Delis, D. C. (2005). Executive functions in autism and Asperger's disorder: Flexibility, fluency, and inhibition. *Developmental Neuropsychology, 27*, 379-401.

Klimkeit, E. I., Mattingley, J. B., Sheppard, D. M, Lee, P., & Bradshaw, J. L. (2005). Motor preparation, motor execution, attention, and executive functions in Attention Deficit/Hyperactivity Disorder (ADHD). *Child Neuropsychology, 11*, 153-173.

Kochanska, G., DeVet, K., & Goldman, M. (1994). Maternal reports of conscience development and temperament in young children. *Child Development, 65*, 852-868.

Lahey, B. B., Applegate, B., McBurnett, K., Biederman, J., Greenhill, L., Hynd, G.W., et al. (1994). DSM-IV field trials for attention deficit/hyperactivity disorder in children and adolescents. *Journal of the American Academy of Child and Adolescent Psychiatry, 151*, 1673-1685.

Levin, H. S., Culhane, K. A., Hartmann, J., Evankovich, K., Mattson, A. J., Harward, H., et al. (1991). Developmental chages in performance on tests of purported frontal lobe functioning. *Developmental Neuropsychology, 7*, 377-395.

Lezak, M. D. (1985). Neuropsychological assessment. In J. A. M. Frederiks (Ed.), *Handbook of Clinical Neurology: Vol. I. Clinical Neuropsychology* (pp. 515-530). New York: Elsevier.

Logan, G. D., Schachar, R. J., & Tannock, R. (1997). Impulsivity and inhibitory control. *Psychological Science, 8*, 60-64.

Luria, A. (1966). *Higher cortical functions in man*. New York: Basic Books.

Mahone, E. M., Hagelthorn, K. M., Cutting, L. E., Schuerholz, L. J., Pelletier, S. F., Rawlins, C., et al. (2002). Effects of IQ on executive function measures in children with ADHD. *Child Neuropsychology, 8*, 52-65.

Mattson, S. N., Goodman, A. M., Caine, C., Delis, D. C., & Riley, E. P. (1999). Executive functioning in children with heavy prenatal alcohol exposure. *Alcoholism: Clinical and Experimental Research, 23*, 1808-1815.

McGee,R. A., Clark, S. E., & Symons, D. K. (2000). Does the Conners' continuous performance test aid in ADHD diagnosis? *Journal of Abnormal Child Psychology, 28*, 415-424.

McMahon, S. A., & Greenberg, L. M. (1977). Serial neurologic examination of hyperactive children. *Pediatrics, 59*, 584-587.

Meehl, P. E. (1970). Nuisance variables and the ex post facto design. In M. Radner & S. Winokur (Eds.), *Minnesota studies in the philosophy of science: Analyses of theories and methods of physics and psychology* (Vol. 4) (pp. 373-402). Minneapolis: University of Minnesota

Press.

Miller, G. A. & Chapman, J. P. (2001). Misunderstanding analysis of covariance. *Journal of Abnormal Psychology, 110*, 40-48.

Naglieri, J. A., Goldstein, S., Delauder, B. Y., & Schwebach, A. (2005). Relationships between the WISC-III and the Cognitive Assessment System with Conners' rating scales and continuous performance tests. *Archives of Clinical Neuropsychology, 20*, 385-401.

Newcombe, F. (1969). *Missile wounds of the brain*. New York: Oxford University Press.

Nigg, J. T. (2001). Is ADHD a disinhibitory disorder? *Psychological Bulletin, 127*, 571-598.

Nigg, J. T. (2006). *What causes ADHD? Understanding what goes wrong and why*. New York: Guilford Press.

Nigg, J. T., Blaskey, L. G., Huang-Pollock, M. A., & Rappley, M. D. (2002). Neuropsychological executive functions and DSM-IV ADHD subtypes. *Journal of the American Academy of Child and Adolescent Psychiatry, 41*, 59-66.

Oosterlaan, J., & Sergeant, J. A. (1995). Response choice and inhibition in ADHD, anxious, and aggressive children : The relationship between S-R compatibility and stop signal task. In J. A. Sergeant (Ed.), *Eunethydis: European approaches to hyperkinetic disorder* (pp. 225-240). Amsterdam: University of Amsterdam.

Passler, M. A., Isaac, W., & Hynd, G. W. (1985). Neuropsychological development of behavior attributed to frontal lobe functioning in children. *Developmental Neuropsychology, 1*, 349-370.

Pelham, W. E., Fabiano, G. A., & Massetti, G. A. (2005). Evidence-based assessment of attention deficit hyperactivity disorder in children and adolescents. *Journal of Clinical*

Child and Adolescent Psychology, 34, 449-476.

Pennington, B. F. & Ozonoff, S. (1996). Executive functions and developmental psychopathology. *Journal of Child Psychology and Psychiatry, 37*, 51-87.

Piage, J. (1963). *The origins of intelligence in children*. New York: W. W. Norton.

Rasmussen, C., & Bisanz, J. (2009). Executive functioning in children with fetal alcohol spectrum disorders: Profiles and age-related differences. *Child Neuropsychology, 15*, 201-215.

Reitan, R., & Wolfson, D. (1985). *The Halstead-Reitan Neuropsychological Test Battery: Theory and clinical interpretation*. Tucson: Neuropsychology Press.

Rowland, A. S., Lesene, C. A. & Abramowitz, A. J. (2002). The epidemiology of attention-deficit/hyperactivity disorder (ADHD): A public health view. *Mental Retardation and Developmental Disabilities: Research Reviews, 8*, 162-170.

Sarkis, S. M., Sarkis, E. H., Marshall, D., & Archer, J. (2005). Self-regulation and inhibition in comorbid ADHD children: An evaluation of executive functions. *Journal of Attention Disorders, 8*, 96-108.

Sattler, J. M. (2001). *Assessment of children: Cognitive applications*. San Diego, CA: Jerome M. Sattler, Publisher, Inc.

Scheres, A., Oosterlaan, J., Geurts, H. M., Morein-Zamir, S., Meiran, N., et al. (2004). Executive functioning in boys with ADHD: Primarily an inhibition deficit? *Archives of Clinical Neuropsychology*, *19*, 569-594.

Schonfeld, A. M., Mattson, S. N., Lang, A. R., Delis, D. C., & Riley, E. P. (2001). Verbal and non-verbal fluency in children with heavy prenatal alcohol exposure. *Journal of Studies of Alcohol, 62*, 239-246.

Schuck, S. E. B. & Crinella, F. M. (2005). Why children with ADHD do not have low IQs. *Journal of Learning Disabilities, 38*, 262-280.

Seguin, J. R., Phil, R. O., Harden, P. W., Tremblay, R. E., & Boulerice, B. (1995). Cognitive and neuropsychological characteristics of physically aggressive boys. *Journal of Abnormal Psychology, 104*, 614-624.

Seidman, L. J. (2006). Neuropsychological functioning in people with ADHD across the lifespan. *Clinical Psychology Review, 26*, 466-485.

Seidman, L. J., Biederman, J., & Faraone, S. V. (1995). Effects of family history and comorbidity on the neuropsychological performance of children with ADHD: Preliminary findings. *Journal of the American Academy of Child & Adolescent Psychiatry, 34*, 1015-1024.

Sergeant, J. A. (2005). Modeling Attention-Deficit/Hyperactivity Disorder: A critical appraisal of the cognitive-energetic model. Biological Psychiatry, 57, 1248-1255.

Sergeant, J. A., Geurts, H., & Oosterlaan, J. (2002). How specific is a deficit of executive function for attention-deficit/hyperactivity disorder? *Behavioural Brain Research, 130*, 3–28.

Shallice, T. (1982). Specific impairments of planning. *Philosophical Transactions of the Royal Society of London, Series B: Biological Sciences (London), 298*, 199-209.

Sonuga-Barke, E. J. S. (2002). Psychological heterogeneity in AD/HD – a dual pathway model of behaviour and cognition. *Behavioural Brain Research, 130*, 29-36.

Sonuga-Barke, E. J. S. (2005). Causal models of Attention-Deficit/Hyperactivity Disorder: From common simple deficits to multiple developmental pathways. *Society of Biological Psychiatry, 57*, 1231-1238.

Stroop. J. R. (1935). Studies on interference in serial verbal reactions. *Journal of Experimental*

Psychology. 6. 643-661.

Tabachnick, B. G. & Fidell, L. S. (2007). Us*ing multivariate statistics*. Boston: Pearson Education, Inc.

Thatcher, R. W. (1991). Maturation of the human frontal lobes. Physiological evidence for staging. *Developmental Neuropsychology, 7*, 397-419.

The Psychological Corporation. (1999). *Manual for the Wechsler Abbreviated Scale of Intelligence*. San Antonio, TX: Author.

Tupper, D. E. & Rosenblood, L. K. (1984). Methodological considerations in the use of attribute variables in neuropsychological research. *Journal of Clinical Neuropsychology, 6*, 441-453.

Van der Meere, J., Marzocchi, G. M, & De Meo, T. (2005). Response inhibition and attention deficit hyperactivity disorer with and without oppositional defiant disorder screened from a community sample. *Developmental Neuropsychology, 28*, 459-472.

Van Mourik, R., Oosterlaan, J., & Sergeant, J. A. (2005). The Stroop revisited: A meta-analysis of interference control in AD/HD. *Journal of Child Psychology and Psychiatry, 46*, 150-165.

Wahlstedt, C., Thorell, L. B., & Bohlin, G. (2009). Heterogeneity in ADHD: Neuropsychological pathways, comorbidity, and symptom domains. *Journal of Abnormal Child Psychology, 37*, 551-564.

Waltz, J. A., Knowlton, B. J., & Holyoak, K. J. (1999). A system for relational reasoning in the human prefrontal cortex. *Psychological Science, 10*, 119-125.

Wechsler, D. (1992). *Manual for the Wechsler Intelligence Scale for Children* (3rd ed.). Toronto: Psychological Corporation.

Wechsler, D. (2003). *Wechsler Intelligence Scale for Children, Fourth Edition technical and interpretive manual*. San Antonio, TX: Psychological Corporation.

Welsh, M. C., Pennington, B. F., & Groisser, D. B. (1991). A normative-developmental study of executive function: A window on prefrontal function in children. *Developmental Neuropsychology, 7*, 131-149.

Willcutt, E. G., Doyle, A. E., Nigg, J. T., Faraone, S. V., & Pennington, B. F. (2005). Validity of the executive function theory of attention-deficit/hyperactivity disorder: A meta-analytic review. *Biological Psychiatry, 57*, 1336-1346.

Wodka, E. L., Loftis, C., Mostofsky, S. H., Prahme, C., Gidley Larson, J. C., et al. (2008a). Prediction of ADHD in boys and girls using the D-KEFS. *Archives of Clinical Neuropsychology, 23*, 283-293.

Wodka, E. L., Mahone, E. M., Blankner, J. G., Larson, J. C., Fotedar, S., Denckla, M. B., & Mostofsky, S. H. (2007). Evidence that response inhibition is a primary deficit in ADHD. *Journal of Clinical and Experimental Neuropsychology, 29*, 345-356.

Wodka, E. L., Mostofsky, S. H., Prahme, C., Gidley Larson, J. C., Loftis, C., et al. (2008b). Process examination of executive function in ADHD: Sex and subtype effects. *The Clinical Neuropsychologist, 22*, 826-841.

Woodcock, R. W., McGrew, K. S., & Mather, N. (2001). *Woodcock-Johnson III Tests of Cognitive Abilities*. Itasca, IW: Riverside.

Zakay, D. (1992). The role of attention in children's time reproduction. *Journal of Experimental Child Psychology, 54*, 355-371.

Appendix A: Tables

Table A1. Meta-analysis results for selected EF measures

Outcome Variable	Weighted Mean Effect Size (+/- 95% CI) Frazier et al., 2004	Number of studies included in analysis, Frazier et al., 2004	Weighted Mean Effect Size (+/- 95% CI) Willcutt et al., 2005	Number of studies that found sign. group difference (p<.05) Willcutt et al., 2005
Behavioral Inhibition				
Stop-Signal RT			.61 (+/-.09)	22/27 (82%)
SST- Go RT	.66 (+/- .20)	10		
SST – Stop RT	.54 (+/-.14)	13		
SST – Probability of Inhibition	.34 (+/-.16)	9		
CPT Comm. Errors	.55 (+/-.08)	40	.51 (+/- .08)	17/28 (61%)
CPT Omiss. Errors	.66 (+/-.08)	33	.64 (+/-.09)	23/30 (77%)
CPT-Mean RT	.39 (+/-.13)	17		
CPT- Hits	1.00 (+/-.13)	19		
Reconstitution/Planning				
Trails A Time	.40 (+/-.14)	13		
Trails B Time	.59 (+/-.13)	14	.55 (+/-.11)	8/14 (57%)
Tower of Hanoi			.69 (+/-.26)	4/7 (57%)
Tower of London			.51 (+/-.18)	3/6 (50%)
Verbal Working Memory				
Letter Fluency	.46 (+/-.13)	13		
Category Fluency	.41 (+/-.17)	9		
Interference				
Stroop Interference	.56 (+/-.10)	20		

Table A2. Predictive Validity of ADHD by selected EF tests

Measure	SE % (Grodzinsky et al./Doyle et al.)	SP % (Grodzinsky et al./Doyle et al.)	PPP % (Grodzinsky et al./Doyle et al.)	NPP % (Grodzinsky et al./Doyle et al.)	TPV % (Grodzinsky et al./Doyle et al.)
Stroop Interference	43/11	--/92	88/62	62/46	68/48
CPT					
# correct	41/--	--	87/--	61/--	67/--
Omissions	--/15	--/91	--/68	--/47	--/50
Comissions	38/--	--	83/--	59/--	65/--
Trail Making Test					
Trails A	20/--	--	68/--	51/--	54/--
Trails B	18/--	--	71/--	51/--	54/--

SE = sensitivity; SP = specificity; PPP = positive predictive power; NPP = negative predictive power; TPV = total predictive value

Table A3. Internal consistency and test-retest reliability values reported in D-KEFS manual

Task Variable	Internal Consistency (Range for ages 8-14)	Test-Retest Reliability (Reported for combined ages 8-19)
Trailmaking		
Combined Number + Letter Sequencing	.59 to .79	n/a
Visual Scanning	n/a	.50
Number Sequencing	n/a	.77
Letter Sequencing	n/a	.57
Switching	n/a	.20
Motor Speed	n/a	.82
Verbal Fluency		
Letter Fluency	.68 to .80	.67
Category Fluency	.58 to .75	.70
Category Switching Total Correct	.37 to .62	.65
Category Switching Total Switching Accuracy	.53 to .76	.53
Color Word Interference		
Color Naming	n/a	.79
Word Reading	n/a	.77
Combined Color Naming + Word Reading Score	.62 to .77	n/a
Inhibition	n/a	.90
Inhibition/Switching	n/a	.80
Tower		
Tower total achievement	.43 to .84	.51

Table A4. Intercorrelations of D-KEFS Variables reported in the Technical Manual

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
1. TM Visual Scan	-												
2. TM Number Seq.	.38	-											
3. TM Letter Seq.	.36	.54	-										
4. TM L-N Switching	.24	.43	.45	-									
5. TM Motor Speed	.28	.33	.37	.23	-								
6. VF – Letter Fluency total correct	nr	nr	nr	.21	nr	-							
7. VF – Category Fluency total correct	nr	nr	nr	.19	nr	.55	-						
8. VF – Category Switch total correct	nr	nr	nr	.18	nr	.40	.45	-					
9. VF – Category Switching Accuracy	nr	nr	nr	.13	nr	.29	.34	.72	-				
10. CW –Color Name	.16	.26	.27	nr	.17	nr	nr	nr	nr	-			
11. CW – Word Read	nr	.20	.25	nr	.18	nr	nr	nr	nr	.57	-		
12. CW – Inhibition	nr	nr	nr	.32	nr	.27	.26	.19	.12	.49	.45	-	
13. CW – Inhibition/Switching	nr	nr	nr	.26	nr	nr	nr	nr	nr	.41	.42	.58	-
14. Tower – Total Achievement	nr	.10	.08	-.10	07	-.03	-.09	-.06	-.03	nr	nr	-.08	-.07

nr = not reported in manual

Appendix B: Forms

Participant Demographic Questionnaire

Child Age:

____

Child Date of Birth:

(MM/DD/YY) _____ / _____ / _____

Child Sex: (circle one)

1=Male 2=Female

Child Race: (circle one)

1= Caucasian	5=Native American
2=African-American	6=Mixed (specify) _______________
3=Hispanic	7=Other (specify) _______________
4=Asian	

Has your child **ever** received an ADHD diagnosis from a physician or psychologist? (circle one)

1=Yes 2=No

Is your child **currently** diagnosed with ADHD by a physician or psychologist? (circle one)

1=Yes 2=No

Has your child **ever** taken medication for ADHD? (circle one)

1=Yes 2=No

If yes, which type of ADHD medication has your child taken in the past:
(circle all that apply)

1. Adderall
2. Adderall XR
3. Attenta
4. Concerta
5. Daytrana
6. Dexedrine
7. Dexedrine SR
8. Dexedrine Spansules
9. Dextroamphetamine Sulfate
10. Dextrostat
11. Equasym
12. Focalin
13. Metadate
14. Metadate CD
15. Metadate ER
16. Methylin
17. Methylin ER
18. Methylphenidate (generic)
19. Mixed Amphetamine Salts
20. Penid
21. Ritalin
22. Ritalin LA
23. Ritalin SR
24. Rubifen
25. Strattera
26. Vyvanse
27. Other (specify) _______________

Does your child **currently** take medication for ADHD? (circle one)

1=Yes 2=No

If yes, which type of ADHD medication does your child currently takes:
(circle all that apply)

1. Adderall
2. Adderall XR
3. Attenta
4. Concerta
5. Daytrana
6. Dexedrine
7. Dexedrine SR
8. Dexedrine Spansules
9. Dextroamphetamine Sulfate
10. Dextrostat
11. Equasym
12. Focalin
13. Metadate
14. Metadate CD
15. Metadate ER
16. Methylin
17. Methylin ER
18. Methylphenidate (generic)
19. Mixed Amphetamine Salts
20. Penid
21. Ritalin
22. Ritalin LA
23. Ritalin SR
24. Rubifen
25. Strattera
26. Vyvanse
27. Other (specify) ______________

Has your child **ever** taken medication for a psychological problem (antidepressant, antianxiety, antipsychotic)?
If unsure, just list any medication(s) that your child has taken in the past for a psychological problem. (circle one)

1=Yes 2=No

If yes, write the name of the medication(s) your child has taken in the past:

____________________ ____________________ ____________________

____________________ ____________________ ____________________

Does your child **currently** take medication for a psychological problem (antidepressant, antianxiety, antipsychotic)?
If unsure, just list any medication(s) that your child currently takes for a psychological problem. (circle one)

1=Yes 2=No

If yes, write the name of the medication(s) your child currently takes:

____________________ ____________________ ____________________

____________________ ____________________ ____________________

Does your child have normal vision? (circle one)

1=Yes 2=No

If your child does **not** have normal vision, does s/he wear glasses or contacts? (circle one)

1=Yes 2=No

Does your child have colorblind vision? (circle one)

1=Yes 2=No

Does your child have any of the following: seizures, schizophrenia, brain damage? (circle one)

1=Yes 2=No

If yes, please specify:

____________________ ____________________ ________________