INFLUENCE OF MOTOR FUNCTION ON A CONTINUOUS PERFORMANCE TEST IN CHILDREN WITH SUSPECTED ATTENTION DEFICIT-HYPERACTIVITY DISORDER

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Dedicated to my loving family.

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by

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Clinicians and researchers have expressed concern about the potential confound of psychomotor skills on Continuous Performance Test variables commonly used in AD/HD assessments. Several studies have addressed this relationship but with limitations. Evidence for this potential influence as well as evidence of slow processing and motor speed in samples of children with known attention and motor deficits are demonstrated in the research. Due to the increasing rate of referrals for AD/HD diagnoses, the increasing use of CPTs, and the lack of knowledge about the influence of psychomotor functioning on these measures, an examination of this relationship is considered necessary to address the use of CPTs in AD/HD evaluations. The sample consisted of 99 children with suspected attention deficits between the ages of 6 and 16 years. Psychomotor functioning was assessed by the WISC-IV Processing Speed Index and the Beery VMI. Attention was measured with the WISC-IV Working Memory Index and subscales of the parent-rated BASC-2.

Results of this study revealed that psychomotor and attention measures on the WISC-IV related to and accounted for variance in T.O.V.A. variables to a moderate degree. Stepwise regressions indicated the WISC-IV Processing Speed Index predicted both Response Time and Response Time Variability. In contrast, another measure of psychomotor skills, the Beery VMI, did not predict T.O.V.A. variables. Interestingly, the Working Memory Index accounted for variance in Commission Errors, a measure of impulsivity, but not Omission Errors, a measure of sustained attention. Also, unexpected, differences among primary T.O.V.A. variables were not found across sub-samples when grouped by BASC-2 scores.

These significant but modest results suggest that when evaluating a child for AD/HD, clinical consideration of the influence of psychomotor skills, as measured by the WISC-IV, on T.O.V.A. Response Time and Response Time

Variability is warranted. Furthermore, the use of both the WISC-IV Working Memory Index and the T.O.V.A. is useful for assessing varying components of attention, such as focused and sustained attention.

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LIST OF ABBREVIATIONS

AD/HD	Attention-Deficit/Hyperactivity Disorder
APA	American Psychiatric Association
AR	Anticipatory Response
CPT	Continuous Performance Test
Cd	Coding Subtest
CE	Commission Errors
CEM	Cognitive-Energetic Model
D	Kolomogov-Statistic
DSM	Diagnostic and Statistical Manual of Mental Disorders
GDS	Gordon Diagnostic System
ISI	Inter-Stimulus Interval
M	Mean
NOS	Not Otherwise Specified
OE	Omission Errors
PRI	Perceptual Reasoning Index
PSI	Processing Speed Index
RT	Reaction Time
RTV	Reaction Time Variability
SD	Standard Deviation

SS	Symbol Search Subtest
T.O.V.A.	Test of Variables of Attention
VCI	Verbal Comprehension Index
VMI	Visual-Motor Integration
WISC	Wechsler Intelligence Scale for Children
WMI	Working Memory Index

CHAPTER ONE

INTRODUCTION

Statement of the Problem

Attention Deficit/Hyperactivity (AD/HD) disorder is a developmental disorder characterized by inattentive and/or hyperactive behaviors. AD/HD evaluations are one of the most common referrals made to evaluation centers. These evaluations may also be one of the more difficult assessments to complete since inattentive behaviors may be indicative of a variety of conditions and differentiating among co-morbid disorders can be problematic. Currently, subjective and objective measures are used to help diagnosis this condition. One of the most widely used objective measures in AD/HD evaluations is the Continuous Performance Test (CPT).

Continuous Performance Tests are computerized assessments that stage an opportunity for objective data collection of inattention and impulsivity. CPTs provide data on participants' responses and response styles in comparison to others without attention deficits therefore providing objective data for AD/HD evaluations, especially when the performance is markedly different from the normative data. Specifically, these tests instruct participants to respond and inhibit responding to certain stimuli displayed on a computer screen. Correct responses are made when a button is pressed in a timely manner to correct stimuli. Delayed or omitted responses are considered evidence for deficits in attention; however, if a response is made late, either due to slow processing or motor speed, CPT variables may calculate the child as appearing inattentive. Researchers and clinicians have voiced concern from clinical experience that variables from the T.O.V.A. may be influenced by psychomotor skills and that CPT results may falsely indicate inattentive behaviors.

The relationship between T.O.V.A. variables and measures of attention and psychomotor speed on the WISC-IV and the Beery VMI were studied to address this concern. The primary aim of the current study was to determine if psychomotor skills predict T.O.V.A. variables. Additionally, a secondary aim was to evaluate diagnostic group differences across T.O.V.A. variables.

CHAPTER TWO

LITERATURE REVIEW

Significance and Background

Attention-Deficit/Hyperactivity Disorder and Continuous Performance Tests

Attention-Deficit/Hyperactivity Disorder (AD/HD), the most common diagnosis of children seen in psychiatric clinics, has an estimated prevalence of 3-7 % in school-aged children (age 4 – 17) in the United States (American Psychiatric Association, 2000). It is estimated that 30-50% of child referrals to mental health agencies are to evaluate for AD/HD (Stefanatos & Baron, 2007). Assessment goals for children suspected of having AD/HD are to detect the presence or absence of frequent overactive, impulsive and/or inattentive behaviors that impair functioning (APA, 2000), as well as to plan treatment.

AD/HD assessment procedures are especially complicated by the paucity of standardized testing methods used to address the numerous differential diagnoses and comorbidities that likely present with this disorder (Barkley, 2004-2008). Among the most frequently used objective measures in AD/HD diagnostic evaluations and assessments are Computerized Performance Tests (CPTs; Llorente et al., 2001). Sitting in front of a computer screen, participants are instructed to press a button in response to certain target stimuli and to refrain from pressing the button to distractor stimuli. Accordingly, CPTs attempt to objectively measure reaction time as well as variables theoretically related to the three primary symptoms of AD/HD: inattention, hyperactivity, and impulsivity.

However, an inherent aspect of CPTs is the requirement of an intact and timely motor response (i.e., pressing a button in response to stimuli), and clinicians have questioned the possible confounding effect of psychomotor abilities on CPT performance (Chae, 1999; Riccio, Reynolds, & Lowe, 2001). Although this issue has been briefly addressed by Chae, in which he concluded that CPTs do not measure psychomotor function, data from that study and other studies in differing populations and CPTs (Grant, Ilai, Nussbaum, & Bigler, 1990; McGee, Clark, & Symons, 2000; Walker & Green, 1982) support the need for an updated, re-examination of these variables in the suspected AD/HD population to "ensure that poor motor control is not interpreted as evidence of deficits in attention" (Riccio et al., 2001,p. 155). Given the increasing use of CPTs and the impact of AD/HD diagnoses on treatment planning, this study is consequential.
A review of pediatric attention and motor literature will provide the background for the current problem. The first section will introduce the construct of attention and the complicated task of assessing AD/HD due to the many differentials and comorbidities that may exist with the diagnosis. Psychometric data for CPTs will also be introduced. Next, the construct of motor function will be explained and illustrated by research with children known to have motor dysfunction: children

with Developmental Coordination Disorder (DCD). The subsequent sections provide findings of attention and motor research in children AD/HD and DCD and then in CPT research.

Attention and Attention-Deficit/Hyperactivity Disorder

Construct and Definition of Attention. The ability to attend to the world around us may appear to some as a simple, easily accomplishable task. However, "paying attention" in a world full of incoming information requires the orchestration of a complex system of tasks. These systems of tasks, the underlying brain structures and connective pathways are as numerous as the definitions and theories of the construct of attention. For the purposes of this paper, attention is defined as the "general state of arousal" that leads to "the ability to focus, divide and sustain mental effort" (Zillmer & Spiers, 2001a, p.170), a definition relatable to one model of attention (Mirsky, Pascualvaca, Duncan, & French, 1999). Since information and stimuli in an environment are first processed by selectively attending to germane stimuli and inhibiting attention to irrelevant stimuli, attention is conceptualized as the "gateway for information processing" (Zillmer & Spiers, 2001a, p. 170) and the "fundamental key to all cognitive tasks" (Siegel, 2000 as cited in Riccio et al., 2001, p. 2).

Neuropsychological models of attention propose distinct cerebral regions for attentional processes (Mirsky et al., 1999). A review of research summarizes attention systems as involving the cortical frontal, prefrontal and parietal structures with the subcortical structures (limbic system, reticular activating system, and basal ganglia) interconnected to projections among the frontal lobes, thalamus and basal ganglia (Riccio et al., 2001).

The etiology of AD/HD is still under investigation. One current study indicates a delay of cortical maturation rather than deviance to contribute to AD/HD symptomatology (Shaw et al., 2007). Other researchers emphasize the role of neurotransmitters in attentional processes such as in the dopaminergic hypothesis. The dopaminergic hypothesis postulates that inattentive behavior results from the underactivation of dopamine-related brain regions (Swanson et al., 2007); other researchers, however, suggest this assumption may be incorrect (Gonon, 2008). Although the underlying mechanisms of attention are not well established, it does appear that disruption to the central nervous system (CNS) often impacts attentional processes (Riccio et al., 2001).

Inattention is a symptom of a variety of neurological and psychiatric syndromes. Disturbances to any structure or pathway of attentional processes in the brain may lead to inattention; thus, inattention is non-specific and suggestive of a number of conditions (Riccio et al., 2001). In some medical and psychiatric disorders, inattention is transient and directly attributable to a cause. For example, a sudden shift in the ability to attend to stimuli may be indicative of a substance intoxication or delirium. Difficulties with attention can also be indicative of mood or anxiety disorders. In contrast to these transient conditions, other attentional disorders are enduring. One such case is Attention Deficit/Hyperactivity Disorder (AD/HD), a chronic condition that first appears in children under the age of seven.

Definition and Subtypes of AD/HD. AD/HD is a disruptive behavioral disorder currently conceptualized as frequent inattentive, hyperactive, and/or impulsive behaviors that are inconsistent with developmental level and cause functional impairment (APA, 2000). AD/HD has not always been conceptualized as involving inattention, hyperactivity and impulsivity. Initially, attention and hyperactivity were defined together with motor coordination and learning problems and termed Minimal Brain Dysfunction. After several decades, the Diagnostic and Statistical Manual (DSM) selected the term Hyperkinetic Reaction of Childhood (APA, 1968) to represent a homogeneous group of symptoms including hyperactivity and poor impulse control. It was not until the latter half of the twentieth century that the DSM began to emphasize inattention as a core symptom of AD/HD. As illustrated in Table 1, the symptoms and subtypes have evolved in each subsequent DSM edition.

The DSM-III (APA, 1980) identified Attention Deficit Disorder (ADD) and distinguished the condition as occurring “with” or “without” hyperactive behaviors, therefore emphasizing inattention as one central feature. The DSM-III-

R removed subtyping and incorporated hyperactivity, renaming this cluster of symptoms as Attention-Deficit/Hyperactivity Disorder (APA, 1987). Progressing into the 1990's, the DSM-IV (APA, 1994) maintained the term AD/HD; however, it differentiated the condition into three subtypes: predominantly inattentive type (AD/HD-PI), predominantly hyperactive-impulsive type (AD/HD-HI), and combination type (AD/HD-C). As illustrated in Table 2, 6 of 9 criteria must be met for diagnosis of AD/HD-PI or AD/HD-HI. AD/HD-C is diagnosed when both subtype (AD/HD-PI and AD/HD-HI) diagnostic criteria are met.

The DSM-IV (1994) and DSM-IV-TR (2000), the most recent edition, define inattention, hyperactivity, and impulsivity using specific behavioral symptoms. Inattentive behaviors are delineated by nine criteria including the appearance that one is not listening when spoken to directly, failure to attend to detail, failure to follow instructions, misplacing important belongings, distractibility, forgetfulness, disorganization, difficulty sustaining attention, and avoidance of tasks that require sustained mental effort. Six hyperactive behaviors are defined in the manual as fidgetiness, difficulty sitting still when required, excessive movement, appearance of being "on the go," talking excessively and playing noisily. Three impulsive behaviors are also noted including blurting out answers, interrupting others and having difficulty awaiting one's turn.

Comorbidity Problem of AD/HD. Prevalence rates of AD/HD have been found to differ by age as AD/HD usually appears in the preschool years and often continues into adolescence and adulthood in various, and sometimes attenuated, symptom manifestations (APA, 2000; Barkley, 2004-2008; Hurtig et al., 2007; Stefanatos & Baron, 2007). Gender differences in diagnostic prevalence have also been noted to occur in epidemiological samples. AD/HD occurs at least two times more frequently in males than in females (APA, 2000; Barkley, 2004-2008). Females are more likely to have AD/HD-PI subtype (Nass, 2005) that consists of relatively less observable behaviors compared to hyperactive behaviors; thus, some have argued that females are under-represented in AD/HD prevalence rates.

AD/HD frequently occurs with other psychiatric disorders. In a large Ontario community-derived sample, 44% of the children diagnosed with AD/HD had one additional psychiatric disorder diagnosed and 43% had two or more (Szatmai, Offord, & Boyle, 1989). Clinically derived samples have yielded higher rates of comorbid conditions. In one clinical study, up to 87% of children with AD/HD had one comorbid condition diagnosed and 67% had two or more diagnoses in addition to AD/HD (Kadesjo & Gillberg, 2001). On average, a technical review of 97 articles and manuals indicated that almost one-third of children with AD/HD have more than one comorbid diagnosis (Green, Wong, Atkins, Taylor, & Feinlieb, 1999). Common comorbidities include oppositional defiant disorder (mean prevalence rates across studies = 35.2%), conduct disorder (mean = 25.7%), anxiety disorders (mean = 25.8%), and depressive disorders (mean = 18.2%; Green et al., 1999). Of central importance to this study, is the fact that half of all children with AD/HD are reported to have motor-related deficits as well (Kadesjo & Gillberg, 1998, 1999; Szatmai et al., 1989; Whitmont & Clark, 1996).

The “comorbidity problem”, or the tendency for developmental disorders, such as AD/HD, to occur with other psychiatric and medical complications (Kaplan, Wilson, Dewey & Crawford, 1998) has researchers speculating as to whether co-occurring presentations consist of two or more independent disorders or a single condition with broader symptomatology, such as minimal brain dysfunction mentioned earlier (Kaplan, Crawford, Cantell, Kooistra, & Dewey, 2006). Milberger, Biederman, Faraone, Murphy and Tsuang specify this quandary with three hypotheses:

“1) the individual with AD/HD plus a comorbid disorder has only the comorbid disorder, but because of overlapping symptoms is misdiagnosed as having AD/HD; 2) the individual with AD/HD plus a comorbid disorder has only AD/HD, but because of overlapping symptoms is misdiagnosed as having the comorbid disorder; and 3) the individual with AD/HD plus a comorbid disorder has both AD/HD and the comorbid disorder” (1995, p. 1794).

Considering these three hypotheses when assessing a child with AD/HD is conceptually indicated for an accurate diagnostic classification. It also reinstates the importance of assessments that aid in differentiating overlapping or “masquerading” (Newcorn et al., 2001, p.138) symptomatology.

Assessing Attention and AD/HD. The nature of attention and the complexity of diagnosing AD/HD create a challenging and daunting task. Attention is multifaceted; therefore, tests of attention may measure various attentional components and processes. Furthermore, the presence of comorbid problems can lead to inaccurate diagnoses since different diagnostic symptomatology can “masquerade” (Newcorn et al., 2001, p.138) as attention problems or can occur as artifacts of data collection (Milberger et al., 1995; Stefanatos & Baron, 2007).

AD/HD is often a diagnosis of exclusion, as alternative diagnoses and/or comorbidities are interpreted, evaluated, and ruled-in or out within the context of the presenting symptoms. With the large amounts of referrals for AD/HD and the contingencies of diagnostic and treatment plans, such as medication selection and dosage, assessment accuracy is consequential.

At this time, no universal assessment model or single measure for AD/HD has been endorsed by a professional psychological organization for the diagnosis of AD/HD (Koonce, 2007). The process of assessing for AD/HD symptoms of inattentive, hyperactive and impulsive behaviors warrants an integration of data from various informants, sources, and tests. Ideally, no one measure can be interpreted in isolation without the consideration of information from subjective interviews, observations, reports, behavioral rating scales, and a comprehensive objective battery of neuropsychological tests. Neuropsychological tests may include intelligence tests and computerized measures of attention. Subjective measures of AD/HD, including clinical interviews, school reports and behavior rating scales, have been approved to provide adequate AD/HD diagnostic evaluation (American Academy of Pediatrics, 2000). Clinical interviews are considered to be the staple of AD/HD evaluations because, at the present time, the most common diagnostic procedure is based entirely upon using DSM-IV-TR symptoms observed in daily life.

Additionally, behavior rating scales have been described as an efficient way of measuring the severity of AD/HD symptoms, and are frequently used. These scales, typically given to parents or teachers, can aid in collecting information about behaviors such as hyperactivity and aggression (externalizing behaviors) or inattentive and anxious behaviors (internalizing behaviors). These results are compared to normative data to assess if the severity of symptoms is clinically elevated.

Two types of subjective behavior rating scales differ in focus, benefits and limitations. “Broadband” or “omnibus” questionnaires, like the Behavioral Assessment System for Children (BASC; Reynolds & Kamphaus, 2004), assess a variety of childhood behaviors and symptoms of psychiatric conditions, including anxiety, depression and attention. These questionnaires are longer and more comprehensive than “narrowband” questionnaires that focus solely on AD/HD behaviors. Broadband questionnaires are useful for screening common comorbidities, a clinical goal of evaluations (Green et al., 1999; Nass, 2005). In addition, broadband questionnaires like the BASC have been effectively utilized in AD/HD diagnostic assessment in several studies (Jarratt, Riccio, & Siekierski, 2005).

Benefits of both types of questionnaires include the low-cost, time efficient nature of the format as well as well-accepted use in research in the diagnosis of AD/HD. Some limitations of behavioral rating scales include halo effects, presenting the self in a better light, and rater bias, differences in how parents and teachers rate AD/HD (Blondis, Accardo, & Snow, 1989). Also, since observing inattentive behaviors is difficult, under-reporting of inattentive symptoms also frequently occurs. Furthermore, symptoms of other disorders (e.g., Oppositional Defiant Disorder, Conduct Disorder or Anxiety) may be misclassified by parents as AD/HD symptoms; therefore, objective measures have been recommended (Newcorn et al., 2001; Schachar, Mota, Logan, Tannock, & Klim, 2000).

Objective measures are an essential component of AD/HD assessments, as their strength compliments the weaknesses of subjective measures. Objective tests systematically measure performance on specific tasks rather than subjectively asking an informant about the frequency of a behavior. However, accurately assessing the “multidimensional” nature of attention is still challenging for objective measures to perform (Zillmer & Spiers, 2001b). Therefore, using a variety of assessments is the optimal approach of AD/HD evaluations.

Two of the most frequently used objective measures of attention are Continuous Performance Tests (CPTs) and the Wechsler series of intelligence tests (Naglieri, Goldstein, Delauder, & Schwebach, 2005). Like all objective measures, these measures do not provide a simple answer as to whether or not AD/HD symptoms are present or absent. Rather, CPTs provide data on sustained attention and impulsivity (Riccio et al., 2001) and the WISC-IV, the Wechsler Intelligence Scale for Children, Fourth Edition (Wechsler, 2003) provides data for intellectual ability and cognitive processing, including focused attention.

Second to CPT, the Wechsler series of intelligence tests is considered as an assisting objective measure in AD/HD evaluations (Naglieri et al., 2005). The current Wechsler pediatric intelligence scale, the WISC-IV, contains four indices, one of which measures short-term memory and the ability to employ attention and concentration, termed the Working Memory Index (WMI). The WMI has been found to be significantly lower in children with AD/HD than controls (Mayes & Calhoun, 2006; Williams, Weiss & Rolfhus, 2003). Although frequently used in AD/HD evaluations, neither the CPT nor the Wechsler series are validated to be diagnostic tests for AD/HD (Leark, Greenberg, Kindschi, Dupuy, & Hughes, 2007; Wechsler, 2002). Descriptions, use and research involving these objective measures in the assessment of AD/HD are discussed in the following sections.

Continuous Performance Tests

Continuous Performance Tests (CPTs) are commonly used in the assessment of AD/HD because of their objectivity in measuring sustained attention and impulsivity. Initially, the original CPT was used to measure vigilance in patients with brain damage (Rosvold, Mirsky, Sarason, Bransome, & Beck, 1956). Early studies showed significant differences between patients and controls as well as larger differences between groups as the CPT format increased in task complexity. Now, CPTs are more frequently used in evaluations of suspected attention problems, such AD/HD, and other psychiatric disorders.

Instructions for a simpler formatted CPT, termed X-CPT, direct the examinee, sitting at a computer with a mouse or keyboard, to respond to a learned target (e.g., pressing a button when “B” appears on the screen) and to inhibit response to non-target stimuli (e.g., not pressing the button when an “X” appears). CPTs are tasks designed to be time intensive (e.g., 15 minutes long), uninteresting, and variable in stimulus presentation thereby staging an opportunity to analyze sustained attention, reaction time, impulsivity and inhibition over time. Hence, the quantitative CPT variables theoretically match aforementioned qualitative AD/HD behaviors. For example, CPT *Errors of Omission* variables (i.e., failure to respond to the target stimuli) can be interpreted as a measure of inattention. *Errors of Commission* (i.e., incorrectly responding to non-target stimuli) can be interpreted as impulsivity or response disinhibition. *Response*

Time (i.e., how quickly an individual correctly pushes the button in response to target stimuli) and *Response Time Variability* (i.e., inconsistencies of response times) are interpreted as indices of information processing and motor reaction speeds (Leark, Dupuy, Greenberg, Corman, & Kindschi, 1996; Leark et al., 2007; Llorente et al., 2001; Sostek, Buchsbaum, & Rapoport, 1980).

There are estimates of over 100 versions of CPTs in use today (Greenberg & Waldman, 1993), with many different formats and levels of difficulties. Today, the four most common CPTs include the Test of Variables of Attention (T.O.V.A.; Greenberg, 1988-1999), Conners' Continuous Performance Test (Conners, 1992, 1995) the Gordon Diagnostic System (GDS; Gordon, 1983), and the Integrated Visual and Auditory CPT (IVA; Sandford & Turner, 1994-1999). Although similar in purpose and paradigm, the formats (e.g., stimuli used and length of test) and variable formulas utilized by these CPTs differ. Therefore, comparison across CPT research is cautioned until research clarifies the effect of CPT differences (Riccio et al., 2001).

Possibly in line with this lack of research, the ecological validity of CPTs remains equivocal (Barkley, 1991) and results are inconsistent. One stance for CPT soundness is the evidence of moderate to strong concurrent validity with direct observational measures, which have been described as representing a higher degree of ecological validity (Barkley, 1991; Garretson, Fein, & Waterhouse, 1990; Harper & Ottinger, 1992). CPTs also strongly correlate with behavioral rating scales (Klee & Garfinkel, 1983) in psychiatric populations. Significant correlations were also found among T.O.V.A. Omission and Commission Errors and the parent-rated BASC subscales of Hyperactivity and/or Attention Problems (Floyd, 1999 as cited in Riccio et al., 2001).

Other studies have not supported the construct validity of CPTs (Campbell, D'Amato, Raggio, & Stephens, 1991; Swanson & Cooney, 1989). For example, Swanson and Cooney (1989) found that CPT variables loaded on factors of cognitive ability, measures which are generally conceptualized as unrelated to attention. Campbell et al. (1991) found CPT variables accounted for 79% of the variance of achievement scores and did not load onto cognitive or behavioral factors in a sample of 53 girls and boys with learning disabilities. However, the authors interpreted this relationship to mean that attentional skills are required for achievement.

Discriminant validity or specificity, of crucial importance in AD/HD assessments, has been inconsistently reported among different CPTs. Some studies have found adequate sensitivity and specificity using CPT tasks as a diagnostic instrument for children with AD/HD (Conners et al., 1996; Gordon, Di Niro, & Mettelman, 1988; Klee & Garfinkel, 1983). Other studies have found moderate sensitivity of CPT in the identification of AD/HD (Corkum & Siegel, 1993; Matier-Sharma, Perachio, Newcorn, Sharma, & Halperin, 1995; Newcorn et al., 2001). And yet, other studies have found no group differences between children with AD/HD and control groups on CPTs (Schachar, Logan, Wachsmuth, & Chajczyk, 1988). More important to clinical use, is the ability of CPTs to differentiate among psychiatric conditions. Although more functional for clinical practice, this type of study among psychiatric groups is less prevalent in the literature.

Despite the aforementioned concerns, CPTs have been found to be valid and reliable measures and continue to be used at increasing rates due to several appealing aspects. Specifically, CPTs have been found to be sensitive to most types of CNS dysfunction and the general notion is that the CPT paradigm measures some aspect of attention (Riccio et al., 2001). Also, CPTs provide objective data that are not influenced by rater bias or rater error. Thirdly, CPTs are also well-researched and used for the sensitivity in variables in medication monitoring (e.g., Teicher, Ito, Glod, & Barber, 1996). Other studies have found CPTs to have indicators of malingering in neuropsychological testing (Henry, 2005). The "ease of administration, time required, cost of administration, and an abundant research base," make CPTs effective and desirable (Riccio et al., 2001, p. 307).

The T.O.V.A.. One of the most used and researched CPT is the Test of Variables of Attention (T.O.V.A.; Greenberg, 2007; Greenberg & Kindschi, 1996; Greenberg, Kindschi, & Corman, 1999; Leark et al., 1996; Leark et al., 2007).

The visual version of the T.O.V.A. is a 22.5-minute, non-language based X-CPT (geometric shapes) that has been standardized on more than 1,000 children and adults aged 4 to 80. Compared to other CPTs, the T.O.V.A. has been argued to be a “purer” test of attention (Riccio et al., 2001, p. 69) because of the use of geometric shapes rather than numbers or letters (language-neutral), the lack of right-left discrimination requirements (Greenberg & Waldman, 1993; Leark et al., 2007), and the minimal requirement of stimulus and spatial discrimination (Riccio et al., 2001). The duration of task of the T.O.V.A. (almost 23 minutes) provides assurance about the measure of sustained attention. Furthermore, timing errors, commonly found when using keyboard or mouse buttons, are controlled within +/- 1 millisecond through a standardized micro-switch that no other CPT possesses.

The format and presentation of the T.O.V.A differentiate it from other CPTs. First, standardized administration includes a three-minute practice test before the test commences. The stimuli consist of an outlined rectangle, approximately 25% of the screen, that contains a square either towards the top (target stimuli) or a non-target square that appears towards the bottom of the outlined rectangle (see Appendix A). Target and non-target stimuli are randomly presented for 100 milliseconds each, with an inter-stimulus interval (ISI, the time lapse between stimuli presentation) of 2000 milliseconds. The first half of the test is considered as the stimulus-infrequent condition and the second half is considered the stimulus-frequent condition, as the target stimulus is shown 22.5% and 77.5% of the trials, respectively. One reason that this format is effective is that inattention and Omission Errors will occur more frequently in the stimulus-infrequent condition and impulsivity and Commission Errors are thought to occur more in the stimulus-frequent condition (Greenberg & Waldman, 1993; Leark et al., 1996; Leark et al., 2007; Riccio et al., 2001).

Two normative samples of Minnesotan child and adult populations comprise the normative data of 1,596 participants (712 males, 884 females; 1,356 children, 250 adults; Greenberg & Crosby, 1992b as cited in Leark et al., 2007; Greenberg & Waldman, 1993). Exclusion criteria included severe behavioral problems as rated by school personnel, psychotropic medication, and history of CNS disorder. There is no specific information about the ethnicity and socioeconomic status of these samples, although it is mentioned that the participants were from upper-middle class, predominantly Caucasian populations. Mean score differences have been reported for gender across age. Males have been reported to have faster reaction times and more anticipatory responses, Commission and Omission Errors than females (Greenberg & Crosby, 1992b as cited in Leark et al., 2007; Greenberg & Waldman, 1993). The normative data corrects for age and gender. Omission and Commission Errors are non-normally distributed in the normative data.

Limitations of the normative data include the exclusion criteria and a non-uniform age distribution (Llorente et al., 2001; Riccio et al., 2001). The exclusion criteria possibly restricted a cohort of AD/HD with severe inattentive and impulsive behaviors from being included in the normative sample (Llorente et al., 2001). Also, the age distribution is non-uniform. For example, the number of 6- to 18- year-old individuals is larger than other age groups. Further, after the age of 19, the number of males in each age group significantly drops (Greenberg & Crosby, 1992b as cited in Leark et al., 2007; Riccio et al., 2001). In addition, a curvilinear effect of age occurs. Decreasing amounts of error and time scores beginning at age five and leveling off in early adulthood, has been found for several T.O.V.A. variables reflecting developmental differences. Specifically, this effect has been found in Omission and Commission Errors, Response Time and Response Time Variability (Greenberg & Crosby, 1992a as cited in Leark et al., 2007).

T.O.V.A. Variables. In addition to primary variables of attention and impulsivity, the T.O.V.A. has secondary indices to provide more information about the subjects' performance (Leark et al., 2007). All eleven indices are reported across quarters, halves and the total test, yet not all variables are standardized. T.O.V.A. variables are reported using raw scores, percentiles, z-scores and standard scores.

The primary variables of the T.O.V.A. Omission Errors (OE), Commission Errors (CE), Response Time (RT) and Response Time Variability (RTV) are similar in concept to other CPTs; however, they are calculated as ratios, not frequencies or percentages (Leark et al., 1996; Leark et al., 2007). One of the secondary T.O.V.A. variables, Anticipatory Responses, is a component of two of the calculations (See Table 3).

Secondary indices include Anticipatory Responses, Multiple Responses, Post-Commission Error, D prime, and an AD/HD Index score. Anticipatory Responses (AR), an index of guessing, is calculated within the first 150 milliseconds after the stimulus appears, a time before perception and processing supposedly takes place. ARs are a measure of test validity. In the calculations of primary variables, ARs are subtracted from correct responses, omission and Commission Errors. This ensures that performance scores are not positively inflated due to guessing or playing the CPT like a game. Multiple Responses, or the number of stimuli responded to more than once, is also used as a measure of validity although it does not subtract from primary performance scores. If Multiple Responses are frequent, the test interpretation may be a reflection of motor hyper-responsivity or presence of a neurological risk status. Post-Commission Errors reflect the mean response time for correct responses immediately following Commission Errors. It is reported that normals tend to slow down after making a Commission Error and this variable measures this phenomenon. D', or response sensitivity, is an indication of "deterioration of performance" over time (Leark et al., 2007, p. 6). As a measure from Signal Detection Theory, d' reflects an individual's ability to accurately discriminate target stimuli from non-target stimuli. The AD/HD Index computes the degree of similarity between the participant's performance scores and performance scores of children with AD/HD (Leark et al., 2007).

The computerized test report includes numeric results, graphs, and cautionary and interpretive statements. Psychometric properties, including reliability, specificity, sensitivity, and validity of T.O.V.A.s are discussed in the following section.

Reliability of the T.O.V.A. The T.O.V.A. has demonstrated robust internal consistency (Leark et al., 1996; Leark et al., 2007; Llorente et al., 2001; Llorente et al., 2008). Leark et al. (1996, 2007), in the T.O.V.A. manuals, report moderate to high Pearson product moment coefficients for the primary variables within stimulus frequent (target shown 126 times in Half 2) and infrequent (target shown 36 times in Half 1) conditions. Leark et al. explain that due to the T.O.V.A.'s nature as a time and speed oriented task and because of its various frequency conditions, Chronbach alpha, Kuder-Richardson reliability coefficients and between conditions analyses are inappropriate (2007). The manual reports reliability coefficients to range from .52 to .99 among T.O.V.A. variables (OE, CE, RT, RTV, d') within conditions of the 'healthy,' normative population. Overall, the authors report that variables are consistent yet distinct. However, Response Time and Response Time Variability were reported to be more robust variables. Omission and Commission Errors were reported be less consistent than other T.O.V.A. variables.

Llorente et al. (2001, 2008), in an independent study of the effectiveness of dietary docosahexaenoic acid supplementation, further analyzed internal consistency, as well as test-retest reliability and reproducibility of individual T.O.V.A. scores. In both studies, forty-nine, predominantly Caucasian 6- to 12-year olds, previously diagnosed with AD/HD were given the visual T.O.V.A. off stimulant mediation (Llorente et al., 2001; Llorente et al., 2008). Children with comorbid learning disabilities or oppositional disorder were not excluded from the study. As the authors continually stress throughout their two publications, the homogeneous sample included in this study reduced the generalizability of the results to children who have been previously diagnosed with AD/HD.

Internal consistency was reported to be high between T.O.V.A. conditions (Llorente et al., 2001) and moderate to high within T.O.V.A. conditions (Llorente et al., 2008). In this cohort of AD/HD children, the initial analyses (2001) included Omission and Commission Errors, however, Response Time and Response Time Variability were excluded. The high coefficients between conditions were reported as .93 for Half 1: Half 2, .96 for Half 1: Total and .99 for Half 2: Total for the correct target responses.

The authors' subsequent study (2008), reported moderate to high Pearson product-moment coefficients for the primary variables (OE, CE, RT and RTV) across conditions (infrequent condition Q1 vs. Q2 and frequent condition Q3 vs.Q4). These reported ranges are lower than those reported by Leark et al. (1996, 2007) and interpreted as being influenced by the homogeneneity of the AD/HD sample versus the healthy population in the Leark studies. Omission Errors (r =.52 to .80) and Response Time (r = .55 to .80) demonstrated greater consistency than Commission Errors (r =.12 to .76) and Response Time Variability (r = .49 to .63), again findings different from those reported in the manual. Last, the authors interpret a trend toward greater correlations coefficients within the second half of the T.O.V.A. relative to Q1 and Q2 as artifacts of outliers and low base rates instead of practice or regression effects.

Temporal stability has been reported to be satisfactory on the primary variables of the T.O.V.A. (Leark et al., 2007; Leark, Wallace, & Fitzgerald, 2004; Llorente et al., 2001). Leark, Wallace and Fitzgerald (2004) studied test reliability in two populations of about thirty children at a 90-minute interval and week interval, simulating the clinical practice of medication monitoring and a subsequent check-up visit, on the primary T.O.V.A. variables. Correlation coefficients ranged from .70 (OE) to .87 (RTV) for the shorter time interval and

.74 (CE) to .87 (RTV) for the longer time interval. Practice effects were found on CE for both the 90-minute and week intervals indicating better scores (fewer errors) occurring over administrations. Response Time was also found to be significantly different after the 90-minute test administration.

Llorente et al. (2001) also found satisfactory but lower test-retest reliability for time intervals of 8 and 16 weeks in the AD/HD cohort previously described. Both sets of authors reference the tendency for coefficients to decrease over lengthier time intervals. Furthermore, Llorente et al. conducted a Bland-Altman procedure to calculate limits of agreement since high reliability may exist with limited individual score repeatability. Although the temporal stability of group scores was satisfactory, individual test scores were less reproducible. Response Time and Response Time Variability variables had greater temporal stability and individual test-retest score agreement than Errors of Omission and Commission. This was partly attributed to the metrics used to measure variables (e.g., errors versus response times). Further investigation of Commission Errors was recommended and a caution was warranted in the interpretation of Errors of Commission and Omission (Leark et al., 2004).

Utility and Validity of the T.O.V.A. The T.O.V.A.'s characteristics, such as brief stimulus appearance, relatively short ISI and longer administration times are characteristics thought to increase the discriminant validity of CPTs (Corkum

& Siegel, 1993). The sensitivity and specificity of CPTs are crucial to the utility of CPTs to aid in diagnostic assessments. The utility of an AD/HD instrument is determined by the ability of a test to distinguish between the presence or absence of AD/HD and other psychiatric conditions. More specifically, “sensitivity” can be thought of as the proportion of children with AD/HD who accurately receive a positive AD/HD finding on the CPT (Leark et al., 2007). “Specificity” refers to the proportion of the group without AD/HD who receive a negative finding on the measure (Matier-Sharma et al., 1995).

Adequate levels of sensitivity and specificity have been found in two reported articles in the T.O.V.A. manual (Greenberg and Crosby, 1992b, 1992c as cited in Leark et al., 2007). In the first study by Greenberg and Crosby (1992), AD/HD (n = 36), children were compared to a normal control group (n=384). Using two cut-off scores of 1.94 and 3.42 on the AD/HD index, false positive rates of 80% and 90%, respectively, were determined with corresponding sensitivity rates reported as .76 and .60. In the second cited article, Greenberg and Crosby (1992c), a Receiver Operator Characteristic (ROC) Analysis was conducted as a more conservative and appropriate measure for CPTs. The T.O.V.A. correctly classified 73 AD/HD children and 775 normal controls. Leark et al. concluded that the T.O.V.A. has utility as the above analyses produced similar sensitivity and specificity criteria at a minimum of .80 level.

Forbes (1998) also found adequate discriminant validity between AD/HD children (*n* = 117) and other psychiatric conditions (*n* = 29) including oppositional defiant disorder, conduct disorder, learning disabilities, adjustment disorder and depression. Forbes tested the criteria for clinical significance from the T.O.V.A. manual, which calls for a diagnosis of AD/HD when any one measure (OE, RT or RTV) exceeds 1.5 standard deviations from the age and sex adjusted mean. Chi square tests of independence found successful discrimination between groups for each criterion. Forbes suggested that using a criterion of greater than 1.5 standard deviations from age and sex adjusted means can help to correctly identify 80% of those with AD/HD/ADD and 72% of those with other psychiatric disorders. Furthermore, cases misclassified by the Revised Conners Teacher Rating Scale (RCTRS; Goyette, Conners & Ulrich, 1978) and ADD-H Comprehensive Teacher's Rating Scale (ACTeRS; Ullmann, Sleator, & Sprague, 2000) were often correctly classified by the T.O.V.A. Since this statement holds true conversely, Forbes emphasized that the T.O.V.A. "does not have sufficient discriminative validity to conclusively determine a diagnosis" and should be used among a battery of tests (p.474).

Clinical utility and discriminant ability of T.O.V.A. variables were also found in 17 AD/HD Japanese male children and 19 normal control 6- to 12-year olds with histories free of stimulant or psychotropic medications (Wada, Yamashita, Matsuishi, Ohtani, & Kato, 2000). Two age groups were separated (6 to 9 and 9 to 13) to study age effects. T-tests compared group means on raw scores. The AD/HD group had significantly higher means than the control group in all variables: OE, CE, RT, RTV, AR, MR and no differences were found in young versus old AD/HD groups. However, in the control group, differences were found in mean RT and RTV with significantly higher scores in younger males than in older males at a .05 level of significance. The authors concluded that the T.O.V.A. contributes to the diagnosis of AD/HD in Japanese male children.

The most recent discriminant validity study by Schatz, Ballantyne and Trauner (2001) evaluated the consistency between the abbreviated Conners' Parent-Rating Scale (Conners, 1991) and the T.O.V.A. in 28 AD/HD and 20 control children. Although both the T.O.V.A. and the Conners' correctly suggested an AD/HD diagnosis in approximately 85% of children who were clinically diagnosed, the T.O.V.A. suggested attention problems in 30% of the controls whereas the Conners did not. The authors suggested that the T.O.V.A. may be picking up on inattentive behaviors that are not functionally impairing, similar to the behaviors found on rating scales. In regards to T.O.V.A. variables, OE did not differentiate between children and adolescents with AD/HD and healthy controls. In contrast, Response Time and Response Time Variability accurately differentiated between AD/HD and control children; it was reported that Response Time Variability may be the most useful diagnostic predictor on the

T.O.V.A.. The authors concluded the T.O.V.A., combined with rating scales, lead to more accurate AD/HD evaluations.

Construct validity is demonstrated in the T.O.V.A. professional manual by a factor analysis of variables (Leark et al., 1996; Leark et al., 2007). The three factors of attention, disinhibition and reaction time were found to be consistent with the hypothesized constructs of the test. Factor loadings for each variable are presented in the professional manual.

Although the T.O.V.A. has demonstrated adequate reliability and validity, it is still unclear if the T.O.V.A. may be measuring motor skills. Chae (1999) reported that a popular concern among T.O.V.A. users at conferences includes the question of whether or not psychomotor skills are being measured either alone or in addition to attention. The answer to this question has an impact on the interpretation of variables used in the T.O.V.A. as well as the validity of this measure.

Motor Function and Developmental Coordination Disorder (DCD)

The next section will provide information on the assessment of motor function and attention in children with attention and motor impairments, including intelligence tests, visual-motor tests, reaction time tasks and CPTs in an effort to provide a background for the exploration of the potential confound of psychomotor skill on the T.O.V.A.

Construct of Motor Function. Similar to inattention, motor dysfunction is nonspecific and is complex in definition, system and assessment. Like the attention system, disruption in the brain structure itself or anywhere along the motor pathways may affect motor performance. Motor function depends on proper functioning of the central nervous, muscular, and skeletal systems; this includes muscles, neuromusclar junctions, motor neurons, the spinal cord, brainstem, cerebral cortex, basal ganglia and cerebellum (Rosenzweig, Breedlove, & Watson, 2005). Specific motor deficits, like spasticity, may be indicative of motor disorders, such as cerebral palsy, while nonspecific neuromotor deficits, like dys-coordination, may be present in developmental delays (Blondis, 1999). If nonspecific motor deficits significantly impact academic achievement or adaptive functioning in children, a diagnosable condition, such as Developmental Coordination Disorder, may be warranted.

Definition of Developmental Coordination Disorder. Motor function problems have been described in an assortment of terms, including “motor coordination problems”, “clumsiness”, “developmental dyspraxia/apraxia” or “minimal brain dysfunction” (Magalhaes, Missiuna, & Wong, 2006). Each term suggests a deficit in the coordination of voluntary movement. The most frequently used term for significant motor dysfunction is the DSM-IV-TR term, Developmental Coordination Disorder (DCD; APA, 2000; Magalhaes et al., 2006). As defined by the DSM-IV, children with DCD present with motor dysfunction that significantly interferes with daily functioning, is significantly below that expected for chronological age and measured intelligence, and is unrelated to a medical condition (e.g., cerebral palsy, 2000). However, there is a lack of universal agreement as to the amount of impairment that qualifies as significant functional interference (Dewey, Kaplan, Crawford, & Wilson, 2002). Furthermore, a dual diagnosis of AD/HD and DCD may be given if poor motor performance in AD/HD children is not directly related to inattention, hyperactivity or impulsivity (APA, 2000).

A relationship between attention and motor deficits has been recognized abroad since the 1970s. In Scandinavian countries, a dual diagnosis of AD/HD and DCD is termed DAMP (Deficits in Attention and Motor [control] Perception; Gillberg, Rasmussen, Carstrom, Svenson, & Waldenstrom, 1982). Gillberg, a Swedish psychiatrist who has published approximately eighty papers on DAMP, theorizes that “truly dysfunctional AD/HD does not exist without motor and perceptual deficits” (Blondis, 1999, p. 902), and predicts greater impairment and less optimistic outcomes for individuals with DAMP (Gillberg et al., 1982).

Assessing Motor Function and DCD. Similar to AD/HD, there is no “gold standard” for the assessment of motor skills (Dewey et al., 2002, p. 907). Among the various motor skills that can be assessed (e.g., gross motor, fine motor, etc.), it has been shown that children can score within normal limits on one test and poorly on others (Dewey & Wilson, 2001). This finding may be related to possible subtypes of DCD or to the variety of assessments used to measure various constructs of motor function (Crawford et al., 2001).

A meta-analysis of DCD information processing research coded five categories of tests frequently used in DCD research (Wilson & McKenzie, 1998). First, “Visual Processing” tests measure visual functioning with or without motor and memory components. Visuospatial motor tests include the Bender-Gestalt Test (Bender, 1938), the Beery-Buktenica Developmental Test of Visual-Motor Integration (VMI; Beery, 1989, 1997), and Block Design subtest of the WISC-IV. Second, “Other Perceptual Processing” tests include kinesthetic perception of limb movement and cross-modal perception. Examples include the Kinesthetic Sensitivity Test (Laszlo & Bairstow, 1985). Third, “Motor Control” tests measure “spatiotemporal parameters of movement planning and execution” (p. 831) and are divided into three subgroups. Chronometrics, such as reaction time, is one such subgroup. Wilson and McKenszie define the fourth category as “General Intelligence” tests, such as the Wechsler Full Scale, Verbal and Performance IQ. Last, “Motor Skills” tests assess global performance skills such as basic skills (balance, gross and fine motor dexterity), motor fitness (running, agility, grip strength and flexibility) and motor skills (such as catching and hopping). Examples of these screening tests include the Bruininks-Oseretsky Test of Motor

Proficiency (BOTMP; Bruininks, 1978) and the Movement Assessment Battery for Children (MABC; Henderson & Sugden, 1992). These categories of tests will be described in the next section.

Attention and Motor Function in Children with AD/HD and DCD

Although occurring in 50% of all AD/HD cases, problems with motor coordination remain under-examined and disregarded in AD/HD research (Doyle, Wallen and Whitmont, 1995; Gillberg et al., 1989; Kadesjo & Gillberg, 1998; Piek et al., 1999; Pitcher et al., 2003; Tseng, Henderson, Chow, & Yao, 2004). Research has demonstrated a consistent relationship between AD/HD and poor motor coordination; AD/HD children are more at risk for motor problems and children with motor problems (DCD) have increased levels of AD/HD (Dewey et al., 2002; Kadesjo & Gillberg, 1999). Recently, attention to the "comorbidity problem," has been discussed in the context of AD/HD and co-occurring motor conditions (Kaplan et al., 2006; Kaplan, Dewey, Crawford, & Wilson, 2001) and theories have been proposed to better understand the relationship between these disorders. One such theory, the Cognitive -Energetic or -Tempo model, relates information processing with motor difficulties in children with AD/HD and DCD (Sergeant, Piek, & Oosterlaan, 2006; Shanahan et al., 2006).

It is not the purpose of this paper to debate which "comorbidity problem" hypothesis is correct but to explore the relationship of AD/HD and motor skills on a frequently used CPT. However, it is noted that one study found less than 10% of children with AD/HD-C to have motor skill problems (Doyle et al., 1995). The authors suggest that poor motor skills found in other studies may be artifacts of attention and concentration (Doyle et al., 1995; Whitmont & Clark, 1996), which in turn may confound this study's findings.

General Intelligence: Processing Speed. Both children with AD/HD and DCD score near the normal range of intellectual functioning as measured by the Wechsler series, but may perform worse on measures of performance IQ (Williams, Weiss, & Rolfhus, 2003). The performance subtests of the WISC-III (Wechsler, 1991) and WISC-IV measure nonverbal abilities required to interpret and respond to information under timed and untimed conditions. Poor performance on the PIQ is interpreted by some as influenced by motor skills rather than intelligence (Coleman et al., 2001). Both the WISC-III and WISC-IV have a Processing Speed Index (PSI), a measure of visual-motor speed, which has been found to be a strong factor in the Performance domain (Sattler, 2008).

The Processing Speed Index (PSI) is often found to be poorer in children with AD/HD than in controls (Mayes & Calhoun, 2006; Pitcher, Piek, & Barrett, 2002; Wechsler, 2003; Williams et al., 2003). The WISC-IV technical manual reports that unlike the medium effect size for group differences on PSI between children with AD/HD (64% on medications) and a matched control group, small effect sizes were observed for group differences on the Verbal Comprehension (VCI) and Working Memory Indices. On the subtest level, large effect sizes were found for the Coding and Arithmetic subtests. Coding was also found to be the lowest mean subtest score among children with AD/HD in two samples, although not at a significant level (Mayes & Calhoun, 2006; Williams et al., 2003) and to be an important subtest in AD/HD research (Barkley, 1990). Mayes and Calhoun interpret the Coding subtest to be greatly confounded by graphomotor ability (2006). Furthermore, PSI has been reported to be the among the best predictors of inattentive symptoms (Chhabildas, Pennington, & Willcutt, 2001). An unpublished doctoral dissertation also found inattentive symptomatology to predict PSI (Pitcher, 2001 as cited in Piek & Pitcher, 2004).

Processing Speed is also an important factor in children with DCD (Dewey et al., 2002; Piek & Skinner, 1999). Children with motor delays typically have lower scores than controls on some measures of performance on the Wechsler Intelligence Scales (Coleman, Piek, & Livesey, 2001; Piek & Coleman-Carman, 1995; Pitcher et al., 2002; Williams et al., 2003). In addition to the large effects found in children with AD/HD, Coding and Arithmetic, as well as Symbol Search and Cancellation (the rest of the PSI) produced large effect sizes for group differences between children with motor impairment and matched control groups; thus a large effect was found for PSI (Williams et al., 2003). In addition to those subtests, other studies have found children with DCD to perform more poorly than controls on Perceptual Organization tasks from the WISC-IV such as Object Assembly and Block Design (Coleman et al., 2001; Piek & Coleman-Carman, 1995).

One unpublished doctoral dissertation looked at populations with known attention and motor deficits. Four groups of children were divided into control, AD/HD, DCD and AD/HD plus DCD groups (Pitcher, 2001 as cited in Piek & Pitcher, 2004). Across these groups, children with AD/HD and DCD had significantly lower scores on PSI. The Processing Speed Index, with its obvious motor coordination and speed components, was therefore deemed as an important variable in researching children with these deficits.

One explanation of why processing speed is important in both children with attention and motor deficits is the Cognitive-Energetic model (CEM; Sergeant et al., 2006). The CEM, which provides some reason why AD/HD and DCD commonly occur together, is a working model since published research about motor and non-motor stages of information processing is limited (Sergeant et al., 2006). The CEM states that processing information is sequentially staged by three levels. The lowest level consists of encoding, central processing and response organization. The higher two levels of the model consist of executive functioning, as defined by the ability to put forth effort; it determines the state of arousal and the degree of activation in the brain. In essence, execution of responding is dependent on these three levels. For example, it is hypothesized that inattentive behaviors may be a manifestation of poor executive functioning that decreases effort, arousal and activation therefore affecting the encoding, central processes and output organization.

Visual Processing and Fine Motor Skill Integration. Studies have found children with both AD/HD and DCD to have impairments in visual and motor processing and integration. Children with DCD display a range of motor deficits including delays in motor developmental milestones (e.g., walking and sitting), dropping things, and poor performance in sports and handwriting (Piek & Dyck, 2004). In a review of 49 empirical studies, children with AD/HD have also been described as at-risk for different types of motor skills deficits (Harvey & Reid, 2003). For example, gross motor skills, like running, hopping and jumping, have been found to be substantially lower than average in children with AD/HD (Harvey & Reid, 1997).

Fine motor skills have also been found to be poor in children with AD/HD. Children with AD/HD were tested on their fine motor skills as measured by the Fine-Motor Composite of the BOTMP and the Repeated Patterns Test (RPT; Waber & Bernstein, 1994), and they demonstrated impairment and significantly lower scores than controls (Marcotte & Stern, 1997; Whitmont & Clark, 1996). Although Marcotte and Stern found that 40 AD/HD-C children performed significantly worse on the RPT quality scores than the 40 AD/HD-PI children and normative data, they found average performances and no significant differences on the Beery VMI and the Hooper Visual Organization Test (Hooper, 1958), a test of visual perception. Different constructs measured by the different tests very likely contributed to this finding. On a clinical level, it may be that if children do not have the capacity to pay attention to overall characteristics and details of a figure, the resulting graphomotor output will be less than expected for the developmental age.

Motor skill deficits have been found to be associated with AD/HD subtype and symptom severity. Severity of inattention has been found to significantly predict motor coordination difficulties in AD/HD males (Piek et al., 1999). Hyperactivity symptoms, as measured by the Hyperactivity Index of the Conner's Rating Scale (Goyette, Conners, & Ulrich, 1978), have been found to strongly associate with impaired fine motor skills (Whitmont & Clark, 1996). Gross motor skill deficits have been found more in the "combined" AD/HD subtype (Piek et al., 1999) and have been predicted by problems with attention, impulse control and activity level (Tseng et al., 2004).

One study examined fine motor skills in children across AD/HD, DCD and DAMP groups. Piek et al. (1999) revealed a substantial number of children with AD/HD who met criteria for DCD and DAMP. The study compared two groups of 16 boys diagnosed with either AD/HD-PI or AD/HD-C, matched for age and Verbal IQ. Regression analyses found a strong relationship between severity of inattentiveness and fine motor ability. A subsequent study replicated these findings in a substantially larger population (n=157) of children using all 3 subtypes of AD/HD (Pitcher, Piek, & Hay, 2003). The authors found 20% of the control group to have motor impairments versus 50% of the AD/HD groups. The authors attributed low fine motor performance to deficits in motor ability and not attention.

Reaction Time. Reaction time, an indication of CNS processing, has also been found to be slower in children with AD/HD and DCD. A common neuropsychological test used to assess motor speed is the finger tapping test, also known as the finger oscillation test. This task assesses motor output by the number of taps completed within a specified time interval (Rommelse et al., 2008). Reaction time tasks are also used to assess motor skills. In healthy individuals, simple reaction times, as indicated by the latency from the start of a stimulus to the depression of a button, averages to be 310 ms (Rosenzweig et al., 2005). The process of this simple reaction time task incorporates a pathway that begins in the retina, then thalamus, primary visual cortex to the prefrontal cortex, "then through premotor and primary motor cortex, down to the spinal motorneurons, and out to the finger muscles" (Rosenzweig et al., 2005, p. 350). Children with AD/HD perform slower than expected on timed neuromotor assessments, such as finger tapping, compared to age-related norms (Denckla &

Rudel, 1978; Gillberg, Gillberg, & Groth, 1989). Motor output variability has been frequently cited in AD/HD children (Pitcher et al., 2002; Rubia, Noorloos, Smith, Gunning, & Sergeant, 2003; Toplak, Dockstader, & Tannock, 2006). In addition, over time, some AD/HD children may continue to show prolonged reaction time despite no longer clearly exhibiting detectable motor problems (Gillberg et al., 1989). However, one study did not find 11-year-old children with AD/HD to have hand movement deficits or slower reaction times compared to a control group (Steger et al., 2001). The authors attribute group characteristics, such as age and less severe AD/HD symptoms, to be potential reasons for this discrepancy.

Pitcher et al. (2002) studied a sample of children with AD/HD with and without DCD, compared with a control group, on sequential finger tapping tasks. The authors found AD/HD children with and without DCD to be significantly slower than the control group, as measured by longer movement times, or inter-tap intervals. However, these groups did not differ significantly from one another. Reaction times were found to be significantly poorer in children with AD/HD plus DCD compared with a control group although significant differences were not found in children with AD/HD only. The authors conclude that the relationship between AD/HD and motor function has the potential to impact "assessment, intervention, theoretical modeling and the general interpretation of cognitive abilities in research with children with AD/HD" (Pitcher, 2002, p. 919).

CPTs: a Measure of Attention and Possibly Motor Function. An inherent aspect of CPTs requires an intact and timely motor response (i.e., pressing a button in response to stimuli). This motor response potentially confounds the interpretation of CPT results and affects the validity of these tests. Clinicians are cautioned “to ensure that poor motor control is not interpreted as evidence of deficits in attention” (Riccio et al., 2001,p. 155). As discussed earlier in the literature review, symptoms of AD/HD and motor impairment are known to commonly coincide; however, few studies have taken this relationship into consideration. The results of relevant studies will be presented.

There are no studies of CPT performance in children with DCD although other types of reaction tasks provide some data. On one such test, with an emphasis on inhibition of responses, the authors found children with DCD produced significantly more errors of inhibition, similar to Commission Errors (Mandich, Buckolz, & Polatajko, 2002).

Four studies examined the relationship between motor function and CPTs. These studies vary widely in CPT parameters, diagnoses of research samples and measures used. The following section will outline the four studies that are most relevant to the purpose of this paper. Chae (1999) examined the relationship between WISC-III and the T.O.V.A. primary variables to investigate if psychomotor skills influence CPT performance. Notably, Chae’s study included a predominantly Caucasian male clinical sample of children with AD/HD, aged 6-

16, with average WISC-III indices. Several pieces of important information were not included in the article, limiting understanding of the methods used. First, it was unclear where the data were collected. Second, the article did not report the type of T.O.V.A. variables score used in the analyses; it is deduced that raw scores were utilized, leaving the unanswered question of whether or not age and gender were corrected or covaried. Noteworthy, using raw scores rather than standard scores reversed the direction of the interpretation of the correlations, lower T.O.V.A. scores and higher WISC-III scores indicate better performance. Another limitation was the exclusion of reported or discussed T.O.V.A. mean scores for the sample.

Chae (1999) concluded that the T.O.V.A. does not measure psychomotor speed as he hypothesized. This conclusion was based on the results that Coding did not significantly correlate with any primary T.O.V.A. variable (See Table 4). Specifically, both Processing Speed subtests of Coding and Symbol Search did not significantly correlate with any primary T.O.V.A. variable. Interestingly, these correlations with Coding were reported as positive correlations, indicating that better WISC-III performance related to longer Response Times, Response Time Variability, and more Commission and Omission Errors. Chae did not comment on this result.

Chae (1999) also stated that T.O.V.A. performance was not found to be significantly correlated with the WISC-III PIQ. However, several significant correlations were reported. PIQ subtests were found to be moderately and significantly associated with T.O.V.A. Omission Errors: Picture Arrangement (r = -.50, p<.01) and Object Assembly (r = -.54, p<.01). The overall Performance Index correlated with Omission Errors at a small to moderate but significant degree (r = -.46, p >.05). These negative correlations indicated worse standard scores on the WISC-III are related to worse raw scores on the T.O.V.A.. Chae stated that these PIQ subtests are not "tasks of psychomotor speed performance such as TOVA Response Time, Coding and Symbol Search" but are tasks that require sustained attention (1999, p. 182).

Eye movements, finger tapping dysfunction and the Beery VMI have also been related to CPT variables (Allen, 1993, as cited in Riccio et al., 2001; Grant, et al., 1990). Grant et al. (1990) investigated the relationship of the Gordon Diagnostic System and a neuropsychological battery in 119 boys with AD/HD (DSM-III or DSM-III-R criteria) aged 6 to 13. There was no control group. The GDS was the selected CPT that uses numbers as stimuli, is 9 minutes long, and requires the participant press the button every time a two-number target combination is presented (e.g., a 1 followed by a 9) recorded over three blocks of time. The GDS Vigilance Correct Responses, a measure of sustained attention, and Commission Errors, were found to be significantly related to finger oscillation. GDS Vigilance Correct Responses were also significantly related to Finger Recognition, a sensory-perceptual test. The authors suggest that either a relationship between sensory-motor tasks and measures of sustained attention exists or the results illustrate the variable profile found in the performance of children with AD/HD. The Beery VMI task correlated with all three blocks of Correct Responses on GDS ($r = .20$ to $.37$, $p < .001, .01, .05$). The VMI was also related to Commission Errors made during the Distractibility Task portion of the GDS ($r = .37$, $p < .001$). The authors speculated that the relationship between the VMI and GDS was an effect of attention, and concluded that the relationship was difficult to interpret and more research was necessary.

McGee et al. (2000) studied several measures of visual processing and visual-motor competence in a sample of 100 clinic-referred children aged 6 to 11. The authors chose two of three tasks on the Wide Range Assessment of Visual-Motor Abilities (WRAVMA; Adams & Sheslow, 1995) that are thought to be minimally influenced by attention. In addition to the Drawing and Pegboard subtests on the WRAVMA, McGee et al. investigated visual processing speed in Visual Matching, a task similar to the Wechsler series Cancellation subtest. Contrary to their hypothesis, no Conners CPT variables were found to be related to the WRAVMA measures. However, the Visual Matching task did correlate with Hit Reaction Time ($r = .25$, $p = .01$) but not with the Conners CPT overall index.

Other studies support the notion of motor skills influencing CPT results. These studies are within different populations and CPT parameters. Walker and

Green (1982) found significant correlations between the BOTMP and CPT-AX variables in a sample of schizophrenic and affective psychotic inpatients. Negative Pearson product moment correlations were reported between the BOTMP motor subtests and CPT variables, indicating a relationship between poor motor skills and poor CPT performance. Errors of Omission were significantly related to scores of Visual-Motor Control in both groups (r = -.75 and -.78) and Bilateral Coordination (r = -.66) and Upper Limb Speed and Dexterity (r = -.58) in the schizophrenic group. Reaction time also was significantly related to Visual-Motor Control in the schizophrenic group (r = -.76). Commission Errors were not significantly correlated with motor performance.

These four studies have found some relationships between motor measures and various CPT variables. Specifically, Walker and Green (1982) found a significant relationship between CPT Reaction Time and the BOTMP Visual-Motor control, and McGee (2000) found a significant relationship between CPT Reaction Time and performance on a Visual Matching test. Grant et al. (1990) found significant correlations between the Beery VMI and the Gordon Correct Responses and Commission Errors scores. Furthermore, the authors found Commission Errors to be related to finger oscillation. Walker and Green did not find any of their motor measures to be related to Commission Errors, although several motor tasks significantly correlated with Errors of Omission, including

Visual-Motor Control, Bilateral Coordination and Upper Limb Speed and Dexterity.

The diagnosis of AD/HD is complex, challenging and consequential. The use of sound objective and subjective measures is paramount for an accurate diagnosis which, in turn, implicates treatment. One commonly used CPT, the T.O.V.A., has aided in AD/HD diagnostic evaluations. Studies have provided evidence that motor functioning may be a potential confound to interpretation of CPT variables, although some have concluded the lack of a relationship. Previous research does not fully address the concern and this problem warrants further investigation.

CHAPTER THREE

RATIONALE, AIMS, AND HYPOTHESES

Rationale and Aims

CPTs are commonly used in diagnostic evaluations of AD/HD because of their objective assessment of sustained attention. CPTs, such as the T.O.V.A., have shown adequate reliability and validity (Greenberg & Crosby, 1992b, 1992c as cited in Leark et al., 2007; Llorente et al., 2001; Llorente et al., 2008); however, researchers and clinicians are concerned that children who are slower in responding to stimuli may be mislabeled as inattentive on CPT variables (Chae, 1999). In order “to ensure that poor motor control is not interpreted as evidence of deficits in attention” (Riccio et al., 2001, p. 155) and potentially misdirects a diagnosis of AD/HD (McGee et al., 2000), these variables need to be investigated.

Although CPTs are widely used, few studies have analyzed the influence of psychomotor performance on CPT variables. In one of these studies, McGee et al. (2000) hypothesized that visual-motor integration, motor speed and visual processing speed are associated with performance on the Conners’ CPT. The authors found that only a visual processing speed task (a matching task) correlated with “hit reaction time” while the other two measures of psychomotor skills did not. They concluded that visual processing speed was the only psychomotor skill to be related to CPT performance. In another study, Chae (1999) hypothesized, studied and concluded that T.O.V.A. variables are not related to psychomotor skills as measured by the WISC-III Processing Speed Index. However, in his results, OE significantly correlated with two PIQ subtests. A study of the current versions of the T.O.V.A. 7.3 and WISC-IV subtests of Processing Speed and Working Memory, along with a visual-motor integration measure, the Beery VMI, is necessary to continue the exploration of psychomotor skills and CPT performance.

The paucity of current research about the T.O.V.A. and potential psychomotor confounds warrants the examination of these variables in children suspected of inattention problems. These studies will help us gain a better understanding about the validity of CPTs when assessing attention in children, especially in the clinical setting where these measures are commonly used. Attention and motor variables need to be investigated together, to determine their relative contributions. If motor functioning is related to CPT performance, interpretation of CPT results may need to be re-examined in some children. The impact of this effect may influence the future use of CPTs and may provide information about the importance of measuring and controlling for motor dysfunction in research as well.

Hypotheses

The purpose of the current study was to investigate the effect of psychomotor function, as measured by the WISC-IV Processing Speed Index and the Beery-Buktenica Developmental Test of Visual-Motor Integration, as well as to evaluate attention, as measured by the WISC-IV Working Memory Index, on the four primary T.O.V.A. scores of Response Time, Response Time Variability, Omission Errors and Commission Errors.

Hypothesis One: Scores on the tests of psychomotor function, the WISC-IV Processing Speed Index and the Beery VMI, will account for significant variance in T.O.V.A. Response Time and Response Time Variability.

Hypothesis Two: Scores on the test of attention, the WISC-IV Working Memory Index, will account for significant variance in T.O.V.A. Errors of Omission and Errors of Commission.

Hypothesis Three: Children with attention and/or hyperactive deficits, as measured by the parent-rated BASC-2, will earn lower scores on the primary T.O.V.A. variables than children who do not have attention and/or hyperactive deficits as rated by the BASC-2.

CHAPTER FOUR
METHODOLOGY

Participants

One hundred files of children referred for suspected attention problems, ages 6 to 16, were selected at the Shelton Evaluation Center in Dallas, Texas. Charts were retrospectively reviewed in reverse chronological order from November 2008 until February 2006 when 100 charts meeting criteria were located. Approximately eight hundred files were included in this time period. Chosen files were selected based on inclusion and exclusion criteria listed below. The eight hundred files that did not meet criteria included those children with intelligence quotients below 70, history of central nervous disease and tests that did not match the ones of interest of this study.

Participant files included demographic sheets, a review of the child's developmental history, school transcripts, clinician notes and observations during testing, objective and subjective tests, raw data, and prior and current psychological evaluation reports. The psychological evaluation generated during the current testing date documented the most current diagnostic impressions and DSM-IV-TR diagnoses. Psychiatric diagnoses were determined by, or under the supervision of a licensed practitioner utilizing unstructured clinical interviews, parent-rated behavioral rating scale (e.g., BASC-2) and objective measures not limited to but including the WISC-IV, Beery VMI and T.O.V.A..

Inclusion Criteria

1. Participants were male or female and ranged in age from 6-16 years at time of testing.

2. Participants completed the Test of Variables of Attention (T.O.V.A.), the Beery-Buktenica Developmental Test of Visual-Motor Integration (Beery VMI) and the Wechsler Intelligence Scale for Children-IV (WISC-IV) at the time of the clinical evaluation.

3. Participants' parents completed the Behavioral Assessment System for Children-2 (BASC-2) at the time of the clinical evaluation.

Exclusion Criteria

1. Participants with a history of central nervous system injury or disease (other than AD/HD) were excluded from the study.

2. Participants with an IQ below 70 were excluded from this study.

3. Because some instruments have not been normed for non-English-speaking populations, participants who are not primarily English-speaking or whose parents are not primarily English-speaking were excluded from this study.

One case was excluded from the database, after meeting criteria for this study, due to consistently low T.O.V.A. performance scores and a clinical note that the child was unable to complete the T.O.V.A. because of severe restlessness and inattention.

Participants consisted of 58 males and 41 females, ranging in age from 6 to 16 (mean age 10.6 years, standard deviation=2.87, mode = 8). The majority of children were in the 2nd grade at the time of testing, attended a private school, and had parents with 16 years of education (see Table 5). A range of psychiatric conditions and comorbidities were found. Although 21 (21.2%) files indicated an absence of a diagnosed DSM-IV-TR psychiatric disorder the remaining cases resulted as following: 33 (33.3%) had one, 29 (29.3%) had two, 9 (9.1%) had three, 6 (6.1%) had 4 and 1 case (1.0%) had 5 DSM-IV-TR psychiatric conditions diagnosed.

The most common psychiatric condition diagnosed was Dyslexia (n=40, 40.4%). Thirty-six (36.4%) participants were diagnosed with AD/HD, 22 of whom were specified as Combined Type, 10 as Predominantly Inattentive Type, 3 as Hyperactive Type, and 1 as Not Otherwise Specified. An additional 37% of cases (n=37) had AD/HD as a rule-out.

Other psychiatric diagnoses documented in the total sample included other developmental disorders. Thirty-five (35.4%) participants were diagnosed with DCD, nine (9.1%) with Learning Disorder NOS, and seven (7.1%) with a

Language Disorder. Other less common disorders included: Mathematics Disorder (5.0%), Mood/Anxiety Disorders (5.0%), Miscellaneous Disorders (4.0%), and Nonverbal Disorders (2.0%).

Parent-reported developmental milestone achievements were found to be within normal limits for about 70.7% percent of this sample. Three reports on this statistic were missing and the other 26.3% had one or more severe delays in speech or motor skills.

Design and Procedures

Files came from the Shelton Evaluation Center in Dallas, Texas. Children were assessed by staff members of the evaluation center during the years of 2006 to 2008. The team during these three years at the center included a doctor of communication disorders, an educational psychologist, a clinical psychologist, licensed psychological associates, testing assistants, post-doctoral clinical psychology students and several clinical psychology interns under the supervision of one psychologist and the director of the evaluation center. As part of the procedures at the Shelton Evaluation Center, more than one clinician assessed each child during the evaluation to gather at least two clinical opinions on the case. Although the evaluators may not have been the same clinicians who scored or interpreted the results, the center maintained consistent evaluators and similar procedures for testing throughout this testing period. Supervisory meetings were required for interns and post-docs as part of training. The director of the evaluation center and, when indicated, a supervisor evaluated and authorized every psychological evaluation.

Data Collection and Storage. In order to maintain confidentiality, each participant was assigned a unique number for this study's database. Codes and names matched to assigned numbers were kept in a separate, secure location. All T.O.V.A. data files were updated from version 7.0 to 7.3. During this process, T.O.V.A. variables were extracted into an Excel file without identifying information. Other measures were entered and stored in a password protected Excel file and later an SPSS database. All entered data were double-checked for accuracy.

T.O.V.A. variables with standard scores reported as "<40" were entered into the database as a standard score of 39. Scores designated as "invalid" by the computerized scoring program were not excluded from this study. According to the T.O.V.A. manual, "invalid" scores arise for various reasons, including the presence of anticipatory responses greater than 10% of total responses and/or omission errors representing greater than 90% of responses per quarter. If a quarter is invalidated, the total score for that variable automatically becomes invalidated. The T.O.V.A. manual indicates that it is up to the researcher to decide if an invalid result should be used in a research study. Because 21 of the 99 files included invalid scores, having an "invalid" score was not considered anomalous; rather, these data were considered to represent a characteristic of the sample and were regarded as providing clinical information about the participant.

Study Design and Analysis. All results were evaluated using the statistical software program SPSS version 17.0. Primary Hypotheses (one and two) utilized a within-group design to analyze the influence of psychomotor and attention performance on T.O.V.A. variables. In order to determine whether distributions of scores were normal in the overall sample, Kolmogrov-Smirnov tests were performed on all variables in conjunction with a study of corresponding Lilleifors significance corrections (Lilliefors, 1967), boxplots, normal probability plots, skew and kurtosis coefficients. Log, square and inverse transformations, and reflected transformations for negatively skewed data, were applied to non-normally distributed variables. These transformations were then re-checked for normality. The best transformation, determined by a combination of the improvement on coefficients of the skew and kurtosis, the number of outliers and the approximation to a normal distribution, was chosen to be run in the following statistics along with the original non-transformed variable. Non-parametric tests were also run to ensure the integrity of these results.

For the first two hypotheses, frequencies and characteristics of test means and standard deviations were analyzed. Several sets of collected demographic information were not included in the results section due to missing data (e.g., health diagnoses) and unreliable coding (e.g., ethnicity based on photograph). Using the variables of interest, Pearson's product moment and Spearman's rank-order correlations were calculated. Bonferroni corrections were not applied. WMI, PSI and VMI scores were then entered in stepwise multiple linear regression analyses to predict T.O.V.A. performance scores. Regressions were run with and without transformations. It was found that some transformations did not change the results; therefore, non-transformed data were reported in the results section.

For the third hypothesis, three groupings were derived to compare T.O.V.A. performance scores across subtypes of AD/HD. Since structured diagnostic protocols were not used as part of this study, the BASC-2 was selected as a grouping variable to create homogeneous groups. Previous research has successfully used the BASC in AD/HD diagnostic evaluations (Jarratt et al., 2005) and other studies have used other behavioral rating scales as a sole measure of attention or a grouping variable (e.g., Piek, Dyck, Nieman, et al., 2007; Barkley, DuPaul & McMurray, 1990).

The BASC-2 Attention and Hyperactivity standard scores were divided into non-clinical (T score ≤ 59) and elevated/clinical scores (T score ≥ 60). If the

Attention Problems Scale was elevated at a level at or above a T-score of 60, these participants were placed in the *Attention* Group or in the *Combined* Group if the Hyperactivity Scale was also elevated at the same threshold. If neither scale was elevated, these participants were grouped into the *Neither* group. Out of the 99 files, six cases presented with only the Hyperactivity scale elevated. These six cases were removed for the analyses of the third hypothesis.

Once the groups were established, variables in the new overall sample (n=93) and across the three groups were explored and analyzed for assumptions of ANOVAs. The same transformation procedures were followed as described in hypotheses one and two. Group means and standard deviations were calculated for the variables of interest. ANOVAs were used to compare T.O.V.A. scores in the Neither, Attention and Combined groups for variables that met the assumptions of normality and equal variance. The non-parametric Kruskal-Wallis analysis was used for variables that violated assumptions.

For exploratory purposes and to address the possibility that attention deficits may affect the relationship between motor functioning and T.O.V.A. performance, Pearson product moment correlations and stepwise regressions that were conducted for the overall sample were repeated for each BASC-2 grouping (Appendix E).

Measures

Behavior Assessment System for Children, Second Edition (BASC-2). The BASC-2 (Reynolds & Kamphaus, 2004) was used to document symptoms of AD/HD and defined the groups for the third hypothesis. The BASC-2 is an omnibus, multi-rater behavioral assessment system for individuals 2 to 21 years of age. The BASC-2 measures both internalizing and externalizing behavior problems, such as inattention and hyperactivity, and compares individual scores to national norms. The Parent Rating Scale (PRS) was used for this study. One metric used with reporting scores on the BASC-2 is the T-score, with a mean of 50 and standard deviation of 10. Interpretation of T-scores includes a “non-clinical” range up to a T-score of 60, an “elevated” range from 60 to 64 and a “clinical” range for scores 65 or greater (Reynolds & Kamphaus, 2004).

Specifically the BASC-2 includes the following scales: Adaptability, Aggression, Anxiety, Attention Problems, Atypicality, Conduct Problems, Depression, Hyperactivity, Leadership, Learning Problems, Social Skills, Somatization, Study Skills and Withdrawal. These scales are grouped into five independent composite scores: Adaptive skills, Behavioral Symptoms Index, Externalizing problems, Internalizing problems, and School problems. Cronbach alpha coefficients range from .80 to the lower .90’s for the parent forms (Reynolds & Kamphaus, 2004).

The BASC has been used successfully in diagnosing AD/HD in research (Jarratt et al., 2005) and the Attention Problems and Hyperactivity scales together have been able to distinguish among AD/HD subtypes (Vaughn, Riccio, Hynd & Hall, 1997). Children with AD/HD have scores that are significantly worse than normal controls on scales of Hyperactivity, Aggression, Conduct Problems, Depression, Atypicality, Attention Problems, Leadership, Externalizing Behaviors and Adaptive Skills (Jarratt et al., 2005; Reynolds & Kamphaus, 2004).

Beery-Buktenica Developmental Test of Visual-Motor Integration, 5^th^ Edition (Beery VMI). The Beery VMI is a test of visual-motor integration for children ages 2 to 18 (Beery, 2004). This test is frequently used in screening visual-motor integration skills in research (Rodger et al., 2003). The child is instructed to copy simple to increasingly complex geometric forms. There are a total of 27 designs in this untimed test. Scaled and standard scores are two of the many scores used to report results. Higher scores on this test indicate better integration of visual-perception, spatial conceptualization, and finger-hand movements. The manual provides 2,512 age-specific norms of a nationally representative sample of children age 2 to 18. The Beery VMI has high internal consistency, test-retest and interrater reliability (Beery, 2004). The Beery VMI has moderate correlations with two other well-known motor tasks. Correlations with the Performance Index of the WISC-R are moderate in magnitude and greater than correlations with the WISC-R VIQ and FSIQ (Beery, 2004). The Beery VMI is also commonly used in research of children with known motor deficits (Rodger et al., 2003).

Test of Variables of Attention (T.O.V.A.). The T.O.V.A., one of most researched and widely used CPTs, compares an examinee's performance on a sustained attention and reaction time computerized task to normative data (Greenberg & Kindschi, 1996; Leark et al., 1996, Leark et al., 2007). The T.O.V.A. has high internal consistency, satisfactory temporal validity (Llorente et al., 2001; Llorente et al., 2008) and sufficient discriminative validity (Forbes, 1998). The primary variables of the T.O.V.A. include Commission Errors, Omission Errors, Response Time, and Response Time Variability. Other measures include d' Prime, Anticipatory Responses, Multiple Responses, Correct Responses and an AD/HD index score. Scores are reported in raw scores, percentiles and standard scores (mean = 100, standard deviation = 15). According to the T.O.V.A. manual, interpretation of standard scores includes the following: scores at 85 or higher are average, 80 to 85 are borderline and below 80 indicate significant impairment (Leark et al., 2007).

Wechsler Intelligence Scale for Children – Fourth Edition (WISC-IV). The WISC-IV is one of the most widely utilized pediatric intelligence tests for children ages 6 to 16:11 (Wechsler, 2003). Ten subtests exclusively combine to produce four composite scores, Verbal Comprehension (VCI), Perceptual Reasoning (PRI), Working Memory (WMI) and Processing Speed (PSI), which in turn yield a Full Scale IQ. Indices are reported in standard scores (mean of 100, standard deviation of 15). Relative to FSIQ, low scores on the PSI and WMI have been found to differentiate children with AD/HD from a control group and children with other psychiatric conditions (Mayes & Calhoun, 2007).

Processing Speed Index (PSI) was one of two indices used in this study, because of its sensitivity to visual-motor speed. In one study, the mean average PSI score of 78.2 (standard deviation 17.8) in children with motor impairment was reported to be significantly lower compared to a control mean average score of 97.7 (standard deviation 17.5; Williams et al., 2003) suggesting the discriminative ability of this scale between these populations. However, these are preliminary results. In AD/HD populations, the PSI also has been found to be a predictor of inattentive symptoms (Chhabildas, Pennington, & Willcutt, 2001; Weiler, Bernstein, Bellinger, & Waber, 2000).

Both Coding (Cd) and Symbol Search (SS) are reliable subtests that have high correlations with the PSI (Sattler & Dumont, 2008). These two PSI subtests, Cd and SS, are core tests in the recent fourth edition; however, SS was supplemental in the previous third edition (Sattler, 2008). In spite of this difference, the PSI in the third and fourth editions of the WISC are comparable.

Overall interpretation of poor scores on Cd and SS may suggest problems with processing speed, visual-perceptual discrimination, visual-motor coordination, attention, concentration, and/or performance under time constraints (Sattler & Dumont, 2008). Coding has been found to be a notable variable in AD/HD research as it has distinguished among clinical groups (Weiler et al., 2000; Barkley et al., 1990). Since Coding primarily consists of graphomotor skill, Mayes & Calhoun (2006) argue the contribution of PSI to the Full Scale IQ leaves some children with these deficits at a disadvantage.

The Working Memory Index (WMI) on the WISC-IV, referred to as the Freedom of Distractibility Index (FDI) in the third edition, measures the ability to hold information in the mind while mentally manipulating the information. Digit Span, Letter-Number Sequencing and Arithmetic have high loadings on the WMI (Sattler, 2008). Both the third and fourth editions of the WISC included Digit Span as a core subtest in this index. In contrast, the fourth edition replaced Arithmetic with Letter-Number Sequencing as the secondary core subtest. The WISC-III FDI and WISC-IV WMI have been found to be lower in children with AD/HD (Mayes & Calhoun, 2006) and WISC-IV WMI in children with AD/HD and a Learning Disability (Williams et al., 2003).

Demographic Data. Age, gender, ethnicity, grade level, type of school attended, years of parent education, developmental history, test examiner, psychiatric diagnoses, and medications on day of testing were collected.

CHAPTER FIVE

RESULTS

Descriptive Statistics in the Overall Sample (n=99)

Higher scores on BASC-2 scales indicate more problem behaviors while higher scores on the WISC-IV and T.O.V.A. indicate better performances. Parent-rated BASC-2 mean scores fell in the non-clinical range (T-score <60) for every BASC-2 scale except for the Attention Problem Scale (mean T-score of 61; see Table 6).

Mean scores for the overall sample fell in the average range for WISC-IV and Beery VMI indices but did not for all T.O.V.A. scores. A summary of all scores can be found in Table 6. The overall mean Full Scale IQ was 102. The overall mean for the indices are as follows, in order from highest to lowest: Verbal Comprehension Index at 105, Perceptual Reasoning Index at 104, Working Memory Index at 99 and Processing Speed Index at 97. The mean score on the Beery VMI for the overall sample also fell in the average range at 94.

T.O.V.A. scores fell in lower interpretive categories and had larger standard deviations and ranges than those of the WISC-IV and Beery VMI scores.

Overall mean Response Time Variability and Omission Error scores fell in the borderline range according to T.O.V.A. categories. In contrast, Response Time and Commission Errors fell in average range in the overall sample. Omission Errors produced the largest standard deviation (SD = 24.77). Ranges of the T.O.V.A. standard scores were larger (differences of 72 to 88 points) than those of the WISC-IV indices (differences of 63 to 75 points). None of these variables significantly correlated with age except for Commission Errors.

Meeting Assumptions in the Overall Sample

After exploring the data, the WISC-IV Working Memory Index, Processing Speed Index and T.O.V.A. Omission and Commission Errors were found to be non-normally distributed (see Table 7). Square root, log, inverse and reflected transformations were applied to these variables. When re-examined after the transformation, only the PSI met criteria for normality. No transformations satisfactorily improved the WMI distribution and did little to correct the problem of the negative skew. Commission and Omission Errors transformations improved the skew, kurtosis and outliers of the original distributions although they did not reach normality according to the Lilliefors significance correction. Nevertheless, transformations of the Processing Speed Index, the Working Memory Index, Commission and Omission Errors were used.

Correlation Matrix for the Overall Sample

Hypothesis One: Scores on the tests of psychomotor function, the WISC-IV Processing Speed Index and the Beery VMI, will account for significant variance in T.O.V.A. Response Time and Response Time Variability.

Hypothesis Two: Scores on the test of attention, the WISC-IV Working Memory Index, will account for significant variance in T.O.V.A. Errors of Omission and Errors of Commission.

Table 8 shows correlations between the variables from the WISC-IV, Beery VMI and T.O.V.A. for the overall sample. Significant correlations were found between the two indices on the WISC-IV and the T.O.V.A. variables, described below; however, T.O.V.A. variables did not correlate significantly with the Beery VMI. As expected, all correlations were positive except RT by VMI, suggesting that for most scores, better performance on the T.O.V.A. was related to better performance on the remaining tests. Transformed scores correlated in the same manner as original scores; therefore, only the original scores are reported. Spearman Rho correlations are reported for Omission and Commission Errors.

The results of the correlational analyses presented in Table 8 show that five out of the twelve correlations were statistically significant when parametric methods were used. Non-parametric analyses showed some differences. Most Pearson and Spearman correlation coefficients yielded similar values, indicating a linear relationship. For these variables only Pearson (r) coefficients are reported.

Moderate correlations indicated that children with lower scores on the Working Memory Index also displayed power performance on T.O.V.A. Response Time Variability (*r* =.30, *p*<.01). The results also showed that children in the overall sample with lower scores on the Processing Speed Index also performed worse on Response Time Variability (*r* =.36, *p*<.01) and Response Time (*r* =.30, *p* <.01).

The relationship of WMI and OE and CE appeared to have some degree of non-linearity. Although the Pearson correlations would suggest that poorer scores on the Working Memory Index suggest poorer scores on Commission Errors (*r* =.35, *p*<.01) and Omission Errors (*r* =.20, *p*<.05), a non-linear relationship was suggested by the discrepancy between Pearson and Spearman coefficients (r_s = .24, *p* <.05). Examination of scatterplots revealed trends towards linear relationships although the truncated scores labeled as standard score "<40" on the T.O.V.A. for some participants may have affected the coefficients. The other difference between the Spearman Rho and Pearson correlational analyses was a significant positive correlation between scores on the VMI and Commission

Errors (r_s = .21, p <.05). Age and Commission Errors correlated significantly (r_s = .22, p <.05).

To investigate the relationship between T.O.V.A. and WISC-IV scores further, Pearson product and Spearman Rho correlations were calculated at the subtest level. Eight of the sixteen correlations were found to be significant among the primary T.O.V.A. variables and the subtests of the WMI and PSI (Table 9). The same pattern as the overall indices was also found at the subtest level. Response Time Variability moderately correlated with Coding (r = .26, p <.01) and Symbol Search (r = .30, p < .01). Response Time also correlated with Coding (r = .26, p <.01) and Symbol Search (r = .23, p <.05) although at smaller magnitudes. Response Time Variability also correlated with the both core WMI subtests, Digit Span (r = .26, p <.01) and Letter-Number Sequencing (r = .27, p <.01). Digit Span, a part of the WMI and a measure of attention, significantly correlated with Commission Errors (r_s = .28, p <.05) and Omission Errors (r_s = .23, p <.05).

Stepwise Regression Analyses in the Overall Sample

Hypothesis One was partially supported. Multiple stepwise regression analyses entered Processing Speed Index or Working Memory Index scores, but not Beery VMI scores, as the best predictors of T.O.V.A. scores (Table 10). The results showed that the PSI variable did in fact account for 13% (R^2 = .13, adjusted R^2= .12, F (1,97) = 14.54, *p* = .000) of the Response Time Variability and 9% of Response Time (R^2 = .09; adjusted R^2= .08, F (1,97) = 9.86, $p < .01$). Scatterplots are presented in Figures 1 through 4.

Hypothesis Two was also partially supported. The results of the stepwise regressions found Working Memory Index accounted for 12% of the variability of the Commission Error score (R^2 = .12; adjusted R^2= .11, F (1,97) = 13.10, *p* = .000) and 4% of the Omission Error score (R^2 = .04; adjusted R^2= .03, F (1,97) = 4.03, $p < .05$). When age and gender were added to the stepwise regressions only Commission Errors were affected (R^2 = .21, adjusted R^2= .19, F(3,97) = 8.61, *p* = .000).

Descriptive Statistics for BASC-2 Diagnostic Sub-groups

Hypothesis Three: Children with attention and/or hyperactive deficits, as measured by the parent-rated BASC-2, will earn lower scores on the primary T.O.V.A. variables than children who do not have attention and/or hyperactive deficits as rated by the BASC-2. BASC-2 groupings for analyzing Hypothesis 3 excluded six cases that solely had elevated scores on the BASC-2 Hyperactivity Scale. The new sample consisted of 54 male and 39 female participants, ranging in age from 6 to 16 (mean age 10.64 years, SD=2.92). Gender and age information is summarized in Table11. Neither gender χ^2 (2, N=93)= 4.39, *p*>.05) nor age (F (2, 90)= .798, *p*>.05) was significantly related to group.

Table 12 presents the distribution of clinical diagnoses across the BASC-2 groups. Clinically diagnosed AD/HD was found in varying proportions across groups. AD/HD was diagnosed in 18.9% of the children in the Neither grouping, 32.0% in the Attention Deficit grouping, and 61.3% in the Combined grouping (See Table 12). Noteworthy, nearly half of the Neither group consisted of children with a diagnosis of DCD.

Similar to the overall sample, WISC-IV indices fell in the average range across all three groups (See Table 13). In contrast, the Neither group's mean score on the Beery VMI fell below the average range. Also, T.O.V.A. means across the groups fell in impaired ranges and had large standard deviations. The Attention group's mean scores were numerically the lowest for all the primary T.O.V.A. variables except for Commission Errors. Response Time Variability and Omission Errors across groups were numerically lower than Response Time and Commission Errors and fell in the borderline or below-average ranges according to T.O.V.A. categories.

Meeting Assumptions for the BASC-2 Diagnostic Sub-groups

Unlike the overall sample, WISC-IV indices for the BASC-2 groupings were normally distributed; therefore, transformations were unnecessary for these variables. However, Commission and Omission Errors continued to distribute in a non-normal fashion. Omission Errors assumed normal distribution after transforming the reflected square root (See Table 14). Even after transformations, Commission Errors violated the assumption of normalcy and equal variance. Therefore, the non-parametric Kruskal-Wallis statistical test was utilized for this variable.

Differences on Measures Across Groups

Hypothesis Three was not supported. One-way analysis of variance (ANOVA) and Kruskal Wallis one-way analysis of variance found no significant differences among the BASC-2 groupings for the four primary T.O.V.A. variables (See Table 15). ANOVA results for three variables, Response Time Variability (F (2,90) = 1.606, η^2=.034, p>.05), Response Time (F (2,90) = 1.606, η^2=.034, p>.05), and Omission Errors transformed (F (2,90) = .752, η^2=.016, p>.05), as well as Kruskal-Wallis results for Commission Errors (χ^2 (2,N=93) = 2.29, p>.05) showed nonsignificant differences across the three BASC-2 groups.

CHAPTER SIX

DISCUSSION

Continuous Performance Tests like the T.O.V.A. are commonly used in the clinical setting as part of the diagnostic evaluation of attention in children. CPT performance variables are assumed to be measures of inattention and impulsivity; however, clinicians and researchers have questioned the potential interference of other influences such as motor function on these variables. Although past research is sparse, there is some evidence that motor function confounds CPT performance.

First, this study explored the relationship among T.O.V.A. variables on the updated version 7.3 and indices of psychomotor functioning and attention on the WISC-IV and Beery VMI, 5th edition. Files of ninety-nine children with suspected attention problems, referred for an AD/HD evaluation and given the T.O.V.A., WISC-IV and Beery VMI, were selected for this study. It was hypothesized that T.O.V.A. variables, conceptually related to motor skills, would be predicted by psychomotor scores while T.O.V.A. variables related to attention would be predicted by attention scores. Stepwise multiple regressions using the WISC-IV Working Memory Index, Processing Speed Index and Beery Visual-Motor Integration standard scores were conducted to determine how much psychomotor skills and attention accounted for variability in T.O.V.A. performance. Independent variables consisted of T.O.V.A. Reaction Time Variability (RTV), Response Time (RT), Omission (OE) and Commission Errors (CE). Second, this study also examined differences on T.O.V.A. scores across three groups of children categorized by parent-rated attention and hyperactivity behaviors.

Relationships with and Predictors of Reaction Time and Reaction Time Variability

The findings of this study partially supported the hypothesis that psychomotor skills confound T.O.V.A. scores, based on the results of correlations and regressions using the WISC-IV PSI; relationships were not found with the Beery VMI. Specifically, the results suggest that children in the overall sample who performed worse on the Processing Speed Index also performed worse on Response Time Variability (r =.36, p<.01) and Response Time (r =.30, p<.01). Both Coding and Symbol Search, subtests of the PSI, significantly correlated with these T.O.V.A. variables. This suggests that if children have worse psychomotor speed as measured by the WISC-IV PSI they may not do as well on the reaction time or consistency of reaction time to target stimuli on the T.O.V.A..

Unlike previous research by Chae (1999), which did not find a significant relationship between WISC-III processing speed subtests and T.O.V.A. variables, the results of this study indicate moderate relationships specifically between PSI and the Response Time and Response Time Variability. The magnitude of these relationships is comparable to the relationship found by McGee et al. (2000) between the Conner's CPT Hit Reaction Time and a psychomotor task.

Regression analyses also provided evidence for this relationship, as PSI was found to be the best predictor of Response Time Variability and Response Time. The WISC-IV PSI variable accounted for 13% of Response Time Variability and 9% of Response Time. The amount of variance accounted for by the PSI is a modest amount yet it does illustrate that these skills influence T.O.V.A. scores.

This finding is consistent with the suggestion that as a CPT examinee is asked to respond quickly to stimuli by pressing a button, his/her performance, in part, depends on how quickly he/she processes information (visual input) and executes the motor program (output). The skills assessed by the Coding and Symbol Search subtests of the PSI involve processing details of visual stimuli and making a motor response. This visual-motor ability appears to contribute to how quickly and consistently a child responds on the T.O.V.A..

The lack of a significant relationship between the T.O.V.A. RT or RTV scores and the Beery VMI may suggest several things. First, the VMI may require different skills from the PSI in that there are more complex visual-motor integration requirements. Second, the PSI is more related to the T.O.V.A. because of the speed requirement that the Beery VMI does not assess. Last, recognizing a visual stimulus and pressing a button is a simple motor program in contrast to the complex integration of visual and motor skills necessary to draw.

A relationship between the GDS CPT and the Beery VMI was previously found to be an effect of attention rather than visual-motor functioning since it was moderately correlated with Correct Responses and Commission Errors (Grant et al., 1990). However, these authors were unsure of the meaning of the results and deferred further investigation. In this study, a small to moderate correlation between Commission Errors and the Beery VMI was also found when a nonparametric procedure was used. It may provide evidence of a relationship between better impulse control and better visual-motor integration. Alternatively, this correlation may be due to chance.

Clinically, the results of analyses for Hypothesis One suggest that when the T.O.V.A. is used to obtain instructions for AD/HD diagnosis, the examiner needs to consider the child’s score on the PSI. Poor performance on the PSI has some influence on the outcome of T.O.V.A. Response Time and Response Time Variability.

In addition to the Processing Speed Index, the Working Memory Index related to Response Time Variability, although it did not account for significant variance. The correlation results indicated that children who performed worse on the Working Memory Index also performed worse on the T.O.V.A. Response Time Variability ($r = .30$, $p<.01$); in other words, children who scored worse on working memory and attention tasks as measured by the WISC-IV showed more variation in their reaction times. Since many children with AD/HD have poor attention and working memory skills (Mayes & Calhoun, 2006) and show more variability in reaction times than normal controls (Teicher et al., 1996), this positive correlation suggests that more attention to the task is related to more consistent responding. Conversely, when a child's attention is inconsistent, the time the child takes to respond to the T.O.V.A. target stimuli varies more from target to target. Although the WMI did correlate with RTV it did not account for significant variance, indicating the lack of a causal relationship between the variables.

The first set of findings is congruent with past research and theoretical explanations of attention and processing speed. Previously, processing speed was found to be the best predictor of inattention in children with AD/HD (Chhabildas, Penninton & Wilcut, 2001). Other researchers have characterized children with AD/HD as having sluggish cognitive tempo based on poor performance on the WISC-R Coding subtest (Barkley et al., 1990). Theoretically, the current findings of this study may be interpreted in two ways. It is possible that the problems with correctly and consistently responding to stimuli on the T.O.V.A. may be due to deficits in attention, inhibiting information from entering the brain, thus affecting processing speed (e.g., Mirsky et al., 1990). Alternatively, these findings may be due to artifacts of attention and concentration (Doyle et al., 1995; Whitmont & Clark et al., 1996). Results of the present study cannot be used to decide between these alternative theoretical explanations.

Relationships with and Predictors of Omission and Commission Errors

Omission and Commission Errors on the T.O.V.A. are objective measures of sustained attention and impulsivity of responding. As hypothesized, both types of error scores on the T.O.V.A. correlated with and were predicted by WISC-IV attention and working memory subtests, with some unexpected findings. First, further investigation into the subtests of the WMI found Digit Span, and not Letter-Number Sequencing, to correlate with the T.O.V.A. measures. Previous research by Chae (1999) found nonsignificant correlations between Digit Span and Omission and Commission Errors ($r = -.078$ and .047, respectively). He concluded that the visual nature of the T.O.V.A. versus the auditory nature of Digit Span to be the reason for the lack of a significant relationship. In the current study, a different conclusion is drawn. The Working Memory Index and Digit Span appear to measure a similar construct as the Commission Errors on the T.O.V.A. although Letter-Number Sequencing does not. Letter-Number

Sequencing may be tapping into a more complex form of attention and working memory. Poor performance on Digit Span may involve not listening carefully and responding impulsively. T.O.V.A. Commission Errors may result from not looking carefully and responding impulsively.

Second, although the WMI predicted both Commission and Omission Errors, it did so at different magnitudes and significance levels. Specifically, the WMI accounted for 12% of the variance of Commission Errors (p <.001) and 4% of Omission Errors (p<.05). In contrast to the compelling evidence of the relationship between Commission Errors and the WMI, the relationship between Omission Errors and WMI is likely due to chance.

This finding suggests that Omission Errors and the WMI are measuring distinct constructs as described in the Mirsky et al. model of attention (1991). Possibly, the T.O.V.A. Omission Error variable may be measuring sustained attention while the WISC-IV WMI may be measuring focused attention and additional factors involved in working memory. Alternatively, as Chae suggested, the nature of these stimuli measures differing visual and auditory abilities. Therefore, both tests would be useful in assessments as they may provide different information.

Age and gender were entered into the stepwise regression models. The only regression equation impacted by these variables was Commission Errors. The T.O.V.A. manual reported a significant age-related decrease in Commission

Errors (Leark et al., 2007). Furthermore, males tend to make more errors of commission than females, particularly in the second half of the test (Greenberg & Waldman, 1993). However, normative data should correct for age and gender and when the overall sample was analyzed, no effect of gender was found.

Clinically, the results of analyses for Hypothesis Two suggest that the different measures of attention should be used in AD/HD evaluations. The T.O.V.A. Omission Errors may be a better indicator of sustained attention while other measures, such as the WISC-IV Working Memory Index may indicate focused attention. Commission Errors on the T.O.V.A., a measure of impulsivity, should be considered with the age, gender and performance of attention on the WISC-IV of the participant individually.

Differences Across Groups

The third hypothesis explored differences across groups on T.O.V.A. scores based upon the presence or absence of symptoms related to inattention and hyperactivity. It was expected that children with elevated scores diagnostic for inattention and hyperactive behaviors would score lower than children without these BASC-2 elevated scores. No significant differences were found among these groups. In other words, children with elevated scores of the BASC-2 Attention and Hyperactivity scales were not found to have poorer Response Time, Response Time Variability, Commission or Omission Errors on the T.O.V.A.. This finding is inconsistent with previous research that has found significant differences between control and AD/HD groups on the T.O.V.A. (Wada, Yamashita, Matsuishi, Ohtani, & Kato, 2000); although this is consistent with other finding by Barkley et al. (1990) that did not found differences in CPT scores across psychiatric groups.

One possible explanation for nonsignificant findings across groups is the large standard deviations of the T.O.V.A. variables. Since the within-group variance of the T.O.V.A. mean was large, significant differences between groups were not found. Another explanation could be the composition of children in the sample. The Neither group (neither the inattentive nor hyperactive BASC-2 subscales elevated) obtained significantly lower mean scores than both other groups on the Beery VMI ($F(2,90) = 4.462$, $p<.05$) and consisted of nearly 50% of children diagnosed with DCD; DCD was previously defined clinically as having motor impairment and lower scores on the Beery VMI. Since a measure was not utilized to control for motor functioning in these group differences analyses, it is possible that motor impairments confounded the results. Therefore, the Neither group scores could have been negatively influenced by children with motoric impairments. In other words, the Neither group did not serve well as a control group. Alternatively, the BASC-2 Attention and Hyperactivity subscales may not be a suitable measure for grouping samples when evaluating cognitive functions in performance based standardized assessment. Previous research concluded that the T.O.V.A. may be picking up on inattentive behaviors that are not functionally impairing as indicated on a parent rating scale of attention (Schatz, Ballantyne & Trauner, 2001).

Trends in the WISC-IV and T.O.V.A. data were also inspected. Previous patterns found in AD/HD research are compared to the results of this study to add to the research about the utility of the WISC-IV in diagnosing AD/HD as well as adding to the WISC-IV profiles in children with attention and/or hyperactive problems as reported by the parent. One pattern found in the research is for children with AD/HD to have WMI or PSI as the numerically lowest WISC-IV indices (Mayes & Calhoun, 2006). Although not at significant levels, the Attention group did have the numerically lowest scores on the WISC-IV WMI and PSI followed by the Combined group. Specifically, PSI was the numerically lowest index for the Attention group (64%) and the Combined group (39%). In contrast, the lowest WISC-IV index for the Neither group (35.1% in the group) was the PRI, an index that has been found to be poor in children with motor problems (Coleman et al., 2001; Piek & Coleman-Carman, 1995). In fact, the Neither group had a significantly lower mean score than the Combined group on the PRI ($F(2,90)=3.746$, $p < .05$) and this finding is again attributed to the potential influence of DCD in the group. Another trend reported in AD/HD research has been lower scores for the Coding subtest compared with Symbol Search in many children with AD/HD (Mayes & Calhoun, 2006). The current study found that the majority of children in all three groupings to have Coding scores lower than Symbol Search, especially the Combined group (Attention 52%, Neither 62% and Combined 84%). WISC-IV profile analyses add to the description of these samples and aid in AD/HD evaluation.

Although the data did not reach statistical significance, children in the Attention group consistently obtained numerically lower scores on the T.O.V.A. and the majority of these measures fell in ranges interpreted by the T.O.V.A. manual as "borderline" or "significantly deviant result" (See Table 15). Although differences across the groups were not significant, these ranges and interpretations for individual children provide some evidence that T.O.V.A. scores may trend toward lower scores for groups with parent-rated inattentive and hyperactive behaviors. The Combined group was found to produce the numerically highest mean score for Response Time on the T.O.V.A. although not at a significant degree. This finding, if considered alone, may reflect hyperactive behaviors of pressing the button quickly and therefore achieving fast response times to correct items. However, this conclusion was not supported by the Combined group's overall average score for Commission Errors. The limitations of the study, described in the next section, further describe these unexpected findings.

Clinically, results from examination of groups formed by BASC-2 Attention Problems and Hyperactivity Scales suggest that T.O.V.A. variables do not add utility in further distinguishing inattentive, hyperactive, or impulsive behaviors in this sample. However, on an individual level the T.O.V.A. may still provide discriminatory benefits. A full battery of neuropsychological testing is recommended for a comprehensive assessment of AD/HD.

Limitations

Demographic Characteristics

There are several limitations of the results that should be addressed. The demographic and sampling characteristics such as referral base, school, parent education, files selected, age and ethnicity may have affected the generalizability of these results. First, the clinically referred basis of this group may not represent the general population of children suspected of having AD/HD. This sample was selected from an evaluation center in an affluent metropolitan area that may be different from the environment of children who are referred to other centers for AD/HD evaluations. Second, the majority of the participants were found to attend private schools and come from families with both parents completing four years of college. This is not a representative sample of the general public. Since environmental factors such as parent education and socioeconomic status have been shown to impact intelligence quotients (Turkheimer, Haley, Waldron, D'Onofrio & Gottesman, 2003) these results are limited to children of similar demographics.

In addition, the selection of files based on the inclusion criteria may have created sample bias. Unlike the consistent use of the BASC-2, WISC-IV and T.O.V.A. in AD/HD evaluations at the center, the Beery VMI was not always used and one assumes that it was chosen in a given evaluation due to a presenting complaint or other clinical reason. It could be possible that the Beery VMI was given when certain presenting complaints indicated a need to screen for visual-motor integration. Therefore, in only selecting files that included the Beery VMI, this sample may be biased towards children who have motor impairments. Therefore, another limitation of the study was the selection within the center.

The last demographic limitation is due to the absence of ethnicity data of the sample. Ethnic background was not included for this sample because of unreliable data. Furthermore, the T.O.V.A. manual does not include adequate information about the ethnicity of the normative sample, besides stating that it was predominantly normed on a Caucasian sample (Leark et al., 2007); this limitation may add to the dearth of research on ethnicity and CPT performance.

Methodological Issues

A variety of methodological issues also limit the generalizability of this study. These issues range from the study design to sample size, grouping methodology and instruments utilized. The study was limited by the retrospective design, which constrains the methods, measures and procedures of the source of data collection. For example, it is unknown how the procedures of the evaluation center varied. Longer testing sessions may produce fatigue effects, the order of testing may have priming effects and examiner presence or absence is found to impact performance on measures. These unknowns for the testing conditions may have confounded the results in positive or negative ways.

The study would have benefited from a larger sample size for the overall sample as well as the BASC subgroups. The smaller sample size may have impacted the distribution of the variables requiring that transformations be used for some of the parametric analyses. Further, non-parametric statistics used in the study may have limited power. Small sample sizes for the groups may also have limited the ability to find differences across T.O.V.A. variables.

This study did not use stringent psychiatric diagnoses for identifying participants or for creating sub-groups, and this produced several limitations. Germane data about these participants may have been lost, especially with the AD/HD diagnosis and AD/HD subtypes. Controlling for comorbidities, such as Major Depressive Disorder, known to influence measures used in this study was not achieved. Additionally, comorbid conditions such as AD/HD and DCD affect results on test data. In the present study, previously mentioned, one of the groupings in the study may have consisted of 50% of children with diagnosed motor impairments.

Another limitation of this study is the absence of a true control group. Having a control group without conditions and psychiatric diagnoses, including attention problems, might have provided a group against which the AD/HD subgroups could be have been compared.

Grouping by BASC-2 scores was the best solution available in the archival data. However, this method may have been inaccurate. This method may be inferior to conducting comprehensive clinical interviews and may have detracted from the findings. Diagnostic subgroups may have been influenced by rater bias since only the Parent-Rated form from the BASC-2 was used. An additional informant, such as a classroom teacher was not included. Although previous research has used rating scales to aid in grouping AD/HD children successfully (e.g., Barkley et al., 1990) a multi-method approach might have been more reliable.

Also, data on medication use on the day of testing would have provided useful information. Unfortunately, this data was inconsistent or absent in the files. Stimulant medication is known to improve attentional abilities on CPTs (e.g., Teicher et al., 2004); thus, T.O.V.A. scores may have been improved in some cases. Conversely, side effects of medications can impact motor or cognitive ability, which could decrease performance. This could potentially be one of the more serious limitations.

Measures utilized for assessing motor skills were satisfactory yet not optimal.   However, the WISC-IV PSI and VMI were the motor tests most consistently used in the available files. The results of this study therefore are confined to those measures. The Beery VMI involves integration of visual and graphomotor skills and may be more complex than tests of generalized motor ability. The Beery VMI may not be the optimal choice for the purpose of this study.

Similarly, using the Processing Speed Index of the WISC-IV as a measure of motor function has limitations. The PSI is defined as involving motor coordination (Sattler, 2007); however, the larger construct of the speed of processing taps into other cognitive processes. Furthermore, the clinical significance of psychomotor tasks in measuring the construct of processing speed is still not well understood (Shanahan et al., 2006).

The T.O.V.A. CPT was used in this study. It was a limitation that other CPTs could not have also been studied. It is possible that different results may be found on different CPTs. Furthermore, only the four primary T.O.V.A. variables were used in this study. A strength of the T.O.V.A. is that it has normative data across quarters of the test as well as secondary variables. These were not used in the study. Only the T.O.V.A. manual presents research indicating that different T.O.V.A. quarters may reveal different findings.   Quarters 2 and 3 are important in children with AD/HD and males tend to make more errors of commission than females particularly in the second half of the test (Greenberg & Waldman, 1993).

Therefore, only using overall scores and including invalid scores may have limited the findings of this current study.

Direction for Future Research

Corrections for the limitations of the current study may improve understanding of how and to what extent psychomotor and attention skills in children are related to the T.O.V.A.. Like many studies, future investigations that use a larger and more diverse sample would resolve some limitations. A larger sample may be more representative of the larger population and decrease non-normal distribution of variables. This, in turn, might preclude the need for transformations and non-parametric statistics, as well as increase the power of the statistics used to detect differences across the groups. Also, future recruitment procedures should aim to collect more demographically diverse samples through multiple sites and regions.

Using standardized diagnostic procedures and interviews for the confirmation or diagnosis of psychiatric conditions is recommended. This might include objective and subjective instruments but would exclude the CPT as a measure used for the diagnosis. Multiple informants for subjective measures might be used (e.g., parent and teacher forms). This would allow for more reliable and valid diagnoses of AD/HD and AD/HD subtypes. Results from this study also suggest that the use of different measures of attention, such as the

WISC-IV Working Memory Index and the T.O.V.A. CPT be used. Future research would benefit from a focus on additional subtypes of AD/HD, such as the sluggish-cognitive tempo type.

Knowledge of other psychiatric comorbidities, such as depression and anxiety, known to affect CPT results in some studies would promote controlled conditions in CPT research. Documenting the functional severity of the AD/HD symptoms, not just the quantity of symptoms or behaviors, would advance the understanding of the present study and provide an additional reference for ecological validity.

Future research may wish to focus on the developmental aspects of the constructs studied. For example, studies have reported on the changes over time in AD/HD (Shaw, 2007), motor ability (Piek, Dawson, Smith & Gasson, 2008), and processing speed (Kail, 2000). Thus, the relationship revealed in the current study may be found to differ at different stages of children's development.

It is recommended that further research focus on the relationship between CPTs and the WISC-IV. Little research has been done examining the relationship between the WISC-IV and the T.O.V.A. (Chae, 1999) although these are commonly used in AD/HD evaluations (Naglieri et al., 2005). It would be interesting to see if the results of this study hold true for CPTs with different formats and test parameters. Specifically for research with the T.O.V.A., analyzing motor findings as differentiated by half or quarter scores may provide more descriptive information about the relationship between attention and motor skills. Other ways of analyzing the data may be helpful. For example, one study has utilized discrepancy scores between WISC-IV FSIQ and CPT, and describes the discrepancies as a better indicator of AD/HD than CPT scores alone (Mayes, Calhoun, Chase, Mink and Stagg, 2007). This technique should be studied further to ensure validity across various CPTs.

Further investigation of psychomotor function in children with suspected AD/HD is warranted. Since much remains to be learned about how to define motor impairment and effectively collect data on motor skills, future research should use a variety of motor measures. One suggestion is a standardized measure like the M-ABC. This would comprehensively survey fine and gross motor skills. However, for a study similar to this one, a simple reaction time task would possibly suffice in providing information on the simple motor aspect of pressing a button on CPTs.

The nature of processing speed alone and relation to motor ability is unknown. Clinical practice as well as research would benefit from understanding the constructs that processing and/or motor speed tasks tap. Also, future studies may benefit from comparing the T.O.V.A., the WISC-IV and the VMI across control, AD/HD and DCD groups. This would aid in comparing children with and without attention and motor skills deficits, and bring further understanding to this topic.

This study has highlighted the relationship of psychomotor function to T.O.V.A. performance in children with suspected AD/HD. More research is necessary to explore the degree to which this relationship may or may not be present in other diagnostic groups.

Conclusions and Clinical Implications

The current study set out to explore the relationship of motor function and T.O.V.A. performance in children suspected of having Attention Deficit/Hyperactivity Disorder. It was hypothesized that the variance of T.O.V.A. Response Time and Response Time Variability scores would be accounted for by measures of motor function, specifically the Processing Speed Index and the Beery VMI. Alternatively, a measure of attention, the Working Memory Index, was hypothesized to account for variance on T.O.V.A. Commission and Omission Errors. Finally, T.O.V.A. scores across AD/HD subgroups were hypothesized to be the lowest for those with elevated attention and hyperactive behaviors as rated by parents on the BASC-2.

The main conclusion is that psychomotor function, as measured by the WISC-IV PSI, is a significant predictor of T.O.V.A. Response Time and Response Time Variability in children referred for AD/HD evaluations, although the Beery VMI is not. Given the effect sizes, however, the clinical relevance of this finding is modest. Clinically, examiners should be cautious in interpreting T.O.V.A. results when poor scores for the PSI are present, but the validity of the T.O.V.A. is not entirely compromised if processing speed deficits exist.

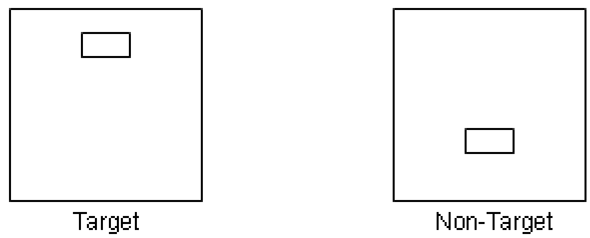
A secondary finding of the study is that the Working Memory Index is a significant predictor of Commission Errors but not Omission Errors. This suggests that different executive functions (working memory and attention processes) are involved in each of these T.O.V.A. variables. Clinically, examiners should assess for these differing components with a variety of measures, such as sustained or focused attention measures.

No differences on T.O.V.A. scores across the subgroups, categorized by parent-rated inattentive and hyperactive behaviors, were found. Rather than attributing this finding to poor sensitivity of the T.O.V.A., methodological limitations in the current study should be considered before definitive conclusions are made. Future research is needed to understand the impact of the constructs of attention, processing speed and motor function and the use of the T.O.V.A. in children presenting with suspected AD/HD.

APPENDIX A
T.O.V.A. Stimuli

Figure 1

T.O.V.A. Stimuli



APPENDIX B

Tables

Table 1
Evolution of DSM Criteria

DSM Ed.	*Subtype Nosology*	*Symptoms*
DSM-II (1968)	Hyperkinetic Reaction of Childhood	Hyperactivity and poor impulse control
DSM-III (1980)	Attention Deficit Disorder (ADD) • ADD with hyperactivity (ADD-H) • ADD without hyperactivity (ADD/noH) • ADD residual type (ADD-RT)	<u>ADD-H</u> : Inattention, impulsivity, and hyperactivity <u>ADD/noH</u> : Inattention and impulsivity
DSM-III-R (1987)	Attention-Deficit Hyperactivity Disorder (AD/HD) • Undifferentiated Attention Deficit Disorder (UADD)	<u>AD/HD</u>: Inattention, impulsivity, and hyperactivity <u>UADD</u>: Inattention
DSM-IV (1994) DSM-IV-TR (2000)	Attention-Deficit Hyperactivity Disorder (AD/HD) • AD/HD predominantly inattentive type (AD/HD-PI) • AD/HD predominantly hyperactive/impulsive type (AD/HD-HI) • AD/HD combined type (AD/HD-C) • AD/HD in partial remission • AD/HD not otherwise specified (AD/HD NOS)	<u>AD/HD-PI</u>: Inattention <u>AD/HD-HI</u>: Hyperactivity and impulsivity <u>AD/HD-C</u>: Inattention, impulsivity, and hyperactivity

Source: Adapted with permission from American Psychiatric Association (1968, 1980, 1987, 1994, 2000), from the *Diagnostic and Statistical Manual of Mental Disorders, 2nd Ed., 1968; 3rd Ed., 1980; 3rd Rev. Ed., 1987; 4th Ed., 1994; 4th Rev. Ed., 2000 APA.*

Table 2

DSM-IV-TR AD/HD Criteria

<table>
<tr><td colspan="2">A. Either (1) or (2):</td></tr>
<tr><td>(1) Six (or more) of the following symptoms of inattention have persisted for at least six months to a degree that is maladaptive and inconsistent with developmental level:

Inattention
a) Often fails to give close attention to details or makes careless mistakes in school work, work, or other activities.
b) Often has difficulty sustaining attention in tasks or play activities.
c) Often does not seem to listen when spoken to directly.
d) Often does not follow through on instructions and fails to finish schoolwork, chores, or duties in the workplace (not to do to oppositional behavior or failure to understand instructions).
e) Often has difficulty organizing tasks and activities.
f) Often avoids, dislikes, or is reluctant to engage in tasks that require sustained mental effort (such as schoolwork or homework).
g) Often loses things necessary for tasks or activities (e.g., toys, school assignments, pencils, books, or tools).
h) Is often easily distracted by extraneous stimuli.
i) Is often forgetful in daily activities.</td>
<td>(2) Six (or more) of the following symptoms of hyperactivity-impulsivity have persisted for at least six months to a degree that is maladaptive and inconsistent with developmental level:

Hyperactivity
a) Often fidgets with hands or feet or squirms in seat.
b) Often leaves seat in classroom or in other situations in which remaining seated is expected.
c) Often runs about or climbs excessively in situations in which it is inappropriate.
d) Often has difficulty playing or engaging in leisure activities quietly.
e) Is often “on the go” or often acts as if “driven by a motor.”
f) Often talks excessively.

Impulsivity
g) Often blurts out answers before questions have been completed.
h) Often has difficulty awaiting turn.
i) Often interrupts or intrudes on others (e.g., butts into conversations or games).
____
AD/HD- PI: If only criteria A1 met
AD/HD-HI: If only criteria A2 met
AD/HD-C : If both criteria A1 and A2 are met</td></tr>
<tr><td>B. Some hyperactive-impulsive or inattentive symptoms that caused impairment were present before age 7 years.</td><td>D. There must be clear evidence of clinically significant impairment in social, academic, or occupational functioning.</td></tr>
</table>

C. Some impairment from the symptoms is present in two or more settings (e.g., at school [or work] and at home).	E. The symptoms do not occur exclusively during the course of a Pervasive Developmental Disorder, Schizophrenia, or other Psychotic Disorder and are not better accounted for by another mental disorder (e.g., Mood Disorder, Anxiety Disorder, Dissociative Disorder, or a Personality Disorder).

Source: Adapted with permission from American Psychiatric Association (2000), from the *Diagnostic and Statistical Manual of Mental Disorders, 4th Rev. Ed., 2000 APA.*

Table 3

T.O.V.A. Variables

Response Time (ms):	$\frac{\Sigma(\text{Correct Response Times})}{(\text{\# Correct Responses})}$
Response Time Variability:	$\sqrt{\frac{(\Sigma_{i=10}(x_i - \text{Mean Correct RT}))^2}{(\text{\# Correct Responses})}}$
Correct Responses (%):	$\frac{\text{\# Correct Responses}}{\text{\# of Targets}} \times 100\%$
Commission Errors (%):	$\frac{\text{\# Commissions}}{(\text{\# of Non-Targets - \# of Non-Targets AR})} \times 100\%$
Omissions Errors (%):	$\frac{\text{\# Omissions}}{(\text{\# of Targets - \# of Targets AR})} \times 100\%$

Adapted From Hughes, S., T.O.V.A. Conference, March 13, 2008 with permission; AR = Anticipatory Response

Table 4

Intercorrelations of T.O.V.A. version 7.0 & WISC-III Subtests

n = 40	Digit Span	Coding	Symbol Search
RTV	-.13	.18	.08
RT	-.26	.17	.13
CE	.05	.14	.21
OE	-.08	.13	.01

Source: Chae (1999). W.I.S.C. = Wechsler Intelligence Scale for Children; T.O.V.A. = Test of Variables of Attention; RTV = Response Time Variability; RT = Correct Response Time; CE = Commission Errors; OE = Omission Errors; *p <.05

Table 5 *Demographic Characteristics of Overall Sample*

(*n*=99)	Frequency	Percent of Total Sample
Gender		
Male	58	58.6 %
Female	41	41.4%
School		
Percent in Private School	65	65.7%
Percent in Public School	34	34.3%
Developmental Milestones		
Within Normal Limits	70	70.7%
Speech or Language	26	26.3%
Delay		
Psychiatric Diagnoses		
Dyslexia	40	40.4%
AD/HD	36	36.4%
DCD	35	35.4%

	Range	<u>M</u> (SD)
Age	6 - 16	10.64 (2.87)
Years in School	K - 11	4.44 (2.81)
Mom Years of Education	12 - 19	15.89 (1.75)
Dad Years of Education	8 - 20	16.26 (2.34)
# of DSM-IV Diagnoses	0 - 5	1.42 (1.16)

Table 6

Ranges, Means and Standard Deviations of Overall Sample (n = 99)

Measure	Range	M (SD)
Standard Scores		
WISC-IV		
Full Scale IQ	73 – 136	102.47 (12.53)
Verbal Comprehension	73 – 148	104.77 (14.36)
Perceptual Reasoning	63 – 133	103.90 (13.62)
Working Memory	59 – 132	98.69 (12.79)
Processing Speed	65 - 131	97.07 (13.40)
Beery VMI	66 - 122	94.18 (12.71)
T.O.V.A.		
Response Time Variability	39 –126	83.43 (21.05)
Response Time	39 –128	90.61 (18.33)
Commission Error	39 –128	97.41 (14.88)
Omission Error	39 –111	80.74 (24.77)
T-Scores		
BASC Attention	40 – 76	60.73 (8.74)
BASC Hyperactivity	38 – 84	56.82 (10.87)

Table 7

Tests for Normalcy of Distribution in VMI, WISC-IV and T.O.V.A. Performance Variables with and without Transformed Corrections for Non-Normal Distributions

		Sample, *n*=99
Measure	D	p-value
VMI	.043	>.200
WISC-IV		
WMI	.117	.002
WMI[a]	.127	.000
PSI	.109	.005
PSI[b]	.069	>.200
T.O.V.A.		
RTV	.076	.172
RT	.071	>.200
CE	.144	.000
CE[c]	.100	.017
OE	.136	.000
OE [d]	.111	.004

Note: D = Kolmogrov-Smirnov Statistic; Lilliefor's Significance Correction; Log-Transformations were not calculated for values where Lilliefor's test showed normal distribution; VMI = Beery Visual-Motor Integration; WISC-IV WMI = Working Memory Index; [a] = Square Root Transformation; PSI = Processing Speed Index; [b] = Inverse Transformation; T.O.V.A. = Test of Variables of Attention; RTV = Response Time Variability; RT = Correct Response Time; [c] = Reflected Square Root; OE = Omission Errors; [d] = Reflected Log Transformation; CE = Commission Errors

Table 8

Pearson (r) and Spearman's Rho (r_s) Correlations Among T.O.V.A., WISC-IV Indices and Beery VMI Scores (n=99)

Pearson (*r*)

	WMI*	PSI*	VMI
RTV	.30**	.36***	.07
RT	.04	.30**	-.08
CE*	.35**	.13	.15
OE*	.20*	.14	.07

Spearman's Rho (r_s)

CE	.24*	.14	.21*
OE	.24*	.14	.12

Note: T.O.V.A. = Test of Variables of Attention; RTV = Response Time Variability; RT = Correct Response Time; OE = Omission Errors; CE = Commission Errors; VMI = Beery Visual-Motor Integration; FSIQ = WISC-IV Full Scale IQ; VCI = Verbal Comprehension Index; PRI = Perceptual Reasoning Index; WMI = Working Memory Index; PSI = Processing Speed Index; *p<.05, **p<.01;***p<.001. *These transformation scores were similar to the original scores, therefore, only the original scores are presented. Pearson (r) is interpreted as .1 small, .3 moderate and .5 large magnitudes (Cohen, 1988).

Table 9

Pearson (r) and Spearman's Rho (r_s) Correlations Among T.O.V.A. and WISC-IV Subtests

Pearson (*r*)

	Digit Span	Letter-Number	Coding	Symbol Search
RTV	.26**	.27**	.29**	.30**
RT	.05	.02	.26**	.23*
CE	.36***	.23*	.08	.15
OE	.20*	.14	.11	.12

Spearman's Rho (r_s)

CE	.28**	.13	.06	.17
OE	.23*	.17	.12	.14

Note. T.O.V.A. = Test of Variables of Attention; RTV = Response Time Variability; RT = Correct Response Time; OE = Omission Errors; CE = Commission Errors; VMI = Beery Visual-Motor Integration; FSIQ = WISC-IV Full Scale IQ; VCI = Verbal Comprehension Index; PRI = Perceptual Reasoning Index; WMI = Working Memory Index; PSI = Processing Speed Index *p<.05, **p<.01;***p<.001. Pearson (r) is interpreted as .1 small, .3 moderate and, .5 large magnitudes (Cohen, 1988).

Table 10

Summary of Stepwise Regression Analysis for T.O.V.A. Performance Measures Using PSI, WMI and VMI

Dependent	Predictors	R/β	R^2	AdjR	F
Response Time Variability	PSI	.36	.13	.12	14.54***
Response Time	PSI	.30	.09	.08	9.90**
Commission Error	WMI	.35	.12	.11	13.10***
Omission Error	WMI	.20	.04	.03	4.03*

Note: T.O.V.A. = Test of Variables of Attention; RTV = Response Time Variability; RT = Correct Response Time; OE = Omission Errors; CE = Commission Errors; VMI = Beery Visual-Motor Integration; WMI = Working Memory Index; PSI = Processing Speed Index; *p<.05, **p<.01, ***p<.001

Table 11

Demographic Characteristics of BASC-2 Sub-groups

	Total Sample (*n*=93)	Neither (*n* =37)	Attention (*n* =25)	Combined (*n* =31)
Gender				
Male	54	17	15	22
Female	39	20	10	9
Age mean	10.64	11.10	10.37	10.29
(SD)	(2.92)	(2.92)	(2.92)	(2.97)

Table 12

Percent of AD/HD and DCD Diagnosis of the BASC-2 Sub-groups

	No AD/HD	AD/HD	No DCD	DCD
Neither	81.0%	18.9%	54.1%	45.9%
Attention	68.0%	32.0%	76%	24.0%
Combined	38.7%	61.3%	64.5%	35.5%

Note: AD/HD: Attention Deficit Hyperactivity Disorder; DCD: Developmental Coordination Disorder

Table 13

Means and Standard Deviations of WISC-IV Indices, Beery VMI, and Primary T.O.V.A. Scores Across BASC-2 Sub-groups

	Neither N = 37	Attention N = 25	Combined N = 31
WISC-IV			
FSIQ	101.92 (12.92)	98.72 (11.62)	103.32 (11.24)
VCI	104.19 (12.22)	101.12 (11.71)	105.94 (16.62)
PRI	100.08 (14.65)	101.00 (13.25)	108.23 (10.34)
WMI	99.51 (9.25)	99.04 (9.25)	95.35 (12.35)
PSI	99.70 (13.26)	92.40 (11.78)	96.45 (14.51)
VMI	88.78 (12.02)	96.88 (9.70)	95.97 (13.67)
T.O.V.A.			
RTV	85.21 (20.79)	76.63 (22.26)	85.85 (20.88)
RT	92.01 (20.12)	84.15 (15)	95.17 (14.15)
CE	98.10 (11.61)	96.16 (19.34)	95.43 (14.96)

OE	83.02 (24.75)	75.10 (26.96)	80.02 (22.43)

Note. TOVA = Test of Variables of Attention; RTV = Response Time Variability; RT = Correct Response Time; OE = Omission Errors; CE = Commission Errors; VMI = Beery Visual-Motor Integration; FSIQ = WISC-IV Full Scale IQ; VCI = Verbal Comprehension Index; PRI = Perceptual Reasoning Index; WMI = Working Memory Index; PSI = Processing Speed Index

Table 14

Tests for Normalcy of Distribution in T.O.V.A. Performance Variables with and without Transformed Corrections for Non-Normal Distributions

	Neither		Attention		Combined	
Measure	D	p	D	p	D	p
VMI	.105	>.200	.144	.194	.090	>.200
WISC-IV						
WMI	.107	>.200	.124	>.200	.134	.169
PSI	.123	.176	.114	>.200	.126	>.200
T.O.V.A.						
RTV	.144	.051	.101	>.200	.100	>.200
RT	.103	>.200	.078	>.200	.113	>.200
CE	.182	.003	.194	.016	.133	.176
-CE[a]	.171	.008	.165	.078	.127	>.200
OE	.153	.028	.156	.116	.117	>.200
-OE[b]	.110	>.200	.135	>.200	.085	>.200

Note: D = Kolmogrov-Smirnov Statistic; Lilliefor's Significance Correction; Log-Transformations were not calculated for values where Lilliefor's test showed normal distributions in all groups. Note. VMI = Beery Visual-Motor Integration; WISC-IV WMI = Working Memory Index; PSI = Processing Speed Index; T.O.V.A. = Test of Variables of Attention; RTV = Response Time Variability; RT = Correct Response Time; CE = Commission Errors; [a] = Reflected Square Root OE = Omission Errors; [b] = Square Root Transformation

Table 15

Comparison of T.O.V.A. Scores Across BASC-2 Sub-groups

	Neither n = 37	Attention n = 25	Combined n = 31	**F**	**p**
RTV	85.21 (20.79)	76.63 (22.26)	85.85 (20.88)	1.60	*ns*
RT	92.01 (20.12)	84.15 (15.00)	95.17 (14.15)	2.64	*ns*
OE [a]	83.02 (24.75)	75.10 (26.96)	80.02 (22.43)	0.75	*ns*
				χ^2	*p*
CE	98.10 (11.61)	96.16 (19.34)	95.43 (14.96)	2.29	*ns*

Note: T.O.V.A. = Test of Variables of Attention; RTV = Response Time Variability; RT = Correct Response Time; OE [a] = Reflected Square Root Transformation Omission Errors; CE = Commission Errors; *p<.05

APPENDIX C

Figures

Figure 1

Scatterplot between Response Time Variability and Processing Speed Index

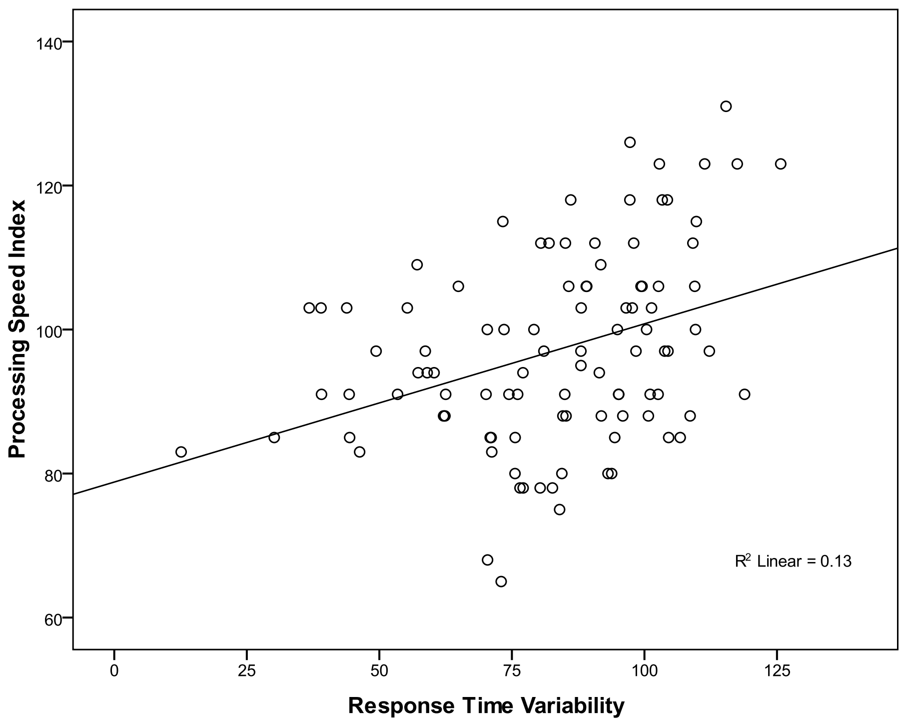


Figure 2

Scatterplot between Response Time and Processing Speed Index

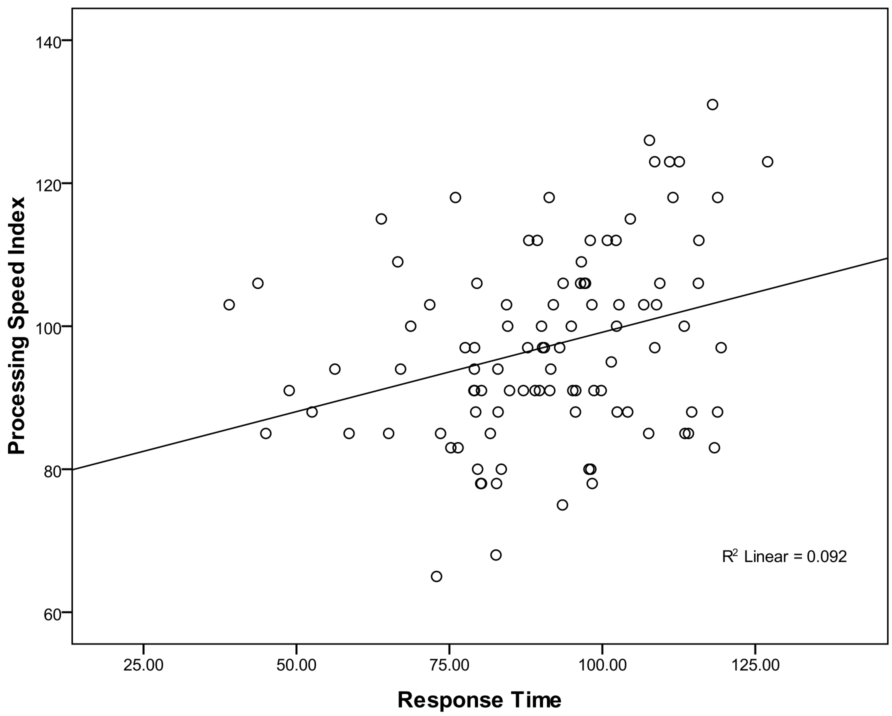


Figure 3

Scatterplot between Commission Errors and the Working Memory Index

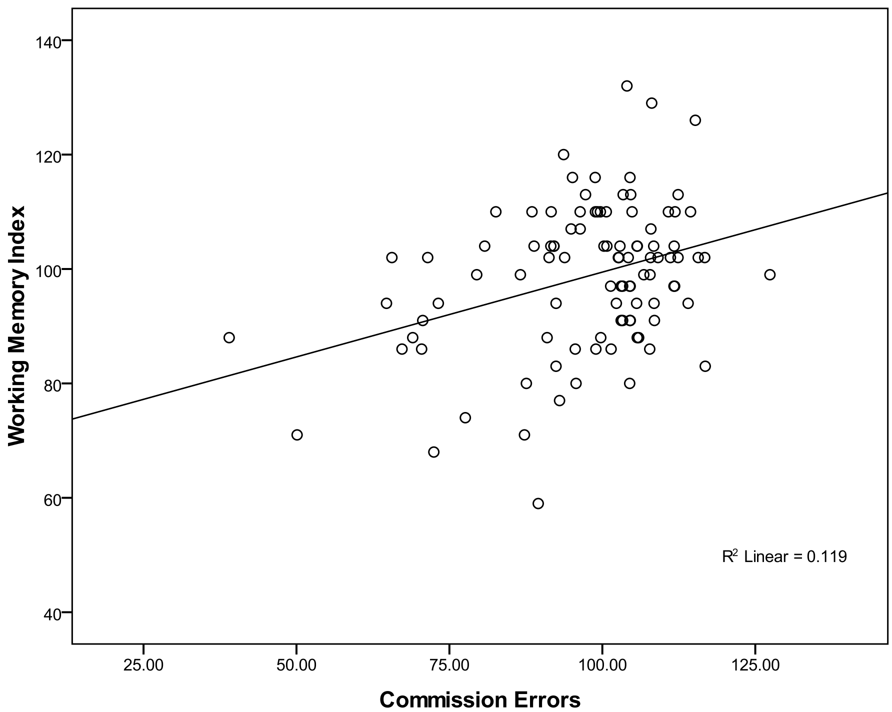
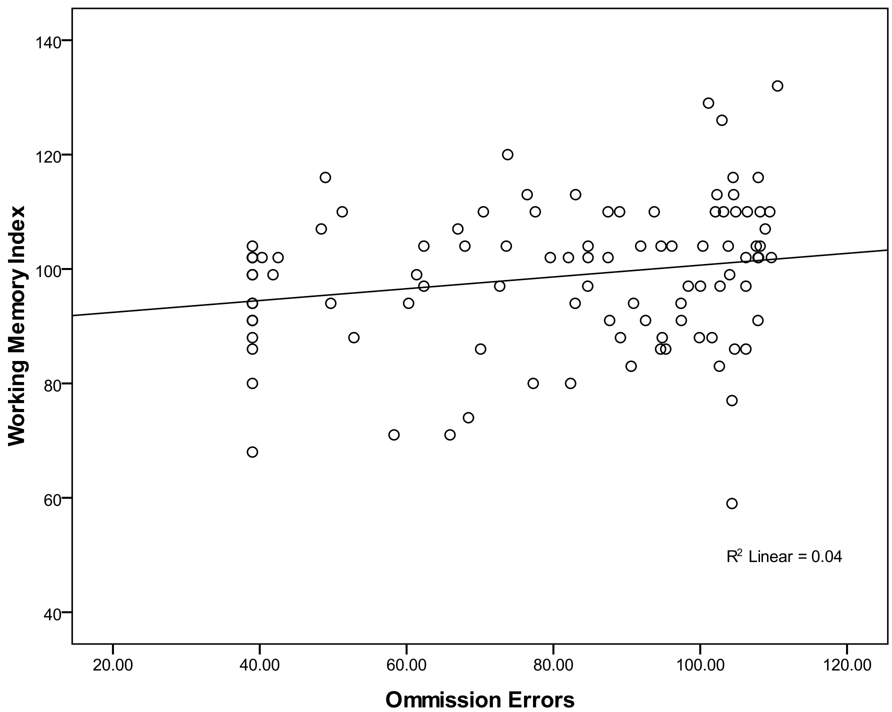


Figure 4

Scatterplot between Omission Errors and the Working Memory Index



APPENDIX D

Characteristics of Grouped Samples

Table D1

Characteristics of Children in the Neither Group

Case	Age	Sex	AD/HD	DCD	All DSM-IV Diagnoses
1.	9	F	C	-	1. Bipolar 2. LD NOS 3. AD/HD-C
2.	10	M	-	DCD	1. DCD 2. Dyslexia 3. Mathematics Dx 4. Adjustment Dx with Depressive Mood 5. Asperger's Dx
3.	7	M	-	DCD	1. DCD 2. Dyslexia
4.	8	M	-	DCD	1. DCD
5.	8	F	C	DCD	1. DCD 2. AD/HD- C
6.	11	M	-	-	1. LD NOS
7.	9	F	-	-	-
8.	14	F	-	DCD	1. DCD 2. Mathematics Dx
9.	9	F	-	-	-
10.	11	M	-	-	1. Dyslexia 2. Mathematics Dx
11.	9	F	-	-	1. Dyslexia
12.	9	M	-	-	-
13.	15	M	C	DCD	1. DCD 2. Dyslexia 3. AD/HD- C
14.	8	M	-	-	1. Dyslexia
15.	15	F	-	DCD	1. DCD 2. Dyslexia 3. Mathematics Dx
16.	10	F	-	-	1. DCD
17.	10	F	-	-	-
18.	14	F	-	-	1. Dyslexia
19.	14	F	-	-	1. Dyslexia
20.	8	M	-	DCD	1. DCD
21.	8	M	-	-	-
22.	6	F	-	-	-
23.	14	M	PI	DCD	1. DCD 2. Dyslexia 3. AD/HD-PI
24.	13	F	-	DCD	1. DCD
25.	14	F	-	-	1. Dyslexia
26.	9	F	-	DCD	1. DCD
27.	14	M	-	-	-
28.	10	M	-	DCD	1. DCD 2. Dyslexia
29.	8	M	-	DCD	1. DCD 2. Dyslexia
30.	6	M	-	Weak	1. Mixed Language
31.	12	M	C	DCD	1. DCD 2. Dyslexia 3. Language Dx 4. AD/HD - C
32.	12	M	C	DCD	1. DCD 2. Dyslexia 3. AD/HD-C
33.	9	F	-	-	-
34.	15	F	-	-	1. Dyslexia 2. Mixed Language

35.	14	F	-	-	-
36.	8	F	-	DCD	1. DCD 2. Language Dx
37.	14	F	PI	-	1. Dyslexia 2. AD/HD-PI

Note: Dx: Disorder; AD/HD: Attention Deficit Hyperactivity Disorder; DCD: Developmental Coordination Disorder

Table D2
Characteristics of Children in the Attention Problem Group

Case	Age	Sex	AD/HD	DCD	All DSM-IV Diagnoses
1.	8	M	-	-	-
2.	7	M	NOS	-	1. AD/HD-NOS
3.	14	M	-	-	1. Dyslexia 2. Dx of Written Expression
4.	7	F	C	-	1. Dyslexia 2. AD/HD-C
5.	9	F	C	-	1. AD/HD-C
6.	8	F	C	-	1. LD NOS 2. AD/HD C
7.	9	F	-	-	-
8.	15	M	C	-	1. AD/HD-C
9.	8	F	-	-	-
10.	15	M	-	-	1. Dyslexia
11.	8	M	PI	DCD	1. DCD 2.Dyslesxia 3. AD/HD-PI
12.	14	M	PI	-	1. Dyslexia 2. AD/HD-PI
13.	7	M	-	DCD	1. DCD 2. Dyslexia
14.	7	F	C	-	1. AD/HD-C
15.	6	M	-	-	1. Language disorder 2. LD NOS
16.	8	M	-	-	-
17.	7	M	-	DCD	1. DCD 2. LD NOS
18.	15	M	-	-	-
19.	7	M	PI	DCD	1. DCD 2.Other Developmental Dx : Spelling 3. AD/HD-PI
20.	14	F	-	-	1. Dyslexia
21.	6	M	C	DCD	1. DCD 2. AD/HD-C
22.	12	F	-	-	-
23.	12	M	-	-	1. Dyslexia
24.	14	F	-	-	1. Dyslexia 2. Mixed Receptive-Expressive language disorder
25.	8	F	C	DCD	1. DCD 2. AD/HD-C

Note: Dx: Disorder; AD/HD: Attention Deficit Hyperactivity Disorder; DCD: Developmental Coordination Disorder

Table D3

Characteristics of Children in the Combined Group

Case	Age	Sex	AD/HD	DCD	All DSM-IV Diagnoses
1.	7	F	C	-	1. AD/HD-C
2.	8	M	HI	DCD	1. DCD 2. AD/HD- HI
3.	8	M	-	-	1. Dyslexia 2. Dx of Written Expression
4.	11	F	-	-	1. Dyslexia
5.	15	M	-	-	-
6.	15	M	-	-	1. Dyslexia
7.	7	M	C	-	1. Dyslexia 2. AD/HD-C
8.	13	F	-	-	-
9.	9	M	HI	DCD	1. DCD 2. Non-verbal LD 3. LD NOS 4. AD/HD-HI
10.	7	M	-	DCD	1. DCD
11.	12	M	PI	-	1. AD/HD-PI
12.	7	M	PI	DCD	1. DCD 2. Other Developmental Dx : Spelling 3. AD/HD-PI
13.	6	M	C	DCD	1. DCD 2. AD/HD-C
14.	7	M	-	-	1. Dyslexia
15.	8	M	HI	-	1. Dyslexia 2. AD/HD-HI
16.	10	M	-	-	1. V62.89 Borderline Intellectual Functioning
17.	10	M	PI	-	1. AD/HD-PI
18.	9	F	C	-	1. LD NOS 3. AD/HD- C
19.	15	F	C	DCD	1. DCD 2. Non-Verbal LD 3. LD NOS 4. AD/HD-C
20.	7	M	-	-	1. Dyslexia 2. Mixed Language Dx
21.	13	M	C	DCD	1. DCD 2. Dyslexia 3. Dx of Written Expression 4. AD/HD-C
22.	13	F	C	DCD	1. DCD 2. Dyslexia 3. AD/HD-C
23.	9	F	-	DCD	1. DCD
24.	8	M	C	-	1. Disruptive Behavior Dx NOS 2. AD/HD-C
25.	7	M	C	-	1. AD/HD-C
26.	15	M	C	DCD	1. DCD 2. Dyslexia 3. LD NOS 4. AD/HD- C
27.	7	M	-	-	1. Dyslexia
28.	14	M	PI	-	1. Dyslexia 2. AD/HD-PI
29.	9	F	PI	DCD	1. DCD 2. Dyslexia 3. Mood Disorder 4. AD/HD-PI
30.	9	F	C	-	1. Dyslexia 2. AD/HD-C
31.	8	M	-	-	1. Mathematics Dx 2. Major Depressive Dx

Note: Dx: Disorder; AD/HD: Attention Deficit Hyperactivity Disorder; DCD: Developmental Coordination Disorder

APPENDIX E

Exploratory Analyses

Table E1

Pearson (r) and Spearman's Rho (r_s) Correlations for T.O.V.A., WISC-IV Indices and Beery VMI Scores for BASC-2 Neither Subgroup (n=37)

	Pearson (*r*)		
	WMI*	PSI*	VMI
RTV	.48**	.47**	.03
RT	.18	.39*	-.16
OE[a]	.35*	.20	.11
	Spearman's Rho (r_s)		
CE	.18	.13	.38*

Note: T.O.V.A. = Test of Variables of Attention; RTV = Response Time Variability; RT = Correct Response Time; OE[a] = Transformed Omission Errors; CE = Commission Errors; VMI = Beery Visual-Motor Integration; FSIQ = WISC-IV Full Scale IQ; VCI = Verbal Comprehension Index; PRI = Perceptual Reasoning Index; WMI = Working Memory Index; PSI = Processing Speed Index
*p<.05, **p<.01;***p<.001

Table E2

Pearson (r) and Spearman's Rho (r_s) Correlations for T.O.V.A., WISC-IV Indices and Beery VMI Scores for BASC-2 Attention Subgroup (n=25)

	Pearson (*r*)		
	WMI*	PSI*	VMI
RTV	.22	-.02	.10
RT	-.03	-.08	.08
OE[a]	-.03	-.11	-.09
	Spearman's Rho (r_s)		
CE	.41*	.23	.10

Note: T.O.V.A. = Test of Variables of Attention; RTV = Response Time Variability; RT = Correct Response Time; [a] = Transformed Omission Errors; CE = Commission Errors; VMI = Beery Visual-Motor Integration; FSIQ = WISC-IV Full Scale IQ; VCI = Verbal Comprehension Index; PRI = Perceptual Reasoning Index; WMI = Working Memory Index; PSI = Processing Speed Index *p<.05, **p<.01;***p<.001

Table E3

Pearson (r) and Spearman's Rho (r_s) Correlations for T.O.V.A., WISC-IV Indices and Beery VMI Scores for BASC-2 Combined Subgroup (n=31)

Pearson (*r*)

	WMI*	PSI*	VMI
RTV	.18	.46**	.14
RT	-.01	.47**	.03
OE[a]	.09	.25	.24

Spearman's Rho (r_s)

CE	.11	.03	.06

Note: T.O.V.A. = Test of Variables of Attention; RTV = Response Time Variability; RT = Correct Response Time; [a] = Transformed Omission Errors; CE = Commission Errors; VMI = Beery Visual-Motor Integration; FSIQ = WISC-IV Full Scale IQ; VCI = Verbal Comprehension Index; PRI = Perceptual Reasoning Index; WMI = Working Memory Index; PSI = Processing Speed Index *p<.05, **p<.01;***p<.001

Table E4

Summary of Stepwise Regression Analyses for T.O.V.A. Performance Measures Using PSI, WMI and VMI in BASC-2 Sub-groups

Dependent	Predictors	R BETA	R^2	AdjR	F
Response Time Variability	*PSI*	*.36*	*.13*	*.12*	*14.54****
Neither	WMI	.48	.23	.21	10.40**
Attention	---				
Combined	PSI	.46	.21	.19	7.85**
Response Time	*PSI*	*.30*	*.09*	*.08*	*9.90***
Neither	PSI	.39	.15	.13	6.21*
Attention	---				
Combined	PSI	.47	.22	.19	8.04**
Omission Error [a]	*WMI*	*.20*	*.04*	*.03*	*4.03**
Neither	WMI	.35	.12	.10	4.85*
Attention	---				
Combined	---				

Note: First line represents the results of the overall sample; “---”: no variables entered; [a]= transformation applied; Commission Errors are not reported due to violations of normalcy; p*<.05, p**<.01, p***<.001

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