ANALYSIS OF SPECIFIC ATTENTIONAL FUNCTIONS IN ATTENTION-DEFICIT/HYPERACTIVITY DISORDER (ADHD): IMPLICATIONS FOR ADHD SUBTYPING THEORY

by

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(Under the direction of Dr. George Hynd)

ABSTRACT

It is important to understand the neurobiological, cognitive, and behavioral factors that underlie ADHD and the ADHD subtypes. It has often been hypothesized that the ADHD-Combined Type (ADHD-CT) and ADHD-Predominantly Inattentive Type (ADHD-PI) subtypes may be the result of different underlying factors and may be associated with different types of attentional deficits. The current study compared 30 children with ADHD-CT and 35 children with ADHD-PI on several neuropsychological variables associated with various aspects of attentional processing. However, it is important to note that only 47 (22 with ADHD-CT and 25 with ADHD-PI) of the participants were assessed with some of the experimental measures. All participants were between the ages of 6 years, 0 months and 12 years, 11 months.

Participants were evaluated using several neuropsychological measures associated with various aspects of attentional processing in order to test five hypotheses regarding possible subtype differences in specific types of attention. The attentional processes of interest included response activation, sustained attention, encoding/working memory, the focus/execute aspect of attention, and attentional stability. These constructs were taken from the theories of Tucker and Williamson (1984) and Mirsky and Colleagues (1999). The attentional measures used in this study were taken from the Test of Variables of Attention (TOVA), the Children’s Memory Scale (CMS), and the Wechsler Intelligence Test for Children-Third Edition (WISC-III). Analysis of possible subtype differences in the occurrence rate of reading disabilities was also conducted. Finally, post hoc analyses were conducted in order to test the hypothesis that specific attentional processes might impact other specific aspects of the neuropsychological functioning of children with ADHD. The attentional processes of interest were response activation and attentional stability. The dependent variables for the post hoc analyses included measures of language ability as well as behavioral ratings of attention and hyperactivity.

No statistically significant group differences were found for any of the variables reflecting the five aspects of attentional processing. Nor were any significant subtype differences in the occurrence rate of reading disabilities or the post hoc analyses. The post hoc analyses did not yield statistically significant results either. Finally, weaknesses of the current study as well as future directions for ADHD research were discussed.

INDEX WORDS: ADHD Subtypes, Attention, Response Activation, Sustained Attention, Focused Attention, Attentional Stability

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TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 1

INTRODUCTION

The core behavioral phenomena associated with Attention-Deficit/Hyperactivity Disorder (ADHD) have long been studied. They include hyperactivity, impulsivity, and inattention. These essential symptoms of ADHD are presumed to be the result of neurological deficits (Barkley, 1990) and their presence can impact many aspects of a person's functioning. By definition, ADHD results in significant impairment in social, academic, or occupational functioning (American Psychiatric Association, 1994). Furthermore, people with ADHD have a high risk of being diagnosed with a comorbid psychiatric disorder, are more likely than people without ADHD to have a learning disability or academic problems, and are more likely to have social problems (Barkley, 1996a).

Several theories have attempted to explain the various symptoms that are characteristic of ADHD. Two of the most prominent suggest that impaired functioning of the frontal lobe and/or the right posterior hemisphere of the brain may cause ADHD. Barkley (1997) proposed a theory that attempts to explain how low behavioral inhibition can lead to deficits in executive functioning which in turn cause the symptoms of ADHD Combined and Predominantly Hyperactive Types. Schaugency and Hynd (1989) proposed a theory which attempts to explain the deficits in Attention Deficit Disorder (ADD) without hyperactivity as the result of deficits in the ability to simultaneously process sensory stimuli due to impaired functioning of the central-posterior region or right posterior hemisphere of the brain. A brief overview of both theories is provided below.

In his 1997 article Barkley cited evidence suggesting that inattentive children that are not hyperactive tend to have deficits in speed of information processing, focused attention, and selective attention while children who are inattentive and hyperactive seem to have a deficit in sustained attention or persistence. Barkley's theory of behavioral inhibition and executive function is intended to explain deficits in sustained attention but not the attentional deficits associated with children who are not hyperactive (Barkley, 1997). Barkley posits that the symptoms of ADHD associated with hyperactivity result from an impaired ability to inhibit responses and stop ongoing responses to environmental stimuli. According to Barkley this results in deficits in various aspects of executive functioning including working memory, self-regulation of affect, motivation, arousal, internalization of speech, and reconstitution. In turn, these deficits may cause children with ADHD to have problems with motor control, goal directed persistence, and sustained attention. Barkley's theory of ADHD is the most widely accepted explanation of the deficits associated with the ADHD Combined and Predominately Hyperactive Types.

A theory proposed by Schaugency and Hynd (1989) attempts to explain the symptoms of impaired selective and focused attention associated with attention deficits that do not involve hyperactivity. Based on the work of Tucker and Williamson (1984), Schaugency and Hynd posit that there are two types of attentional control. One type of attentional control is associated with the arousal system of the brain, which controls perceptual responsivity to stimuli. The other is associated with the activating system of the brain, which controls readiness to respond motorically. The activating system is proposed to be associated with hyperactivity and more frontally located dysfunction. This idea is consistent with Barkley's theory of ADHD. The arousal system is thought to be associated with structures located in a more central-posterior area of the brain. Such systems are believed to be involved in attentional processing. Schaugency and Hynd (1989) also suggest that deficits in attention without hyperactivity could be due to impaired function of the right posterior hemisphere of the brain.

The theories of Barkley (1997) and Schaugency and Hynd (1989) are both supported by research. There have been several studies that indicate that there is an association between the right frontal lobe and measures of sustained attention (Pennington and Ozonoff, 1996). The frontal lobe is also associated with behavioral regulation (Barkley, 1990; Barkley, 1997; Riccio et al., 1993). Much research has documented the impaired functioning of hyperactive children on neuropsychological tests associated with the frontal lobes (See Barkley et al., 1992 or Pennington & Ozonoff, 1996 for extensive reviews of this literature). Aman and colleagues (1998) recently provided evidence of both frontal lobe and right parietal lobe dysfunction in children with ADHD-Combined Type. Furthermore, disorders of attention have frequently been found in adults with right hemisphere lesions (Voeller & Heilman, 1988). These findings suggest that ADHD may involve dysfunction in both frontal and posterior systems.

Individuals with ADHD compromise a heterogeneous group with a variety of social and behavioral characteristics. This makes the subtyping of the ADHD syndrome extremely important. Research suggests that failure to diagnose and study subtypes of ADHD could result in confounded clinical and research populations (Hynd et al., 1991).

In the DSM-IV (American Psychiatric Association, 1994) there are three subtypes of ADHD: Predominantly Inattentive Type (PI), Predominantly Hyperactive-Impulsive Type (HT), and Combined Type (CT). However, the majority of the research dealing with attention deficits and hyperactivity was based on the DSM-III (American Psychiatric Association, 1980) or DSM-III-R (American Psychiatric Association, 1987) nosologies. The DSM-III notes two essential subtypes: Attention Deficit Disorder with Hyperactivity (ADD/H) and Attention Deficit Disorder without Hyperactivity (ADD/WO). This diagnostic nomenclature allowed for the study of within group variance among people with ADD.

The results of an experimental study by Morgan and colleagues (1996) suggest that the DSM-IV diagnosis of ADHD-PI corresponds very closely to the DSM-III diagnosis of ADD/WO while the DSM-IV diagnosis of ADHD-CT corresponds very closely to the DSM-III diagnosis of ADD/H. However, one crucial difference between the diagnoses of ADHD-PI and ADD/WO is that symptoms of impulsivity are not required for a diagnosis of ADHD-PI but were required for a diagnosis of ADD/WO. A factor analysis of ADD symptoms suggested that impulsivity and hyperactivity form a single factor and inattention forms a distinct factor (Lahey et al., 1988). The fact that symptoms of impulsivity were required for a diagnosis of ADD/WO could have resulted in this group being "impure" (Barkley et al., 1992) because children diagnosed as having ADD/WO were required to exhibit symptoms which are not typically associated with inattention that does not involve hyperactivity. Furthermore, research suggests that many children diagnosed as ADHD-HT may have been excluded using DSM-III criteria (Morgan et al., 1996). Despite the differences between the DSM-III and DSM-IV criteria it appears that the diagnostic categories of ADD/WO and ADD/H are related to the categories of ADHD-PI and ADHD-CT respectively.

Biederman and colleagues (1997) conducted a study that suggests diagnostic continuity between DSM-III-R and DSM-IV systems for diagnosing ADHD. However, no research comparing subtypes used the DSM-III-R criteria for ADHD because it utilized a unidimensional approach to the symptoms of ADHD. In other words, the DSM-III-R criteria for ADHD did not differentiate between hyperactive and inattentive symptoms or subtypes.

The present study is an attempt to examine possible ADHD subtype differences by testing hypotheses based on cognitive theories of attention, research findings on the neurobiology of attention and ADHD, as well as previous research findings on and theories of ADHD subtyping. The following chapter reviews the literature in these areas. Hypotheses about possible neuropsychological differences between the subtypes based on the research literature are then proposed. In subsequent chapters these hypotheses are tested and the results are discussed.

CHAPTER 2

REVIEW OF THE LITERATURE

This chapter integrates research literature that has implications for ADHD theory and subtyping. Cognitive theories of attention and findings about the neurobiological basis of attention are reviewed in order to provide a framework within which to examine the validity and utility of ADHD theories and subtypes. Next, research on the neurobiology of ADHD and research on ADHD subtype differences is reviewed. ADHD theory and subtyping nosology are then evaluated in light of cognitive and neuropsychological theories of attention, research about the neurobiological mechanisms of attention, research about the neurobiology of ADHD, and research on ADHD subtype differences. Finally, hypotheses are made regarding the possibility of subtype differences in attentional processing.

Cognitive and Neuropsychological Theories of Attention

There are numerous cognitive theories of attention. A few are deserving of mention in order to provide a historical perspective from which to view more current models.

Broadbent's (1958) "filter theory" of attention was one early theory. Broadbent proposed that attention serves as a filter which helps select relevant stimuli for further processing. In 1971 Broadbent amended his theory to allow for two attentional processes: filtering, or attenuating, stimuli and "pigeonholing". Pigeonholing refers to the process of assigning relevance or relative importance to stimuli. Though Broadbent's theory was inadequate in its detail and in its implications both neuropsychologically and behaviorally, these processes are still believed to be involved in attention.

Luria's (1961) theory of attention was more detailed and more directly measurable by behavioral and neuropsychological methods. He described two distinct patterns of behavior, impulsivity and decreased tone of nervous processing, which he believed to be fundamentally related. These behaviors frequently occur in people with attention problems.

In 1984 Tucker and Williamson proposed a model of attention which is consistent with Luria's observations. Their model stated that there are two separate attentional control systems within the brain: an arousal system controlling perceptual responsivity to stimuli and an activating system controlling readiness to respond (Tucker and Williamson, 1984).

Posner and Peterson's (1990) theory of attention included three attentional processes that are all similar to constructs proposed by either Broadbent (1971) or Tucker and Williamson (1984). According to Posner and Peterson attentional processing involves orienting to sensory events, selecting signals for conscious processing, and maintaining a vigilant or alert state. Several other aspects of attention are also referred to in the cognitive literature on attention. Many of these have been described by Taylor. Taylor (1995) refers to the "intensive", "sustained", "selective", and "control" aspects of attention. The intensive aspect of attention involves highly concentrated effort and is often referred to as focused attention. Sustained attention involves prolonging attentional efforts and is similar to the construct of vigilance. Selective attention is identifying stimuli for conscious awareness. Attentional control refers to the process of allocating one's limited attentional capacities in order to carry out the various attentional processes. Many of these constructs from cognitive theories of attention are similar to constructs proposed in neuropsychological theories of attention such as that of Mirsky and colleagues (1995; 1999).

Mirsky and colleagues (1995; 1999) reported a neuropsychological model of attention based on the results of a factor analysis of neuropsychological tests believed to measure attention. The measures included in their analysis were The Trail Making Test, The Talland Letter Cancellation Task, The Stroop Test, The Continuous Performance Test (CPT), The Wisconsin Card Sorting Test (WCST), and three Subtests from the Wechsler Adult Intelligence Test (WAIS): Digit-Symbol Substitution, Digit Span, and Arithmetic. Five factors of attention resulted. One factor was comprised of The Trail Making Test, The Talland Letter Cancellation Task, The Stroop Test, and Digit Symbol Substitution. It was labeled the *focus/execute* aspect of attention. Scores from the CPT formed another factor which was labeled *sustain*. Digit Span and Arithmetic formed a factor which was labeled *encoding*. The fourth factor was comprised of the WCST and was labeled *shifting* attention (Mirsky et al., 1995; Mirsky et al., 1999). The final factor consisted of response time measurements from the CPT and was labeled *stability*. Results of this factor analysis are consistent with various aspects of the cognitive theories discussed above.

Mirsky and colleagues (1999) describe the *focus/execute* aspect of attention as ability to concentrate attention on a specific task while screening out distracting stimuli. This construct has considerable overlap with what Posner and Peterson (1990) refer to as the orienting aspect of attention (Mirsky, 1996). The *sustain* aspect of attention refers to the ability to stay on tasks for extended periods of time (Mirsky et al., 1999) and is consistent with Posner and Peterson's (1990) construct of vigilance (Mirsky 1996). The *encoding* aspect of attention is the ability to hold information briefly in mind while performing a cognitive operation on it (Mirsky et al., 1999) and has considerable overlap with the construct of working memory. Mirsky and colleagues (1999) describe *shifting* attention as the ability to change attentional focus between target stimuli smoothly and efficiently. Finally, *stability* refers to the ability to maintain a consistent response rhythm to stimuli.

Cognitive theorists have proposed a wide variety of attentional mechanisms and processes. Many of the constructs they have proposed are important to theories of ADHD and ADHD subtyping. The constructs of sustained attention, working memory (encoding), and impulsivity (readiness to respond) are central to Barkley's (1997) theory of ADHD-CT. Schaugency and Hynd (1989) suggest that impairments in selective and focused attention are key aspects of ADHD without hyperactivity. While less is known about how some other attentional constructs may relate to ADHD, it seems possible that subtype differences in many of these constructs may exist.

Many of the constructs proposed in cognitive theories of attention are consistent with and seem to relate to research on the neurobiological basis of attention. The next section reviews this research and discusses the relationships between the neurobiological aspects of attention and some of the constructs proposed in these cognitive theories of attention.

Neurobiological Basis of Attention

Structures throughout the brain are involved in attentional processes. They include the reticular formation, diffuse cortical areas, the thalamus, the basal ganglia, and the cerebellum. Each of these structures is crucial to attentional processes. This section reviews studies about the functions and connections of each of these structures in order to describe the neurobiological basis for attention. In addition, research on neurotransmitter systems involved in attention and hemispheric asymmetry of attentional processing is reviewed. Finally, the congruence between cognitive theories and neurological research on attention will also be discussed.

Reticular Formation

One structure that is involved in attention is the reticular formation. The reticular formation is activated by neuronal input from the superior temporal sulcus (French et al., 1955; Heilman et al., 1993). Damage to the superior temporal sulcus and the reticular formation cause hypoarousal (Heilman et al., 1993). The role of the superior temporal sulcus in attention is discussed further in the following section on cortical areas. Stimulation of the reticular formation has been shown to cause arousal and synchronization of cortical neuronal firing (Munk et al., 1996). Synchronization of neuronal responses by the reticular formation raises their saliency, suggesting that it plays a role in attentional processing (Munk et al. 1996).

Furthermore, profound neglect results from reticular formation lesions in cats and monkeys (Watson et al., 1974). Heilman and colleagues (1993) define neglect as the failure to report or respond to novel or meaningful stimuli when this failure cannot be attributed to either sensory or motor defects. There is research suggesting that neglect is a deficit in attention-arousal (Heilman & Valenstein, 1972; Watson et al., 1973; Watson et al., 1974). In summary, evidence that reticular formation lesions cause neglect supports the notion that the reticular formation is crucial to arousal and maintaining an alert state and may play an important role in attentional processes.

Kinomura and colleagues (1996) review anatomical and electrophysiological studies that suggest a connection between the reticular formation and the intralaminar thalamic nuclei. Research suggests that stimulation of the intralaminar thalamic nuclei by the reticular formation evokes behavioral arousal (Steriade & Glenn, 1982; Kinomura et al., 1996). The results of a positron emission tomography (PET) study showed activation of the left intralaminar region of the thalamus and the reticular formation during visual and semantic attention tasks (Kinomura et al., 1996).

Stimulation of the reticular formation also serves to inhibit the thalamic reticular nucleus (Heilman et al., 1993). The thalamic reticular nucleus surrounds the rest of the thalamus and modulates input to the thalamic relay nuclei (Guillery et al., 1998). Inhibition of the thalamic reticular nucleus by the reticular formation results in enhanced thalamic transmission (Heilman et al., 1993). Thus, it appears that the reticular formation plays a key role in attention by maintaining vigilance and perhaps by enhancing thalamic transmission.

Cortical Areas and Connections

Three primary cortical areas appear to be central to attentional processes: the cingulate gyrus, the inferior parietal lobule, and the prefrontal cortex. These three cortical areas are extensively interconnected (Baleydier & Mauguiere, 1980; Goldman-Rakic, 1988; Morecraft et al., 1993). This cortical network is characterized by parallel connections among subareas in which a specific portion of each cortical area shares reciprocal connections with specific portions of the others (Goldman-Rakic, 1988). Evidence suggests that each of these cortical areas is involved in attentional processing.

The cingulate gyrus is a part of the limbic system that integrates limbic information and connects the limbic system with other structures including the prefrontal cortex and the inferior parietal lobule (Baleydier & Mauguiere, 1980). Limbic structures that have connections with the cingulate gyrus include the hippocampus and the amygdala (Baleydier & Mauguiere, 1980). These structures may play a key role in the encoding/working memory aspect of attention (Mirsky et al, 1995; Mirsky et al, 1999). Powell and Hines (1974) cite information which suggests that the cingulate gyrus may be a crucial interface for limbic information and other types of information, and that it may participate in selective modulation of sensory mechanisms (i.e. attention). The cingulate gyrus consists of two anatomically heterogeneous cytoarchitechtonic regions that correspond to Brodmann's Areas 23 and 24 (Baleydier & Mauguiere, 1980).

Area 23 is the posterior portion of the cingulate gyrus. It receives input from sources including the inferior parietal lobule, the dorsolateral prefrontal cortex (sulcus principalis), the orbitofrontal cortex, several thalamic nuclei, and the superior temporal sulcus (Baleydier & Mauguiere, 1980). Area 23 sends projections to area 24, the posterior parietal cortex, the superior temporal sulcus, the intralaminar thalamic nuclei, and the caudate nucleus (Baleydier & Mauguiere, 1980).

Area 24 is the anterior portion of the cingulate gyrus. It receives input from sources including the arcuate sulcus, sulcus principalis, area 23, and thalamic nuclei. Area 24 projects to the inferior parietal lobule, area 23, the intralaminar thalamic nuclei, the striatum, and several limbic structures including the hippocampus and the amygdala (Baleydier & Mauguiere, 1980). One key difference between the divisions of the cingulate gyrus is that area 23 sends output to the superior temporal sulcus and has extensive connections with the inferior parietal lobe while area 24 does not (Baleydier & Mauguiere, 1980). Furthermore, Baleydier and Mauguiere (1980) hypothesize that area 23 is involved in attentional processing of sensory information while area 24 is involved in arousal. This theory is consistent with findings showing the intralaminar thalamic nuclei to be involved in arousal (see previous section) and that the posterior parietal lobe is involved in sensory processing (see below). In addition, research indicates that damage to the cingulate cortex can result in attention problems and neglect (Watson et al., 1973; Baleydier & Mauguiere, 1980; Posner & Peterson, 1990).

The inferior parietal lobule is a cortical area inferior to the superior temporal sulcus. It consists of Brodmann's area 7 in nonhuman primates and Brodmann's areas 39 and 40 in humans. In other words, area 7 is the nonhuman homonid equivalent of areas 39 and 40 in humans (Watson et al., 1994). Goldman-Rakic (1988) reviews studies which demonstrate that inferior parietal lobule is connected to the anterior and posterior cingulate gyrus, the dorsolateral prefrontal cortex (dlPFC), the superior temporal sulcus, and the frontal eye fields in nonhuman primates.

Areas 39 and 40 in humans and area 7 in other homonids are believed to be involved in attention and neglect. Watson and colleagues (1994) demonstrated that lesions to both the superior temporal sulcus and the inferior parietal lobule can cause neglect and reported that lesions to areas 39 and 40 are the most common cause of neglect in humans. Both Watson and colleagues (1994) and Heilman and colleagues (1993) hypothesized that the inferior parietal lobule's connection with limbic structures and polymodal cortical areas make it a key factor in the mechanisms which underlie attention and neglect. Functional imaging studies indicate that the inferior parietal lobule plays a key role in selective attention (Pardo et al., 1991; Shayawitz et al., 1999).

The prefrontal cortex is another cortical area that has been associated with attention. Studies have shown that lesions to the prefrontal cortex result in attention problems and distractibility (Brutkowski, 1963; Bartus and Levere, 1977). The dlPFC has been shown to have extensive connections with the cingulate gyrus and the inferior parietal lobule (Baleydier & Mauguiere, 1980; Goldman-Rakic, 1988). Woods and Knight (1986) demonstrated that lesions to the dlPFC result in distractibility. Knight and colleagues (1989) found that patients with lesions in the dlPFC displayed increased distractibility and increased amplitude in the Pa component during a recording of auditory evoked potentials. The Pa component is involved in early selection of auditory signals and the increased amplitude in the Pa component may represent a decrease in the gating of auditory signals (Knight et al., 1989). In summary, the cingulate gyrus, the inferior parietal lobule, and the prefrontal cortex appear to be crucial to attentional processes. Figure 1 (below) provides a graphic example of the interconnections between the cortical areas involved in attention and their connections with the reticular formation.

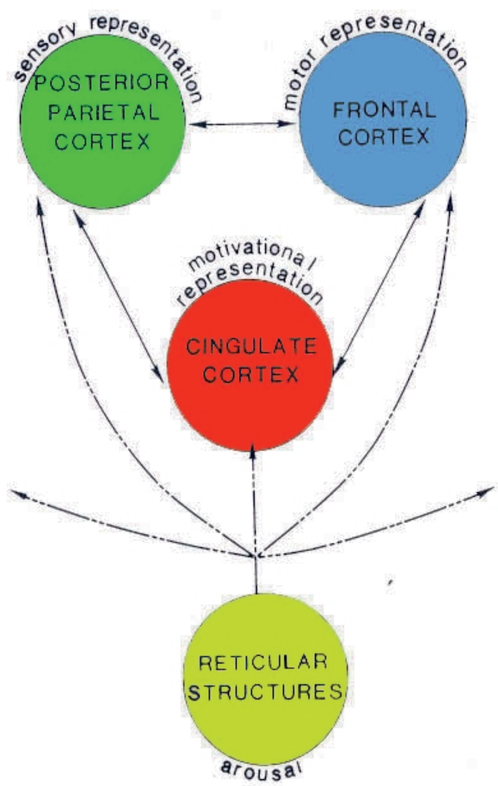

Figure1: This graphic (Mesulam, 1981) demonstrates the interconnections between the cortical areas involved in attention and their connection with the reticular formation.

Basal Ganglia

The basal ganglia has extensive reciprocal connections with several cortical areas. Such connections form distinct feedback loops between the basal ganglia and interconnected cortical areas (Yeterian & Hoesen, 1978). Figure 2 (below) provides a graphic example of how the basal ganglia forms feedback loops with interconnected cortical areas.

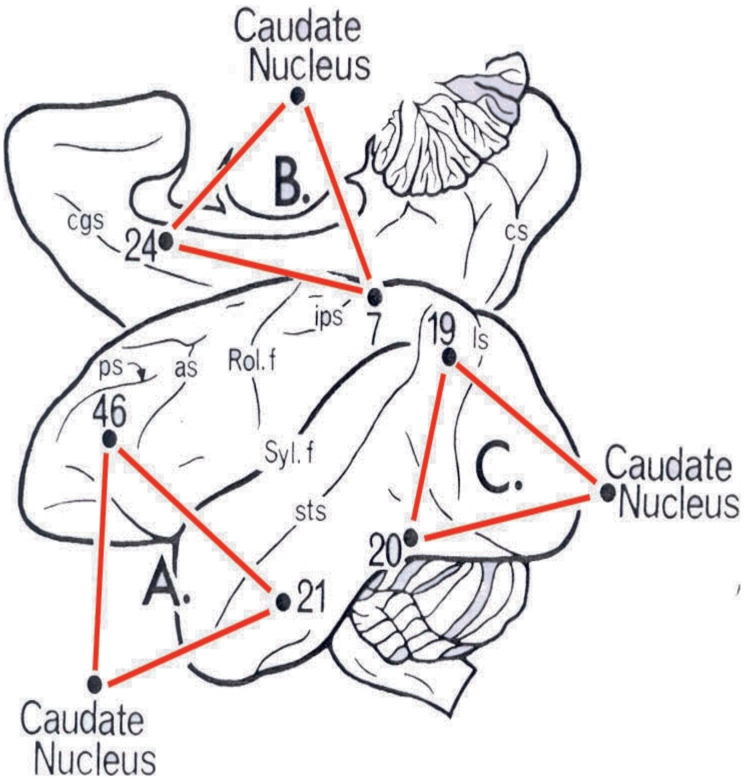

Figure 2: This graphic (Yeterian & Hoesen, 1978) provides demonstrates the feedback loops that interconnected cortical areas form with the basal ganglia.

Several of these feedback loops involve cortical areas that are believed to play a role in attention. Such areas include the dlPFC, the lateral orbitofrontal cortex, the anterior cingulate gyrus, and area 7 of the posterior parietal cortex (Alexander et al., 1986). Each loop consists of part of the striatum, globus pallidus, substantia nigra, thalamus, and cortex. The striatum, globus pallidus, and substantia nigra all integrate cortical input that is then returned to the cortex. Figure 3 (below) provides a graphic example of how the basal ganglia integrates and returns cortical input.

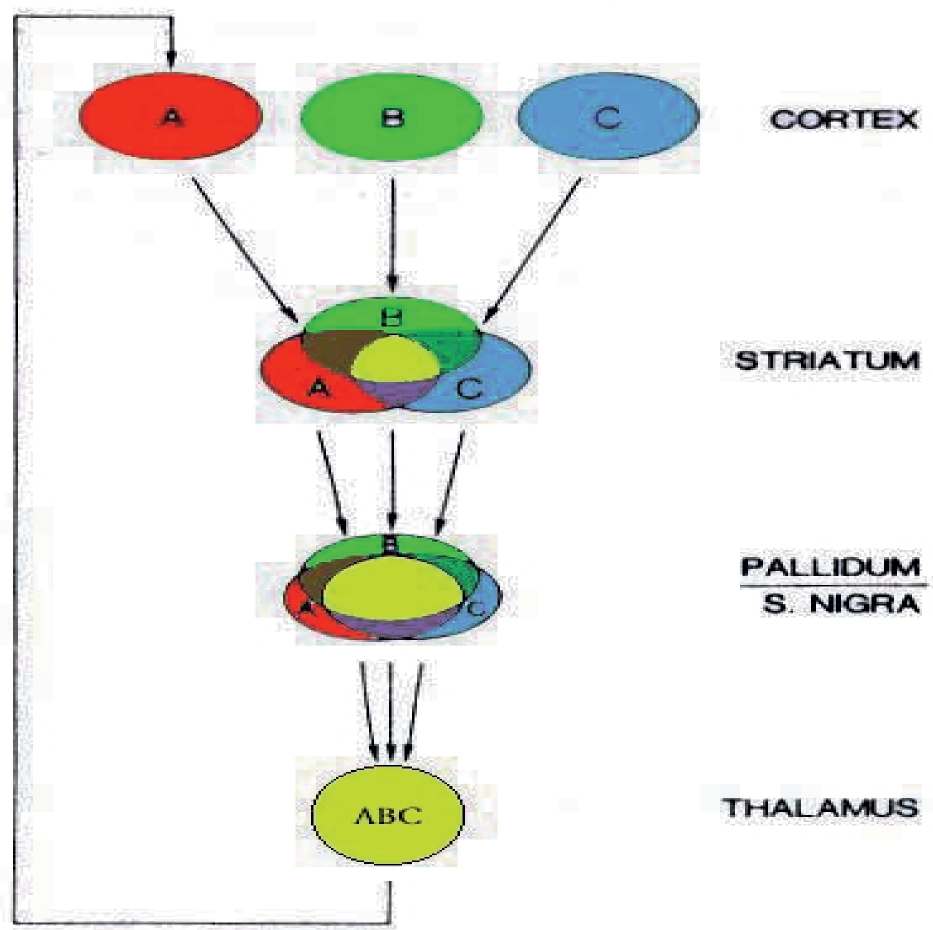

Figure 3: This graphic (Alexander et al., 1986) demonstrates the process by which the structures of the basal ganglia and the thalamus integrate input from cortical structures and return it to a specific cortical area.

Alexander and colleagues (1986) review evidence that suggests that some of the cortical connections of the basal ganglia serve a non-motor or associational function. Infarctions of the basal ganglia, especially the caudate nucleus, have been shown to cause neglect (Healton et al., 1982). Furthermore, lesions to the basal ganglia can result in deficits in sustained attention (McDonald & Burns, 1964). These findings have led to the hypothesis that the basal ganglia, especially the caudate nucleus, is involved in attentional processing (Hynd et al., 1993).

Cerebellum

Though the cerebellum has traditionally been believed to be primarily motoric in function, recent evidence also implicates the dentate nucleus of the cerebellum in cognitive processes including attention (Leiner et al., 1993; Kim et al., 1994). A PET study by Peterson and Fiez (1993) showed activation of the lateral cerebellum during a non-motor cognitive task. The dentate, the most lateral of the deep cerebellar nuclei, is far more developed in humans than it is in other homonids (Leiner et al., 1993). In humans the highly developed portion of the dentate is referred to as the neodentate and is believed to have evolved along with the prefrontal cortex (Leiner et al., 1993). Using retrograde tracing techniques, Middleton and Strick (1994) demonstrated that the dentate has extensive connections with the dlPFC that are distinct from its connections with the motor cortex. It has been hypothesized that these connections between the dentate and the dlPFC allow the cerebellum to be involved in cognitive tasks including attention (Akshoomoff & Courchesne, 1992).

Aksoomoff and Courchesne (1992) suggest that the dentate may be involved in disengaging attention from one source and engaging neural responsiveness to another. They have shown that patients with neocerebellar damage had deficits in shifting attention when compared to other patients with brain damage in the frontal, occipital, and parietal lobes. The results of a fMRI study by Kim and colleagues (1994) indicated that the dentate nucleus showed greater activation during an attentional task using a pegboard than during rote movement of the pegs. Thus, research suggests that the human cerebellum may be involved in shifting attention.

Thalamus

Thalamic nuclei serve as relays between widespread cortical areas and subcortical structures such as the reticular formation, the basal ganglia, and the cerebellum. Two thalamic nuclei that appear to be central to attentional processes are the reticular thalamic nuclei and the pulvinar. The role of the thalamic reticular nucleus was discussed in the previous section on the reticular formation. The medial pulvinar has connections with the cingulate gyrus while the lateral pulvinar has connections with cortical area 7 and is believed to be involved in visual-spatial attention (Robinson & Peterson, 1992). Patients with thalamic lesions have been shown to have difficulty shifting attention to the visual field (Voeller, 1998). Furthermore, PET studies indicate that increased metabolism in the lateral pulvinar occurs during visual selective attention tasks (LaBerge and Buchsbaum, 1990; Robinson & Peterson, 1992). The nuclei of the thalamus, especially the reticular thalamic nuclei and the pulvinar, are important in several aspects of attention such as arousal, selective attention, and visual-spatial attention.

Due to its importance in arousal and selective attention, thalamic functioning may also play an important role in the some of the symptomology associated with ADHD. Voeller (1991) reviewed research suggesting that hypoarousal is a key aspect of ADD/WO. According to Schaugency and Hynd's (1989) theory of ADHD selective inattention may also be one of the key deficits in ADHD without hyperactivity. Thus, thalamic functioning may relate to some of the deficits associated with ADHD.

Neurotransmitters

There are two primary neurotransmitter systems involved in attentional processing: the dopamine system and the norepinepherine system. Both of these systems appear to play a crucial and unique role attention. This section discusses the neuroanatomic location, afferents and efferents, and possible roles that these neurotransmitter systems play in attentional processing.

The dopaminergic system appears to be central to attention and involves the substantia nigra pars reticulata (SNpr) and its connections (Voeller, 1998). The SNpr projects to widespread areas of the reticular formation (Jayarman et al., 1977). It also projects to the ventral anterior and the ventral lateral nuclei of the thalamus (Parent, 1996) and to the superior colliculus (Jayarman et al., 1977; Parent, 1996). The SNpr receives extensive projections from the caudate nucleus and some projections from the prefrontal cortex (Parent, 1996). The dopaminergic system also has extensive projections to the prefrontal cortex and area 7 (Foote & Morrison, 1987). A prolonged suppression of SNpr action occurs during orientation and fixation to a meaningful stimulus (Steinfels et al., 1983). All of these findings implicate a relationship between dopaminergic activity and attentional systems.

Foote and Morrison (1987) suggest the dopaminergic system acts to influence higher-order integrative processes. Furthermore, Tucker and Williamson (1984) suggest that the dopamine system is involved in behavioral activation. While evidence suggests that dopamine is crucial to attentional processes, the exact role that dopaminergic activity plays in attention remains unclear.

Norepinepherine also plays an important role in attention. The Locus Coeruleus (LC) is the origin of norepinepherinergic projections to the neocortex (Foote and Morrison, 1987). The PFC (Cedarbaum & Aghajanian, 1978; Dalsass et al., 1981) and area 7 (Foote & Morrison, 1987) receive extensive projections from LC. Afferents to LC originate from the reticular formation and the deep cerebellar nuclei (Arnsten & Goldman-Rakic, 1984) as well as other structures. It has been proposed that norepinepherinergic systems may serve to enhance and modulate neuronal transmission (Foote & Morrison, 1987) and that they may influence cortical arousal (Tucker & Williamson, 1984). Research indicates that norepinepherine is a key mechanism in attentional processing.

Both dopamine and norepinepherine play unique roles in attentional processing. While dopamine appears to be involved in behavioral activation and response readiness, norepinepherine seems to be related arousal. Thus, it seems possible that these differences between the neurotransmitter systems central to attentional processes may also be related to differences between the ADHD subtypes. ADHD-CT involves greater levels of impulsivity than ADHD-PI (American Psychiatric Association, 1994). This difference could be attributable to differences in dopaminergic activity between subtypes since dopamine is involved in behavioral activation. Furthermore, children with ADHD-PI tend to be hypoactive whereas children with ADHD-CT do not (Lahey et al., 1994; Lahey et al., 1988; Barkley et al., 1990). This difference could be attributable to differences in norepinepherinergic activity between subtypes since norepinepherine is involved in arousal. Findings that ADD subtypes respond differentially to methylphenidate (Barkley et al., 1991) are consistent with the idea of subtype differences in neurotransmission. Neurotransmission and attentional systems are also briefly discussed in the following section dealing with hemispheric asymmetry.

Hemispheric Asymmetry In Attentional Systems

Evidence suggests that there are asymmetries in attentional systems. Dimond and Beaumont (1971a & 1971b) found that the left hemisphere committed more false positives than the right on a hemispatial visual attention task and that the left hemisphere showed decrement in performance over time while the right hemisphere did not (1973). Another study replicated these findings with six commissurotomy patients during auditory, visual, and tactile vigilance tasks (Dimond & Beaumont, 1979). Heilman and Van DeAbell (1980) cite evidence suggesting that temporoparietal regions of the human brain are involved in attentional processing on both sides but that the right temporoparietal region is dominant for attention. Using EEG, they found that the left temporoparietal region showed a much larger desyncronization when stimuli were presented in the right visual field than in the left visual field. However, the right temporoparietal region showed equal amounts of desyncronization when participants were presented with stimuli in the right and the left visual fields. Thus, it appears that the right temporoparietal area may be dominant for attention.

Tucker and Williamson (1984) cite evidence suggesting that the neurotransmitter systems involved in attention may also be lateralized. They review an extensive literature that suggests that the norepinepherine system is responsible for arousal, and that this function is lateralized primarily to the right hemisphere. Research literature also indicates that the dopamine system is responsible for activation, and that this function is lateralized primarily to the left (Tucker & Williamson, 1986).

Voeller (1986) conducted a study examining behavioral and neuropsychological characteristics of 14 children who suffered from either a right-hemisphere lesion or right-hemisphere dysfunction (diagnoses were made on the basis of CAT scan results and/or neuropsychological evaluation). Participants were between the ages of 5 and 13 and children with bilateral lesions were excluded. All but one of the participants were highly inattentive and were found to meet the DSM-III criteria for a diagnosis of ADD. This suggests that right hemisphere functioning is crucial to attentional processes.

Pardo and colleagues (1991) conducted a positron emission tomography (PET) study in which the dlPFC and area 7 showed greater activation in the right hemisphere than the left hemisphere during visual and somatosensory sustained attention tasks. Participants in this study were 23 adults without known neurological problems. During the somatosensory attention task participants were instructed to focus their attention on either their left or right great toe in order to detect brief pauses in a volley of light touches. During the visual attention task the participants were required to detect slight changes in luminance of a central fixation mark though no actual changes occurred. Based on the results of these studies it appears that attentional systems are lateralized.

Summary

Several neurobiological mechanisms appear to be involved in attention. The reticular formation appears to be crucial to maintaining an alert state. The superior temporal sulcus may also play a key role in maintaining vigilance/arousal due to its input to the reticular formation. The cingulate gyrus appears to play a key role in integrating limbic information in order to help select stimuli for conscious processing (selective attention). It has extensive connections with the inferior parietal lobule and the dlPFC. In turn, the inferior parietal lobule and the dlPFC are also extensively interconnected. The inferior parietal lobule may serve to integrate sensory information across modalities and thus play an important role in selective attention. The dlPFC also appears to be involved in selective attention. The basal ganglia, particularly the caudate nucleus, also appears to play a crucial role in attention because it integrates cortical input from areas believed to be involved in attentional processing. Recent evidence also suggests that the neodentate of the cerebellum may play a key role in shifting attention by disengaging attention from one source and engaging neural responsiveness to another. Thalamic nuclei, especially the thalamic reticular nuclei and the lateral pulvinar, also appear to be involved in attentional processes. Much evidence implicates the dopaminergic and norepinepherinergic neurotransmitter systems in attentional processes. Finally, evidence suggests that attentional mechanisms are lateralized.

Research about the neurobiological mechanisms underlying attention relates well to many aspects of the cognitive theories of attention previously discussed. The arousal system postulated by Tucker and Williamson appears to involve the superior temporal sulcus, the reticular formation, and the reticular thalamic nuclei. The cingulate gyrus, the inferior parietal lobule, the dlPFC, and the lateral pulvinar appear to play a prominent role in selective attention. Furthermore, the cerebellum may be involved in the shifting aspect of attention proposed by Mirsky and colleagues (1995; 1999).

The Neurobiological Basis of ADHD

It is often suggested that ADHD is the result of neurobiological dysfunction. Evidence suggesting a neurobiological basis for ADHD has been provided by neuroanatomic, functional imaging, electrophysiological, neurochemical, and neuropsychological studies. Most studies of the neurobiology of ADHD have examined the prefrontal cortex and caudate nucleus. Studies attempting to find dysfunction of the reticular formation in populations with developmental attention deficits have been inconclusive (Hynd et al., 1991). Evidence for the neurobiological basis of ADHD is reviewed in this section.

Extensive research has documented dysfunction of the frontal lobes in ADHD. Hynd et al. (1990) found a reversal of the normal right > left frontal asymmetry in children with ADHD. Furthermore, Positron Emission Tomography (PET) research has shown that superior PFC and premotor cortex are metabolically under active in adults with ADHD

(Zametkin et al., 1990). Faraone and Biederman (1998) cite neuroimaging studies that suggest that frontosubcortical pathways are involved in ADHD. Zametkin and Liotta (1998) cite evidence suggesting that people with ADHD also display decreased glucose metabolism in the cingulate gyrus. The results of several neuropsychological studies using a variety of prefrontal measures have indicated that children display impaired functioning of the PFC (Barkley et al., 1992; Goodyear & Hynd, 1992; Seidman et al., 1997; Aman et al., 1998). Thus, the role of the frontal cortex in ADHD is well established.

The caudate nucleus has also been frequently implicated in the etiology of ADHD. Lou and colleagues (1984) found that children with ADHD demonstrate decreased metabolism in the corpus striatum. Zametkin et al. (1990) found decreased metabolism in caudate nucleus in adults with ADHD. In particular, Lou et al. (1989) pinpointed the right striatum as an area that is metabolically deficient in people with ADHD. Two studies have shown that children with ADHD have reversal of the normal right > left asymmetry of the caudate nucleus (Hynd et al., 1993; Zametkin & Liotta, 1998). These studies suggest that dysfunction of the caudate nucleus is associated with ADHD.

Event related potential studies and neurochemical studies have also provided evidence of a neurobiological basis to ADHD. Studies have shown that people with ADHD and ADD display reduced amplitude of the P3b component during tasks requiring sustained attention which may represent a decreased deployment of attentional capacity (Klorman, 1992). While research on selective attention has yielded less consistent results, several studies report that individuals with ADHD and ADD have reduced amplitude of negative components which may be indicative deficits in selective attention (Klorman, 1992). Extensive research has documented abnormalities in the dopaminergic and norepinepherinergic systems in people with ADHD (Zametkin et al., 1987; Hynd et al., 1991; Hynd et al., 1993). Consequently, evidence suggests that there are electrophysiological and neurochemical abnormalities in people with developmental attention deficits.

Children with ADHD and ADD have also demonstrated impaired performance on tests of stimulus detection and neuropsychological tests associated with right parietal lobe functioning. In a study that examined the 51 children between the ages of 7 and 16 using a computerized continuous performance task, a higher percentage of children with ADD or Conduct Disorder (CD) demonstrated impaired performance than did clinical controls (Klee & Garfinkel, 1983). The control group was comprised of children who were referred to a psychiatric hospital for including mood disorders, thought disorders, and severe behavioral problems.

A study by Voeller and Heilman (1988) demonstrated that children with ADD committed increased numbers of mean errors and left sided errors on a stimulus detection task. Participants in this study were 7 children between the ages of 7 and 12 who met DSM-III criteria for ADD. The dependent measure was a letter cancellation task in which participants had to cross out a letter that was randomly distributed among other letters on a page. Such tasks have been used to elicit evidence of left hemispatial neglect in people with right hemisphere dysfunction. The performance of children with ADD was found to be similar to people who suffer from right hemisphere lesions (Voeller & Heilman, 1988).

Aman and colleagues (1998) reported that children with ADHD were impaired in their performance on two psychological tests that are sensitive to right parietal functioning. Their sample consisted of 22 boys with ADHD and 22 boys without ADHD. All participants were between the ages of 10 and 14. The boys with ADHD demonstrated deficits on two visual-spatial tasks in relation to normal controls. Children without ADHD out performed children with ADHD on a mental rotation task. In addition, the control group showed greater improvement between test and retest than the group with ADHD on the Spatial Relations subtest of the Woodcock-Johnson Psycho-Educational Battery-Revised (Woodcock & Johnson, 1989). These results provide support for the theory that ADHD involves right parietal dysfunction.

All of these findings suggest that there is a neurobiological basis to the behavioral and cognitive deficits observed individuals with ADHD. Extensive evidence has implicated the prefrontal cortex, the caudate nucleus, dopaminergic systems, and norepinepherinergic systems. However, evidence that many of the other neurobiological mechanisms underlying attention are involved in ADHD is lacking. Future research into the neurobiological basis of ADHD should attempt to determine the nature of the role of other attentional mechanisms in ADHD. This line of research could have extremely important implications for ADHD theory and ADHD subtyping.

Evidence Concerning ADHD Subtypes

Individuals with ADHD comprise a heterogeneous group. This makes research examining the ADHD subtypes extremely important, particularly if one posits that differential diagnosis may lead to differential treatment. It has been hypothesized that attention problems with hyperactivity and attention problems without hyperactivity are the result of distinct syndromes (Lahey et al., 1984). Research examining subtype differences in ADHD and ADD has been conducted in the areas of electrophysiological activity, neuropsychological functioning, behavioral functioning, psychiatric comorbidity, and academic performance. This section reviews the results of research that examines possible attentional differences between the ADHD subtypes.

Clarke and colleagues (1998) compared the electrophysiological activity in individuals diagnosed with ADHD-CT and ADHD-PI using EEG during an eyes closed resting condition. While both groups were found to have greater levels of theta (slow wave) activity and deficiencies in alpha and beta (fast wave) activity when compared to normal controls, the ADHD-CT also showed significant differences from the ADHD-PI group. Furthermore, the ADHD -PI group was more similar to controls in levels of theta, alpha, and beta activity than the ADHD-CT group. These results suggest that ADHD-CT may be associated with greater levels of slow wave activity and less fast wave activity than ADHD-PI.

Another study examined EEG activity in subjects with ADHD-CT and ADHD-PI during an eyes open condition, an eyes closed condition, and while completing the Test of Variables of Attention (TOVA). Both groups exhibited excessive slow wave activity when compared to normal controls. However, most of the significant differences were between the ADHD-PI group and normal controls. The two ADHD groups did not significantly differ (Stewart, 1998). While such studies demonstrate that people with ADHD have greater levels of slow wave activity than normal controls, results of studies examining subtype differences in electrophysiological activity are inconsistent.

Sergeant and Scholten (1985) found attentional differences between subjects with ADD/H and subjects with ADD/WO using a high-speed visual search task. The task required subjects to respond with their preferred hand to the presence of a target stimulus among several visual stimuli. Subjects were instructed to respond to the absence of target stimuli with their non-preferred hand. Subjects with ADD/H did not significantly differ from the control group in rate of search. However, the ADD/WO group had a significantly slower search rate than the ADD/H group and controls. This could indicate that individuals with ADD/WO have a deficit in selective attention that is not found in ADD/H (Sergeant & Scholten, 1985).

Research conducted by Trommer et al. (1988) using the Go-No-Go Paradigm also provides tentative support for the theory that ADD/WO involves greater impairment in selective attention than ADD/H. The Go-No-Go Paradigm requires examinees to emit a motor response to a specific stimulus while not responding to other stimuli. Trommer and colleagues examined omission errors in addition to commission errors. Though there were not enough omission errors committed to allow for statistical significance, the ADD/WO group made more omission errors than the ADD/H and control groups (Trommer et al., 1988). This suggests that people with ADD/WO may have a deficit in selective attention that distinguishes them from people with ADD/H (Goodyear and Hynd, 1992).

Another study indicating that people with ADD/WO may have a deficit in selective attention used the Continuous Performance Test (CPT). The CPT is a vigilance test in which numbers are displayed on a computer screen at the rate of one per second. Subjects are required to respond to target numbers. Barkley et al. (1990) used the CPT to compare subjects with ADD with and without hyperactivity. Both ADD groups displayed impaired performance on the CPT. However, behavioral observations of subjects taking the CPT suggested that subjects with ADD/WO may have more problems with focused or selective attention while subjects with ADD/H may have more difficulty with sustained attention and impulsivity (Barkley et al., 1990). The CPT employed in this study did not allow for an error analysis that could confirm these observations (Barkley et al., 1990).

The results of another study that used the CPT also suggest that people with ADD/WO have unique attentional deficits which do not occur in ADD/H (Barkley & Grodzinsky, 1994). In this study a distinction between errors of omission and errors of commission was made. Errors of omission occur when subjects fail to respond to a target stimulus. Though a small sample size precluded statistical significance, the ADD/WO group made more errors of omission than the ADD/H and control groups (Barkley & Grodzinsky, 1994). These results suggest the possible existence of a deficit in focused attention in people with ADD/WO but not in those with ADD/H (Barkley & Grodzinsky, 1994). Such findings are consistent with the theories of ADHD proposed by both Barkley (1997) and Schaugency and Hynd (1989).

Slow cognitive tempo is one behavioral phenomenon that has been associated with attentional dysfunction. The symptoms of slow cognitive tempo include daydreaming, being “lost in a fog”, being easily confused, staring frequently, and being hypoactive (Barkley, 1997). Differences in cognitive tempo could indicate that ADHD-PI and ADHD-CT involve unique attentional impairments (Lahey et al., 1984).

Several studies have shown that children with ADD/WO display more symptoms of slow cognitive tempo than children with ADD/H. Lahey et al. (1988) performed a factor analysis and cluster analysis of the symptoms of ADD to determine what factors tend to go together. Using teacher ratings on the SNAP Checklist and clinician ratings on 20 attention descriptors it was determined that there are three primary behavioral factors associated with ADHD. These factors were labeled motor hyperactivity/impulsivity, inattention/disorganization, and sluggish tempo (Lahey et al., 1988). A cluster analysis revealed that children with ADD/WO were high on the sluggish tempo factor while non-diagnosed children and children with ADD/H tended to be low on this factor (Lahey et al., 1988). Other studies have found similar differences in cognitive tempo between the ADD subtypes (Lahey et al., 1985; Lahey et al., 1987; Barkley et al., 1990). One weakness of all of these studies was that only children 13 years old and younger were included in their samples. Even so, these results demonstrate the utility and importance of subtyping ADD.

One study that examined the ADHD subtypes also suggests that there are differences in cognitive tempo between hyperactive and non-hyperactive children with attention deficits (Skansgaard & Burns, 1998). Skansgaard and Burns (1998) found that teachers rated children with ADHD-PI as displaying more symptoms of slow cognitive tempo than children with ADHD-CT and children from a control group. Skansgaard and Burns (1998) also used the Achenbach Direct Observation Form (DOF) as a measure of slow cognitive tempo. The ADHD-PI group displayed more symptoms of slow cognitive tempo than a control group according to observer ratings on the DOF. However, the ADHD-CT group was not significantly different from ADHD-PI group or the control group. Small sample size (N=24) could explain these findings (Skansgaard & Burns, 1998). However, it remains unclear whether or not subtypes differences in cognitive tempo can be detected using direct structured observations.

Research on ADHD and ADD subtype differences in attentional functioning and behavioral indicators of slow cognitive tempo provide an indication that ADHD subtypes may involve different types of attentional deficits. However, such research is far from conclusive. Future studies should examine attentional and behavioral factors that are highly specific in order to determine if the ADHD subtypes involve distinct attentional deficits. By examining specific aspects of attention and specific behavioral indicators of the various types of attentional processing researchers could greatly expand our understanding of developmental disorders of attention.

Summary and Conclusions

Several neurobiological mechanisms are involved in attentional processing. They include the reticular formation, the PFC, the cingulate gyrus, the inferior parietal lobule, the basal ganglia, the cerebellum, the thalamus, the dopaminergic system, and the norepinepherinergic system. Each of these mechanisms plays a distinct role in attentional processes. Research has provided extensive evidence that the PFC, the basal ganglia, the dopaminergic system, and the norepinepherinergic system are involved in the deficits associated with ADHD. However, other attentional mechanisms have not been studied extensively in populations with ADHD. It seems likely that some or all of these mechanisms play a role in the behavioral symptomology of ADHD. Research intended to examine the functioning of these mechanisms in populations with ADHD would greatly enhance our understanding of the attentional deficits associated with ADHD.

People with ADHD display a wide variety of symptomology. For this reason subtyping of ADHD is very important. It has been hypothesized that attention problems with hyperactivity and attention problems without hyperactivity may be the result of distinct syndromes (Lahey et al., 1984). Some studies have supported this notion. However, much more research is needed in this area. Studies examining specific types of attentional processing in ADHD and the ADHD subtypes would be particularly useful. Barkley (1997) and others have hypothesized that the subtypes of ADHD may be associated with different types of attentional deficits. Unfortunately this hypothesis goes largely untested. A better knowledge of the various types of attentional dysfunction associated with ADHD and the ADHD subtypes would improve our ability to diagnose and treat the disorder. Subtyping of ADHD based of the types of attention deficits present (i.e. selective, sustained, and focused attention) in addition to the presence/absence of hyperactivity and impulsivity would likely prove quite useful in behavioral, cognitive, and pharmacological treatment and research.

The theories of Barkley (1997) and Schaugency and Hynd (1989) are both supported by research examining the neurobiological basis of ADHD. However, research testing the hypothesis that dysfunction of posterior systems is an important factor in ADHD is much more sparse at this time than research examining the role of frontal systems in ADHD. Future efforts to understand the neurobiological basis of ADHD should focus on posterior systems in addition to frontal systems. Current research on ADHD and ADD has focused almost exclusively on impulse control, executive functioning, behavioral disinhibition, and sustained attention. While this line of research is crucial to understanding the etiology of ADHD, research on other aspects of attention such as selective attention and focused attention is equally important.

Statement of the Problem

The present study is designed to extend the research examining the hypothesis that the ADHD-PI and ADHD-CT subtypes are associated with unique attentional deficits. It has been well demonstrated in the research literature that people with ADHD exhibit deficits in various aspects of attentional processing. While there is evidence suggesting that the ADHD-PI and ADHD-CT subtypes may involve unique attentional deficits, research on possible subtype differences in attentional capability is far from conclusive.

Five primary aspects of attention will be examined in the current study. Attentional variables will include neuropsychological tests that are believed to measure (1) the response activation aspect of attention, (2) sustained attention, (3) the encoding/working memory aspect of attention, (4) the focus/execute aspect of attention, and (5) attentional stability. Examining these attentional processes could help to provide a better theoretical understanding of the unique deficits that may underlie the ADHD-PI and ADHD-CT subtypes. It could also help to further bridge the gap between cognitive/neuropsychological theories of attention and theories regarding the underlying deficits in ADHD.

The construct of the activating system of attention is based on the work of Tucker and Williamson (1984). The activating system is a central feature in the theory of attention espoused by Schaugency and Hynd (1989). It is a hypothetical neurological system that is responsible for maintaining a readiness to respond motorically to stimuli. Schaugency and Hynd (1989) hypothesized that children with inattention and hyperactivity have a dysfunction of the activating system that causes them to behave impulsively and be overactive. The activating system is believed to be a function of prefrontal structures. This notion is consistent with Barkley's (1997) theory of ADHD-CT which posits that behavioral inhibition is the key deficit in ADHD-CT. Based on these theories, it seems possible that ADHD-CT may involve an over-responsiveness to stimuli that is not found in ADHD-PI.

The construct of sustained attention has been posited by a number of theorists and is defined as the ability to maintain attentional focus over an extended period of time. The ability to sustain attention appears to be a function of midbrain structures, particularly the reticular formation, and the superior temporal sulcus (Heilman et al., 1993; Kinomura et al., 1996; Mirsky et al., 1999; Munk et al., 1996). It has been hypothesized that children with ADD/H or ADHD-CT have more significant deficits in sustained attention than children with ADD/WO or ADHD-PI (Barkley et al., 1990; Barkley, 1997).

The encoding aspect of attention was proposed by Mirsky and colleagues (1995; 1999) and is highly similar to the construct of working memory. Encoding/working memory is the ability to hold information briefly in mind while performing a cognitive operation on it. Research indicates that limbic structures including the hippocampus and amygdala are largely responsible for the encoding/working memory aspect of attention (Mirsky et al., 1995; Mirsky et al., 1999). Barkley (1997) theorized that ADHD-CT involves unique deficits in working memory that may not be found in ADHD-PI. While it remains unclear whether or not the ADHD subtypes have group differences in encoding/working memory, such differences have been hypothesized.

The focus/execute aspect of attention was also proposed by Mirsky and colleagues (1995; 1999) and is defined as the ability to concentrate attention on a specific task while screening out distracting stimuli. This construct has considerable overlap with what Posner and Peterson (1990) refer to as the orienting aspect of attention (Mirsky, 1996). Research suggests that structures such as the superior temporal gyrus, the inferior parietal cortex, and the corpus striatum play a crucial role in the focus/execute aspect of attention (Mirsky et al., 1999). According to the theory of Schaugency and Hynd (1989) ADHD without hyperactivity may involve a unique deficit in focused attention that is not found in ADHD-CT.

The construct of attentional stability was also proposed by Mirsky and colleagues (1995; 1999) and is defined as the ability to maintain a consistent response rhythm to stimuli. Attentional stability is a relatively new construct and has not been studied extensively. However, it has been hypothesized that the ADHD subtypes differ in their ability to maintain a consistent response rhythm to stimuli.

In summary, the goal of the present study is to provide information that may be helpful in determining whether or not the ADHD-PI and ADHD-CT subtypes are associated with unique attentional deficits. The specific attentional processes that will be examined include the response activation, the sustained, the encoding/working memory, the focus/execute, and the stability of aspects of attention. These constructs will be measured using data from the Test of Variables of Attention (TOVA) (Greenberg et al., 1996), the Children’s Memory Scale (CMS) (Cohen, 1997), and the Wechsler Intelligence Scale for Children-Third Edition (WISC-III) (Wechsler, 1991).

The following five hypotheses are examined in the current study. (1) Children with ADHD-CT have a tendency to over-respond on measures of response activation as measured by the TOVA Response Time and Commission Errors scores when compared to children with ADHD-PI. (2) Children with ADHD-CT tend to display more significant deficits in sustained attention as measured by the TOVA 3rd and 4th Quarter Omissions scores when compared to children with ADHD-PI. (3) Children with ADHD-CT tend to display deficits in encoding/working memory as measured by the CMS Numbers Backward and Sequences subtests that are not characteristic of children with ADHD-PI. (4) Children with ADHD-PI have less capacity for focusing/executing attention as measured by the WISC-III Symbol Search and Coding subtests than children with ADHD-CT. (5) The ADHD subtypes differ in their capacity for maintaining a consistent response rhythm when responding to stimuli (attentional stability) as measured by the TOVA Response Variability score.

CHAPTER 3

METHOD

This chapter provides an overview of the research methods used in the present study. Participants, measures, procedures, and approach to data analysis are discussed.

Participants

Participants were selected from a clinical population referred to the Pediatric Neuropsychology Service in the Department of Neurology at the Medical College of Georgia (MCG), Augusta. This clinic provides neuropsychological assessment and recommendations for children with epilepsy, traumatic brain injury (TBI), learning problems, attentional difficulties, and other neurological syndromes. Research data are kept for children who receive neuropsychological evaluations at the Pediatric Neuropsychology Service at MCG. Based on the results of such evaluations children were selected for the present study based on the specific guidelines that are outlined below.

All participants met the DSM-IV criteria for a diagnosis of ADHD Predominately Inattentive Type or Combined Type. Diagnoses at the Pediatric Neuropsychology Service (PNS) at MCG are made in concert by a student clinician or a psychometrician and a licensed child neuropsychologist. Children with epilepsy, TBI, and other documented neurological insult/symptomology were excluded from the present sample. Children with diagnoses of ADHD comorbid with other comorbid Behavior and Emotional Disorders were also excluded. Diagnoses were made based on information from The Behavior Assessment Scale For Children-Teacher Rating Scale (Reynolds and Kamphaus, 1992), The Behavior Assessment Scale For Children-Parent Rating Scale (Reynolds and Kamphaus, 1992), Conners' Parent Rating Scale-Revised (Conners, 1997), the DSM-IV criteria for ADHD, a case history, and a clinical interview. All participants were between the ages of 6 years 0 months and 12 years 11 months at the time they were evaluated. Finally, it is important to note that while many of the children were evaluated with two or more of the measures of interest and were included in two or more analyses, the groups used for the analysis of Test of Variables of Attention (TOVA) data, the groups used for the analysis of Children's Memory Scale (CMS) data, and the groups used for the analysis of the Wechsler Intelligence Scale for Children-Third Edition (WISC-III) data did not completely overlap. Table 1 presents the number of participants who were assessed using each of these measures.

Instruments

Test of Variables of Attention (TOVA)

The TOVA (Greenberg et al., 1996) is a computerized continuous performance task (CPT) in which visual stimuli are presented on a computer screen. The visual stimuli consist of colored squares that contain smaller squares that are adjacent to either the top or bottom edges of the larger squares. Subjects are instructed to respond by pressing a microswitch as quickly as possible after a presentation of the target stimulus (the small square is adjacent to the top edge of the large square) is presented. Stimuli are presented for 100 milliseconds every two seconds for 20 minutes. During the first 10 minutes the target stimulus is presented on 22.5% of trials. During the second 10 minutes the target stimulus is presented on 77.5% of trials. These varying ratios allow for the effects of different response demands on attention and impulsivity to be examined (Greenberg & Waldman, 1993). The TOVA provides standard scores that describe performance on each quarter of the test as well as overall standard scores. This allows for analysis of the effects of practice and fatigue on attention and impulsivity.

There are four primary indices that can be obtained from the TOVA. They include omission errors, commission errors, mean response time for correct responses, and response variability. Omission errors are failure to respond to the target stimuli. Conversely, commission errors are a response to non-target stimuli. Standard scores are reported for each of these four indices. Greenberg and Waldman (1993) reported the standard error of measurement for each of the four index scores of the TOVA. On the first half of the TOVA, when target stimuli are presented on 22.5% of trials, the SEM is 2.34 for Omission Errors, 0.93 for Commission Errors, 31.83 for Response Time (in milliseconds), and 42.62 for Response Variability (in milliseconds) for the first half of the TOVA. The SEM is 1.31 for Omission Errors, 6.78 for Commission Errors, 36.30 for Response Time (in milliseconds), and 22.87 for Response Variability (in milliseconds) on the second half of the TOVA when target stimuli are presented on 77.5% of trials. It is important to note that a good deal of measurement error is associated with many of the scores provided by the TOVA.

Findings from a test-retest reliability study conducted by Greenberg and Waldman (1993) indicated that the test-retest correlation for omission errors is only .14. The authors suggested that this might be due to the relative rarity of omission errors. Test-retest correlations were found to be much higher for commission errors (.5) and for response time mean and variability (.8).

Another reliability study of the TOVA found high levels of internal consistency for many of the scores provided by the TOVA (Leark et al., 1996). Leark and colleagues (1996) found internal consistency coefficients of .70-.99 for omission errors, .79-.82 for commission errors, .93-.99 for response time, and .70-.99 for response time variability. Llorente and colleagues (2000) also studied the reliability of the scores provided by the TOVA. They found a test-retest reliability of .51 to .61 for omission errors. This finding suggests that the omission error score on the TOVA may be far more reliable than originally suggested by Greenberg and Waldman (1993). Llorente and colleagues (2000) also found test retest reliabilities of .58-.71 for commission errors, .70-.82 for response time, and .66-.75 for response time variability.

CPT's have been used to study attentional variables by many researchers. Studies by many authors have demonstrated that CPT's can be useful in distinguishing between children with ADHD and children without ADHD (Barkley et al., 1990; Klee & Garfinkel,

TABLE 1

Number of Participants Assessed With Each Measure*

Measures	Total	ADHD-CT	ADHD-PI
TOVA	47	22	25
CMS	65	30	35
WISC-III	47	22	25

*Number of participants

1983; Nuechterlein, 1983; Voeller, 1991). Results of a normative study for 775 children between the ages of 6 and 16 indicated that the TOVA is sensitive to attentional functioning and impulsivity (Greenberg & Waldman, 1993). Finally, Leark and colleagues (1996) also helped to demonstrate the construct validity of the TOVA with factor analytic data. By analyzing the various scores provided be the TOVA they found three factors that suggested the TOVA measures attention, disinhibition, and reaction time.

Because continuous performance tasks such as the TOVA have been demonstrated to be sensitive to the effects of stimulant medication (Greenberg, 1987; Hastings & Barkley, 1978), all children who were assessed using the TOVA were off medication when they completed the TOVA. Furthermore, the TOVA was administered to all participants prior to 12:00 p.m. in accordance with the normative data collected on the TOVA.

Riccio and colleagues (2001) recently published an in depth review of the literature on continuous performance tests including the TOVA. They cite evidence that continuous performance tests have strong relationships with other measures of attention and executive control as well as with behavioral rating scales. While such data supports the ecological validity of the continuous performance tests such as the TOVA, research also suggests that continuous performance tests are unable to accurately differentiate clinical samples (Riccio et al., 2001). Such data led Riccio and colleagues (2001) to conclude that while continuous performance tests do not distinguish between specific disorders they still can be useful in assessing disruptions of attention and executive control.

Mirsky and colleagues (1999) did not use the TOVA itself but used a nonpublished test called the Continuous Performance Test (CPT) that is very similar in nature to the TOVA. As previously discussed, Mirsky and colleagues (1999) found that various scores provided by the CPT loaded on several factors with other measures believed to reflect different aspects of attentional processing. In their study CPT scores similar to those provided by the TOVA loaded on the factors they named the *sustain* and *stability* aspects of attention. Thus, TOVA scores were used as measures of sustained attention and attentional stability in the present research as well as to assess response activation since research has demonstrated that the TOVA also measures reaction time (Leark et al., 1996).

Children's Memory Scale (CMS)

The CMS (Cohen, 1997) is a comprehensive test of memory ability comprised of 15 subtests that assess immediate and delayed auditory memory, immediate and delayed visual memory, and attention/concentration (Cohen, 1997). The subtests that are purported to measure attention/concentration were of particular interest in the present study. They include the Numbers and Sequences subtests (Cohen, 1997). Scores from the Numbers and Sequences subtests are used to determine the Attention/Concentration Index (ACI). The administration procedure of these subtests, as well as information on the reliability and validity of the Numbers and Sequences subtests and the ACI are discussed in this section.

The Numbers subtest requires examinees to repeat number strings immediately after they are read by the examiner, and then to say other number strings in reverse order immediately after the examiner reads them. Administration procedures for the Numbers subtest are the same as the procedures for administering the Digit Span subtest of the WISC-III (Wechsler, 1991). The key difference between the Numbers subtest and the Digit Span subtest is that separate norms are provided for the forward and backward portions of Numbers but not for Digit Span.

The Sequences subtest requires examinees to mentally manipulate and sequence verbal information as quickly as possible. Information is presented in the auditory modality. Items on this subtest include various tasks such as counting backwards from 20 to 1, saying the months of the year in order, and saying the months of the year in reverse order.

The ACI has an equivalent halves reliability coefficient of .87 (Cohen, 1997). The test-retest stability coefficient is .85 for children age 5 to 8 and .89 for children 9 to 12 (Cohen, 1997). With regard to validity, the subtests composing the ACI formed an independent factor that was distinct from verbal/auditory memory and visual/spatial memory. Furthermore, Cohen (1997) reported that the ACI has a high correlation (r=.73) with the Freedom From Distractibility Index (FFD) of the WISC-III (Wechsler, 1991). Research has indicated that the FFD may measure working memory (Cohen et al., 1990; Hynd et al., 1998). Riccio and colleagues (1997) found a significant association between the FFD factor and several measures of working memory. Thus, the moderate to strong association between the FFD and the ACI support the validity of the subtests that comprise the ACI as measures of working memory/encoding. Finally, while Mirsky and colleagues (1999) did not include the CMS variables in their factor analysis of attentional variables, they did include the adult versions of the subtests (Digit Span and Arithmetic) that comprise the FFD of the WISC-III. Thus, the Numbers and Sequences subtests from the CMS are used a measures of encoding/working memory.

Wechsler Intelligence Scale for Children-Third Edition (WISC-III)

The WISC-III (Wechsler, 1991) is a comprehensive intelligence test that provides a measure of general intelligence as well as several factors of intelligence. Two WISC-III subtests, Coding and Symbol Search, were used as dependent variables in the current study. The Symbol Search subtest is a supplemental subtest that is not normally used when calculating a person's intelligence. It combines with the Coding subtest to form the Processing Speed Index of the WISC-III. The Symbol Search subtest has an average reliability of .76 across age groups while the reliability of the Coding subtest has an average reliability of .79 across age groups (Wechsler, 1991).

During the Coding subtest participants are required to copy simple symbols that are paired with either geometric shapes (ages 6-7) or single digit numbers (ages 8-16). Using a key the participant writes each symbol under the corresponding shape or number. The participant's raw score is based on the number of symbols correctly drawn within a two-minute time period. During the Symbol Search subtest participants are required to visually scan two groups of symbols. The first group of symbols consists of either one (ages 6-7) or two (ages 8-16) target symbols. A participant indicates by marking a box labeled

“YES” or a box labeled “NO” whether or not the second group of symbols contains the target symbol(s). Like the Coding subtest, the Symbol Search has a two-minute time limit. A person’s raw score is calculated by subtracting the number of items completed incorrectly from the number of items they completed correctly.

Mirsky and colleagues (1999) used subtests from the Wechsler Adult Intelligence Scale-Revised (WAIS-R) (1981) in their factor analysis of measures of attention. The WAIS-R is an adult intelligence test that is quite similar to the WISC-III. The WAIS-R contains a subtest called Digit-Symbol Substitution, an adult version of the Coding subtest. Mirsky and colleagues (1999) found that Digit-Symbol Substitution loaded the *Focus/Execute* factor. There is not a subtest comparable to the Symbol Search subtest on the WAIS-II. However, symbol search is similar in nature to Coding and several of the other tests that load on Mirsky and colleagues’ (1999) *Focus/Execute* factor. Symbol Search and Coding have a correlation of .53 across age ranges (Wechsler, 1991). For these reasons the Symbol Search and Coding subtests were used as measures of the focus/execute aspect of attention in the current study.

Measures of Response Activation

Response activation was assessed using data on commission errors and response time from the TOVA. Commission errors are incorrect responses to non-target stimuli and are considered to be sensitive to impulsivity (Greenberg et al., 1996). Response activation is the function of a hypothetical neurological system (the activating system) which is responsible for maintaining a readiness to respond motorically to stimuli. It has been hypothesized that children who have attention problems with hyperactivity have a dysfunction of the activating system that is not present in non-hyperactive children with attention problems and causes them to behave impulsively and be overactive (Schaugency and Hynd 1989). The present study tested this hypothesis by statistical analysis of possible group differences in the Commission Errors and Response Time Standard Scores from the TOVA.

Measures of Sustained Attention

Ability to sustain attention was also assessed using variables from the TOVA. Sustained attention is the ability to maintain attention on a stimulus or stimuli over an extended period of time. As previously mentioned, standard scores on the TOVA are provided for four intervals (five minute each). Sustained attention was assessed using the Omission Errors Standard Score from the third and fourth time quadrants. It has been hypothesized that children with ADD/H or ADHD-PI have more significant deficits in sustained attention than children with ADD/WO or ADHD-PI (Barkley et al., 1990; Barkley, 1997). The third and fourth quarter TOVA scores were used to test this hypothesis.

Measures of Encoding/Working Memory

Encoding/working memory ability was assessed using the Numbers Backward and Sequences subtests from the CMS. Encoding/working memory is the ability to hold information briefly in mind while performing a cognitive operation on it. The Numbers Backward and Sequences subtests are auditory measures of encoding/working memory (Cohen, 1997). Barkley (1997) theorized that ADHD-CT involves unique deficits in working memory. Numbers Backward and Sequences Scaled Scores were converted to standard scores and used to test the hypothesis that the ADHD-CT and ADHD-PI differ in their capacity for encoding/working memory.

Measures of Focus/Execute

The focus/execute aspect of attention was assessed using the Coding and Symbol Search subtests of the WISC-III. The focus/execute aspect of attention is the ability to concentrate attention on a specific task while screening out distracting stimuli. Coding and Symbol Search both require concentration on visual stimuli and are similar to the measures Mirsky and colleagues (1999) found to reflect the focus/execute aspect of attention. Individuals with ADHD-PI have been theorized to have a unique deficit the ability to focus attention (Schaugency & Hynd, 1989). Scaled scores from the Coding and Symbol Search subtests were used to test the hypothesis that the ADHD-PI subtype has a deficit in ability to focus/execute attention that is not found in ADHD-CT.

Measure of Stability

The stability of attentional processing was measured using response variability data from the TOVA. The Response Variability Standard Score from the TOVA provides information on the stability of a subject's responses to stimuli. Attentional stability is the ability to maintain a regular, even response rhythm to stimuli over time (Mirsky et al., 1999). While little if any research on subtype differences in attentional stability has been reported, it is possible that the ADHD-PI and ADHD-CT subtypes may differ in their capacity for attentional stability. The Response Variability Standard Score from the TOVA was used to test this hypothesis.

Procedure

The data analyzed in the present study were collected from participants who were referred by a variety of health care professionals including neurologists, pediatricians, school psychologists, and psychiatrists. The parents or legal guardians of all participants signed an informed consent that gave permission to use the results of their child's evaluation for research purposes. The consent form that was used is in accordance with the requirements and guidelines of the Institutional Review Boards at The Medical College of Georgia and The University of Georgia. After consent was obtained children received a comprehensive neuropsychological evaluation and a clinical interview was conducted with their parent/guardian. Clinical diagnoses were then made based on the assessment results. Assessment results were also used as the dependent variables that were previously described. However, it is important to note that the dependent variables were not used as criteria for determining which ADHD subtype to diagnose.

Statistical Analyses

Preliminary Analyses

Preliminary statistical analyses were conducted in order to provide descriptive information pertaining to the composition of each group used to examine the independent variable (ADHD Subtype). Descriptive statistics were reported for six groups: children who were diagnosed with ADHD-PI and were evaluated using the TOVA, children who were diagnosed with ADHD-CT and were evaluated using the TOVA, children who were diagnosed with ADHD-PI and were evaluated using the CMS, children who were diagnosed with ADHD-CT and were evaluated using the CMS, children who were diagnosed with ADHD-PI and were evaluated using the WISC-III, and children who were diagnosed with ADHD-CT and were evaluated using the WISC-III. It is important to note that the data reported for groups assessed using the CMS was also reflective of the overall sample since all participants were administered the CMS. The data reported on each group included descriptive statistics for the demographic variables of age, gender, ethnicity, and socioeconomic status as well as tests for group differences. Correlations were reported for the relationships between SES and the dependent variables for both diagnostic groups. Descriptive statistics (mean and standard deviation) for the dependent variables were also provided for each group. In addition, Levene's Test for the Equality of Variances was computed for all dependent variables.

Analyses of Group Performance on Attentional Variables

One independent samples t-test and four Multivariate Analysis of Variance's (MANOVAs) were used to address the primary goal of the present research regarding attentional functioning in the ADHD subtypes. All five analyses had ADHD subtype (ADHD-CT or ADHD-PI) as an independent variable. The four MANOVAs used the following dependent variables to assess the specific attentional constructs as follows: (1) TOVA Response Time Standard Scores and TOVA Commission Errors Standard Scores were used as measures of response activation, (2) TOVA 3rd and 4th Quarter Omissions

Standard Scores were used as measures of sustained attention, (3) the CMS Numbers Backward and Sequences Standard Scores were used as measures of encoding/working memory, and (4) the WISC-III Coding and Symbol Search Scaled Scores were used as measures of the focus/execute aspect of attention. The t-test had the TOVA Response Variability Standard Score as a dependent variable and was used to assess the construct of attentional stability. The degrees of freedom, the F-statistics or t-statistics, the p-values, and a Partial Eta Squared were reported for each of the analyses.

Additional Analyses

In addition to analyses of the attentional variables, possible subtype differences in comorbid reading disability were examined. The rate of occurrence of each reading disability subtype (dysphonetic, dyseidetic, mixed, and graphomotor/frontal) in the overall sample and in each ADHD subtype was also analyzed using a Chi-Square Test of Homogeneity. Chi-Square and p values were reported.

CHAPTER 4

RESULTS

The statistical analysis of the participants' performance on the nine measures of attentional functioning (TOVA Commission Errors, TOVA Response Time, TOVA 3rd Quarter Omissions, TOVA 4th Quarter Omissions, CMS Numbers Backward, CMS Sequences, WISC-III Symbol Search, WISC-III Coding, and TOVA Response Variability) is the focus of this chapter. Descriptive statistics and tests for group differences on demographic variables as well as tests for the equality of the variances for the dependent variables are provided in the first section. The primary analyses, additional analyses, and post-hoc analyses are reported in the subsequent sections.

Preliminary Analyses

Preliminary analyses were conducted in order to investigate the magnitude of variance between the two ADHD subtypes with regard to age, gender, ethnicity, and socioeconomic status (SES) as described in the previous chapter. The mean ages and standard deviations for age for all three samples are presented in Table 2. Table 3 displays t-test results for age differences in the three samples. No significant group differences in age were found in any of the samples.

Gender, ethnicity, and SES were assessed using categorical variables. Therefore, means and standard deviations are not reported for these variables. Instead three separate Chi Square Tests of Independence were performed for gender, ethnicity, and SES. Table 4 presents the Chi Square results for the experimental groups analyzed using the CMS and for the overall sample. Significant group differences in SES were found (Chi-Square = 13.716; $p = .001$). Table 5 and Table 6 present the Chi Square results for the experimental groups analyzed using the TOVA and WISC-III respectively. No statistically significant group differences were found in the sample assessed using the TOVA.

TABLE 2

Means and Standard Deviations of Participant Age for the Experimental Groups*

Measures	ADHD-PI Mean (SD)	ADHD-CT Mean (SD)
CMS/Overall Sample	105.31 (22.94)	103.00 (18.17)
TOVA	108.92 (22.21)	110.64 (14.39)
WISC-III	107.54 (24.50)	103.32 (16.70)

*The mean age and standard deviation in months

TABLE 3

T-Test Results for Age in the Experimental Groups

Sample	df	t-statistic	p-value
CMS/Overall Sample	63	.445	.658
TOVA	45	-.310	.758
WISC-III	45	.723	.473

TABLE 4

Chi-Square Results for the Demographic Variables in the Overall Sample

Variable	df	Chi-Square	p-value
Sex	1	3.188	.074
Ethnicity	2	3.834	.147
SES	5	13.716	.001

TABLE 5

Chi-Square Results for the Demographic Variables in the TOVA Sample

Variable	df	Chi-Square	p-value
Sex	1	1.566	.211
Ethnicity	2	3.146	.207
SES	5	7.361	.195

TABLE 6

Chi-Square Results for the Demographic Variables in the WISC-III Sample

Variable	df	Chi-Square	p-value
Sex	1	1.427	.232
Ethnicity	2	4.763	.092
SES	5	17.311	.004

Significant group differences in SES were found in the sample assessed using the WISC-III (Chi-Square = 17.311; p = .004). The percent of participants in each SES category for the overall sample, the sample assessed using the TOVA, and the sample assessed using the WISC-III are presented in Table 7, Table 8, and Table 9 respectively. It is important to note that the participants assigned to the ADHD-PI group tended to have a higher SES than the participants assigned to the ADHD-CT group in the samples assessed using the CMS and the WISC-III.

Correlations between SES and the dependent variables were computed for the ADHD-PI and ADHD-CT groups. Table 10 presents the correlations and p-values for SES and all of the dependent variables for both diagnostic groups. The correlation between SES and the WISC-III Coding subtest was statistically significant in the ADHD-PI sample but not the ADHD-CT sample. Furthermore, the correlation between SES and the CMS Numbers Backward subtest was significant for the ADHD-CT group but not the ADHD-PI. Thus caution should be used when interpreting findings related to the WISC-III Coding and CMS Numbers Backwards subtests.

Means and standard deviations for all of the dependent variables are presented in Table 11. Levene's Test for Inequality of Variances was performed for all of the dependent variables. The results are summarized in Table 12. Two variables were found to have unequal variances among the experimental groups: TOVA Commission Errors (F = 4.848; p = .033) and TOVA 3rd Quarter Omissions (F = 5.627; p = .022). Alternate procedures were not used to analyze these variables because when sample sizes are close to equal in number adjustments need not be made for unequal variance (Huberty, 1994).

Primary Analyses

Nine neuropsychological measures believed to be associated with five aspects of attentional functioning were used in order to test several hypotheses regarding possible ADHD subtype differences. These hypotheses were tested using one t-test and four separate MANOVAs as outlined in the previous chapter. Table 13 contains a summary of

TABLE 7

Percent of Participants in Each SES Category for the Overall Sample*

SES Category	ADHD-PI	ADHD-CT
<$10,000	2.9	16.7
$10,000 – 20,000	2.9	10.0
$20,000 – 30,000	5.7	16.7
$30,000 – 40,000	8.6	13.3
$40,000 – 50,000	5.7	13.3
>$50,000	74.3	30.0

*Percentage

TABLE 8

Percent of Participants in Each SES Category for the TOVA Sample*

SES Category	ADHD-PI	ADHD-CT
<$10,000	0.0	9.1
$10,000 – 20,000	4.0	9.1
$20,000 – 30,000	4.0	13.6
$30,000 – 40,000	12.0	18.2
$40,000 – 50,000	8.0	13.6
>$50,000	72.0	36.6

*Percentage

TABLE 9

Percent of Participants in Each SES Category for the WISC-III Sample*

SES Category	ADHD-PI	ADHD-CT
<$10,000	0.0	16.0
$10,000 – 20,000	3.6	12.0
$20,000 – 30,000	3.6	20.0
$30,000 – 40,000	13.6	8.0
$40,000 – 50,000	3.6	16.0
>$50,000	78.6	28.0

*Percentage

TABLE 10

Correlations and P-Values for SES and the Dependent Variables

Dependent Variable	ADHD-PI Correlation (p-value)	ADHD-CT Correlation (p-value)
TOVA Commission Errors	.243 (.242)	-.181 (.421)
TOVA Response Time	-.214 (.304)	.223 (.319)
TOVA 3rd Quarter Omissions	-.267 (.197)	.034 (.881)
TOVA 4th Quarter Omissions	-.139 (.508)	.017 (.939)
CMS Numbers Backward	.261 (.135)	.366* (.047)
CMS Sequences	.153 (.396)	.170 (.369)
WISC-III Symbol Search	-.121 (.540)	.119 (.570)
WISC-III Coding	-.490* (.006)	-.064 (.760)
TOVA Response Variability	-.063 (.766)	-.170 (.450)

*Statistically Significant at the .05 level

TABLE 11

Means and Standard Deviations for the Dependent Variables

Variable	ADHD-PI Mean (SD)	ADHD-CT Mean (SD)
TOVA Commission Errors	96.20 (18.86)	85.77 (30.56)
TOVA Response Time	84.32 (20.58)	75.95 (15.90)
TOVA 3rd Quarter Omissions	77.64 (26.99)	83.32 (19.62)
TOVA 4th Quarter Omissions	75.84 (28.57)	72.77 (27.64)
CMS Numbers Backward	99.41 (16.04)	97.33 (19.11)
CMS Sequences	95.91 (14.71)	90.17 (14.71)
WISC-III Symbol Search	9.07 (3.72)	8.48 (3.62)
WISC-III Coding	9.07 (3.76)	9.08 (3.29)
TOVA Response Variability	75.16 (24.72)	65.68 (26.53)

TABLE 12

Levene's Test Results for the Dependent Variables

Variable	F	p-value
TOVA Commissions	4.848	.033
TOVA Response Time	1.053	.310
TOVA 3rd Quarter Omissions	5.627	.022
TOVA 4th Quarter Omissions	0.010	.921
CMS Numbers Backward	1.566	.215
CMS Sequences	0.050	.824
WISC-III Symbol Search	0.098	.755
WISC-III Coding	1.095	.300
TOVA Response Time Variability	0.505	.481

TABLE 13

Measures Reflecting Each Attentional Construct

Attentional Construct	Measure(s) Reflecting Construct
Response Activation	TOVA Commission Errors Standard Score
	TOVA Response Time Standard Score
Sustained Attention	TOVA 3rd Quarter Omissions Standard Score
	TOVA 4th Quarter Omissions Standard Score
Encoding/Working Memory	CMS Sequences Standard Score
	CMS Numbers Backward Standard Score
Focus/Execute	WISC-III Symbol Search Scaled Score
	WISC-III Coding Scaled Score
Stability	TOVA Response Variability Standard Score

the measures that were used to assess each attentional construct. The results of these analyses (degrees of freedom, t-score or F-score, and p-value) are reported in Table 14. No significant group differences were found on any of the variables. However, some variables had fairly large mean differences between the subtypes. These nonsignificant differences involved the TOVA Response Time, Commission Errors, and Response Variability variables. The mean Response Time standard score of the ADHD-PI group was 10.43 points higher than the mean for the ADHD-CT group. The mean Commission Errors standard score for the ADHD-PI group was 8.37 points higher for the ADHD-CT group. Finally, the mean Response Variability standard score of the ADHD-PI group was 9.48 points than that of the ADHD-CT group. Refer to Table 11 for the means and standard deviations of all dependent variables. Table 15 contains effect sizes for each of the primary analyses. While none of the findings were statistically significant, the differences on the Response Time and Commission Errors were clinically significant and are further discussed in the following chapter.

Additional Analyses

If the ADHD-CT and ADHD-PI subtypes are associated with different attentional deficits, then it is possible that their neuropsychological functioning in other areas may differ as well. Subtype differences in the neurobiological systems that underlie attention or differences in affinity for specific attentional processes themselves could impact neuropsychological functioning in other areas such as reading or language. The current study examines possible differences in the occurrence rate of reading disability between the ADHD-PI and ADHD-CT subtypes. These hypothetical differences were analyzed using a Chi Square Test of Homogeneity. An attempt was initially made to include five reading disability groups in this analysis: no reading disability, dysphonetic reading disability, dyseidetic reading disability, mixed reading disability, and graphomotor/frontal reading disability. However, there were not enough participants classified as having dyseidetic, mixed, and graphomotor/frontal reading disabilities to allow for such an analysis. For this

TABLE 14

T-Test and MANOVA Results for the Dependent Variables

Attentional Construct	df	t	F	p-value
Response Activation	1, 44	-	2.213	.121
Sustained Attention	1, 44	-	1.589	.216
Encoding/Working Memory	1, 59	-	1.375	.261
Focus/Execute	1, 44	-	.129	.879
Stability	45	1.267	-	.212

TABLE 15

Effect Sizes for the Primary Analyses

Attentional Construct	Partial Eta Squared
Response Activation	.121
Sustained Attention	.067
Encoding/Working Memory	.045
Focus/Execute	.006
Stability	.034

reason only three reading disability groups were used: no reading disability, dysphonetic reading disability, and other type of reading disability. The other reading disability group was made up of participants who were diagnosed with either dyseidetic, mixed, and graphomotor/frontal reading disabilities. No significant differences in the occurrence rate of reading disability between the ADHD subtypes were found (Chi-Square = 3.325; p-value = .198). The percent of participants in each experimental group that were classified in each reading disability subtype are presented in Table 16.

Post-Hoc Analyses

While no significant group differences were found between subtypes for any of the variables believed to reflect attentional processing, fairly large (though non-significant) differences were apparent on three of these variables (TOVA Response Time, Commission Errors, and Response Variability). Such differences may warrant further investigation (see the previous section containing the results of the primary analyses). Post-hoc analyses of the data were conducted in order to determine whether or not the three TOVA variables were related to other aspects of neuropsychological functioning in children with ADHD. Correlations with the TOVA Response Time, Commission Errors, and Response Variability scores were computed using the following measures: the Sentence Imitation subtest from the Detroit Tests of Learning Aptitude-Fourth Edition (DTLA-IV) (Hammill, 1998), the Concepts and Directions subtest from the Clinical Evaluation of Language Fundamentals-Third Edition (CELF-III) (Semel et al., 1995), the Reading subtest from the Wide Range Achievement Test-Third Edition (WRAT-3) (Wilkinson, 1993), the Attention scale from the Behavioral Assessment System for Children-Teacher Rating Scales (BASC-TRS) (Reynolds & Kamphaus, 1992), the Hyperactivity scale from the BASC-TRS, teacher ratings on the Attention scale from the DSM-IV Symptom Checklist, and teacher ratings on the Hyperactivity scale from the DSM-IV Symptom Checklist. DSM-IV Symptom Checklist is an unpublished Likert scale. This scale uses the DSM-IV symptoms of ADHD with the permission of the American Psychiatric Association. Standard scores were

TABLE 16

Percentage of Participants in Each Subtype Diagnosed with a Reading Disability (RD)*

Subtype	No RD	Dysphonetic RD	Other RD
ADHD-PI	74.3	20.0	5.7
ADHD-CT	66.7	13.3	20.0

*Percentage of participants in each subtype used for the DTLA-IV, CELF-III, WRAT-3, and BASC variables while raw scores were used for the DSM-IV Symptom Checklist variables.

None of the correlations between the three TOVA variables and the other neuropsychological variables were found to be statistically significant. Table 17 presents the correlations between the selected TOVA variables and the other variables of interest.

TABLE 17

Correlations for Selected TOVA Variables and Other Neuropsychological Measures*

	Response Time	Commission Errors	Response Variability
Sentence Imitation	-.019	.064	-.181
Concepts and Directions	.091	.147	.036
WRAT-3 Reading	-.030	.227	-.061
BASC-TRS Attention	-.118	-.120	-.051
BASC-TRS Hyperactivity	.083	-.100	.150
DSM-IV Attention	.018	-.154	-.021
DSM-IV Hyperactivity	.018	-.275	-.032

*Correlations

CHAPTER 5

DISCUSSION

Attentional processes and the neurological substrates of attention have been the focus of a wide variety of research that has utilized diverse methodologies. This research has demonstrated that attention is an extremely complex construct that consists of many component processes and is the result of a wide variety of neurobiological mechanisms. Such research has been the basis for several cognitive theories of attention that outline a number of attentional processes. In an attempt to apply the constructs from these theories of attention to the study of ADHD researchers such as Barkley (1997) and Schaugency and Hynd (1989) have theorized that the subtypes of ADHD may be associated with different types of attentional deficits.

Individuals with ADHD compromise a heterogeneous group with a variety of social and behavioral characteristics. This makes the subtyping of the ADHD syndrome extremely important. Research suggests that failure to diagnose and study subtypes of ADHD could result in confounded clinical and research populations (Hynd et al., 1991). Under the current system for diagnosis of ADHD no distinction is made between attentional processes. Distinctions between the ADHD subtypes are based solely on the presence or absence of the symptoms of hyperactivity/impulsivity and/or inattention. While some studies have attempted to examine other possible subtype differences in the various attentional processes, the research literature in this area is lacking.

The current study was an attempt to examine possible differences in attentional functioning between two of the ADHD subtypes: ADHD-PI and ADHD-CT. Neuropsychological measures believed to reflect five different attentional processes were used. The attentional processes of interest included response activation, sustained attention, encoding/working memory, the focus/execute aspect of attention, and stability of attention. If subtype differences in these attentional processes could be found they might be indicative of neurobiological differences between the ADHD subtypes. Such findings could have a major impact on how we diagnose and treat the symptoms of ADHD.

As reported in the previous chapter, the ADHD-PI and ADHD-CT subtypes did not differ significantly on any of the attentional measures. Such results do not provide support for the notion that the ADHD subtypes differ in the types of attentional deficits they display. Both ADHD subtypes performed in the average range on all of the measures associated with the encoding/working memory and focus/execute aspects of attention suggesting that these types of attentional processing may not be deficient in either the ADHD-PI or ADHD-CT subtypes. Furthermore, such results do not support Barkley's (1997) assertion that deficits in working memory are an underlying factor in the behavioral phenomena associated with ADHD-CT.

Both ADHD subtypes were found to have below average scores on TOVA 3rd Quarter and 4th Quarter Omissions. This suggests that while they do not differ in their ability to sustain attention both groups are impaired in this area. Thus the present data support the assertion that sustained attention may be an important area of deficit in both the ADHD-PI and ADHD-CT subtypes. However, Barkley's (1997) assertion that ADHD-CT involves a unique deficit in sustained attention that is more significant than any deficits in sustained attention that may be associated with ADHD-PI is not supported by the present data.

As reported in the previous chapter, there were fairly large yet nonsignificant differences on the two variables believed to reflect the response activation. The ADHD-PI group slightly outperformed the ADHD-CT group on both measures of response activation (TOVA Commission Errors and TOVA Response Time). The mean performance of the ADHD-PI was in the average range on both of these measures. The mean performance of the ADHD-CT group was in the low average to slightly below average range for TOVA Commission Errors and below average for TOVA Response Time. While not a statistically significant finding, these results demonstrate the need to further test Schaugency and

Hynd's theory (1989) that ADHD-CT may be associated with greater problems in response activation than is found in ADHD-PI. Any future research providing support for Schaugency and Hynd's theory would also be consistent with Barkley's (1997) theory of ADHD. However, it is important to note that in the current study the within group variance was greater than the differences between the diagnostic groups on both variables associated with response activation. Thus, the present data provide no firm support for hypothesis that the ADHD subtypes differ in their capacity for response activation.

Another fairly large yet nonsignificant difference emerged for TOVA Response Variability. While both groups performed well below average, the ADHD-PI group outperformed ADHD-CT group. Such results suggest that both the ADHD-PI and ADHD-CT subtypes are associated with deficits in the stability aspect of attention. Though the difference was not statistically significant, the mean performance of the ADHD-CT was somewhat lower in this area than the ADHD-PI group. However it is important to note that while such mean differences emerged for the variables associated with the stability aspect of attention, such differences were less than the variability of performance found within each diagnostic group and do not provide convincing evidence of subtype differences in attentional processing. While such data do not provide convincing evidence for subtype differences in the stability aspect of attention, further research in this area would be useful in examining ADHD subtyping theory and the neurobiological factors that underlie attention.

As described in the previous chapter, post-hoc analyses were attempted with the variables believed to reflect response activation and the stability aspect of attention. These analyses were designed in order to test the hypothesis that specific attentional processes might impact other specific aspects of the neuropsychological functioning of children with ADHD. None of the diagnostic groups based on response activation and attentional stability differed on any of the language or behavioral variables. Thus, the results of the post-hoc analyses do not support the previously mentioned hypothesis. While deficits in attentional processing likely impact other aspects of a person's neuropsychological functioning, it remains unclear whether specific attentional deficits relate to other specific aspects of neuropsychological functioning in children with ADHD.

In summary, no solid evidence for ADHD subtype differences in attentional processing is provided by the current study. While three nonsignificnat trends in the data were evident, no between group differences which were greater than the within group differences were found. However, the present data do clearly suggest that both ADHD subtypes involve deficits in sustained attention and attentional stability but appear not to involve deficits in the focus/execute and encoding/working memory aspects of attention. Furthermore, the present data provide a tentative indication that the ADHD-CT may also involve deficits in response activation. The remainder of this chapter discusses the weaknesses of the current study and how they may be corrected as well as possible directions for future research on individual differences in the symptomology associated with ADHD and ADHD subtyping.

Three key issues were problematic in the current study. First, subtype differences in SES were found to exist. Another weakness of the current study arose from the fact that many of the measures that are believed to reflect attentional processing have not been extensively validated as measures of specific attentional processes in children. A third weakness was the small sample size of the study and the fact that not all participants were evaluated using each measure. If possible these issues should be addressed in any future research.

Subtype differences in SES are rarely, if ever, noted in the research literature on ADHD. Thus, the subtype differences in SES were likely due to chance or were an artifact of a pattern in the referrals to the clinic from which provided the data for this study. No effort was made to control for group differences in SES in the present study because there were no statistically significant findings. Reanalysis of the data would have been conducted in order to control for SES had significant differences occurred between the experimental groups that differed on SES. However, when group differences on demographic variables occur researchers should always take this into consideration and make an effort to control for such issues when there are group differences on the dependent variables.

Future research on attentional processes in children must address the lack of research linking many of the measures that are used to assess attentional processing to specific attentional processes in children. In order to gain a more complete understanding of attentional processes in children, researchers must understand how different attentional processes and different measures of attention interrelate. Mirsky and colleagues (1999) and several other researchers have conducted research that helps to outline the various attentional processes in adults. Research that ties attentional processes to specific attentional measures in adult populations has also been provided (Mirsky et al., 1999). However, our knowledge of attentional processing in children is not as extensive. When studying the symptomology associated with ADHD it is important to view attentional processes from a developmental perspective. Until the research on the relationships between specific attentional processes and specific measures of attention is extended to child populations, it will be difficult to gain a clear understanding of the individual differences that exist in children with ADHD.

The relatively small sample size of the current study and the fact that all participants were not assessed using every dependent measure is also problematic. A larger sample in which all participants were assessed using each measure would have allowed for a better analysis of possible subtype differences in attentional processing. While the current sample allowed for an analysis of group differences in attentional processes more in depth analyses such as a cluster analysis would allow for a better understanding of how measures of attention and different attentional processes interrelate in children. Future studies should make an attempt not only to analyze possible differences in attentional processing but how specific attentional processes relate to and interact with one another in order to influence the cognitive and behavioral phenomena associated with ADHD and the various ADHD subtypes.

Another issue related to sample size is that children of widely varying ages had to be used in order to have enough participants to obtain the statistical power necessary to find possible subtype differences. Future research should attempt to use tighter age ranges when possible. This is important because many of the neurobiological systems and structures that underlie attention continue to develop throughout childhood and adolescence. Thus the relationship between measures that reflect attentional processing and other variables of interest may vary at different developmental levels Further research on the developmental aspects of attentional processing is necessary in order to gain a better understanding of the symptoms associated with ADHD and the ADHD subtypes as well as the factors that underlie these symptoms.

The constellation of symptoms associated with ADHD is impacted by a wide variety of underlying mechanisms. Furthermore, people with ADHD comprise a vastly heterogeneous group. For these reasons it is important to further our understanding of how the various neurobiological and cognitive factors that underlie attention interact to cause developmental attention problems. It is also important to understand the nature of individual differences in attentional processing among people diagnosed as having ADHD. Thus, subtyping is crucial to our understanding of ADHD and its behavioral and cognitive features.

No distinction is made between the various attentional processes under the current system for diagnosing and subtyping ADHD. Instead ADHD subtypes are based solely on the presence or absence of the symptoms of hyperactivity/impulsivity and/or inattention. Future research should attempt to further our understanding of how specific aspects of attentional processing vary among individuals with ADHD and to determine how such variance relates to variance in the behavioral symptomology of ADHD. Researchers should also attempt to determine whether or not patterns in the variance in specific aspects of attentional processing and behavioral symptomology are consistent with the current system for subtyping ADHD. If the later is not the case then it may be useful to add a mechanism for delineating between specific types of attentional processing deficits to current system of ADHD subtyping.

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