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Self-regulatory functions in ADHD children

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SELF-REGULATORY FUNCTIONS IN ADHD CHILDREN

by

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Abstract

SELF-REGULATORY FUNCTIONS IN ADHD CHILDREN

by

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The similarity between children with attention-deficit hyperactivity disorder (ADHD) and adult patients with frontal lobe lesions has led several investigators to posit that these children have impairments in "executive" or self-regulatory functions. Two experiments were conducted to test the hypotheses that 1) the ADHD symptom dimension of inattention in normal children would be correlated with measures of executive function, and 2) that ADHD children have impairments in executive functioning.

Experiment I evaluated 123 non-referred boys between the ages of seven and twelve years using standard measures of cognitive and academic functioning, as well as laboratory measures of inattention, impulsivity, overactivity and executive functioning. Executive functions were assessed using the Hand Movements subtest of the Kaufman Assessment Battery for Children, subtests from the Neurological Examination for Soft Signs, and a computerized version of Luria's competing motor programs test. Behavior ratings were also obtained from both parents and teachers. The results of Experiment I indicated that objectively-assessed inattention, but not impulsivity or overactivity, was

associated with measures of executive functioning. It was concluded that only a subset of ADHD children who manifest impairments attention, would be characterized by deficits in executive functioning.

Experiment II examined the relationship of attention to measures of executive function in a sample of 62 six to twelve year old boys who were referred to an urban child psychiatry outpatient clinic. The patients along with 18 normal controls were administered a similar test battery to that used in Experiment I. The patients were divided into ADHD and non-ADHD children. The ADHD children had significantly more difficulties on the competing motor programs test than either of the other groups. However, this decrement in performance could not be attributed to poor executive functioning. Rather, it appeared that the ADHD group had difficulties in the maintenance of effortful processing. The results are discussed in light of neuropsychological and cognitive models of executive/self-regulatory functioning.

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Introduction

Attention-deficit Hyperactivity disorder (ADHD) is the most frequently diagnosed child psychiatric disorder, affecting between 3 to 9 percent of all school age children (Anderson et al., 1987; Bird et al., 1988; Szatmari et al., 1989). ADHD children are referred to health care professionals due to problems with attention, impulse control and activity level. Associated difficulties include poor peer relations, impairments in the regulation, planning and organization of goal-directed behaviors, and difficulties with the initiation and inhibition of responses. While ADHD children have traditionally been grouped into a single diagnostic category, which allegedly captures the main symptomatology of the disorder, recent investigations have questioned the validity of ADHD as a unitary diagnosis. These children vary considerably with regard to presenting symptomatology, associated features, comorbidity, treatment response and long-term outcome (Barkley, 1990).

Approaches to understanding the impairments seen in ADHD children have been generated by researchers working within the domains of developmental neuropsychology and cognitive psychology. Developmental neuropsychologists have noted the similarity between the pattern of impairments seen

in ADHD children and the "executive function" deficits seen in adult patients with frontal lobe dysfunction (Becker, 1 Isaac & Hynd, 1987; Chelune, et al., 1986; Mattes, 1980; Welsh & Pennington, 1991). Similar to ADHD children, these adult patients frequently have difficulties with attention, behavioral inhibition and the regulation of behavior. Furthermore, the behavior of patients with frontal lobe lesions can be extremely variable and erratic. They are often socially inappropriate and frequently have trouble modulating their behaviors in response to task demands, often despite adequate comprehension of rules. Due to the behavioral similarities between ADHD children and adult patients with frontal lobe dysfunction, it has been suggested that these two groups share a common functional impairment. As such, several investigators have proposed that ADHD children may best be conceptualized as having a deficit in self-regulatory or executive functions. According to this model, the ADHD symptoms of inattention, impulsivity and hyperactivity reflect impairments in executive functioning.

Cognitive psychologists have provided another level of analysis which may be useful for conceptualizing the deficits which characterize ADHD children. Similar to the neuropsychological models, cognitive models have focused on the dysregulated behavioral output of ADHD children (Douglas, 1988; van der Meere, van Baal & Sergeant, 1989).

One model has attempted to provide an explanation of the self-regulatory deficits which are seen in patients with frontal lobe dysfunction (Shallice, 1988). This model can be employed to provide a functional explanation of the impairments seen in ADHD. There have been few attempts to empirically investigate these cognitive models in children. However, the work of Douglas and colleagues (1988) suggests that further work should be conducted to examine the impact of impaired self-regulation on information processing in ADHD children.

This dissertation was designed to investigate executive/ self-regulatory functions in ADHD children and to examine the relationships among executive functions, behavior problems, attention, impulse control and activity level in both a non-referred and a clinical sample of children. Both neuropsychological and cognitive models were employed when assessing the relationship among the measures. The goals of this study were: 1) to further examine the nature of the cognitive processing deficit in ADHD children, and 2) to determine whether a unitary executive function deficit, similar to that seen in patients with frontal lobe disorder, could account for the diverse symptomatology seen in ADHD children.

Attention-deficit Hyperactivity Disorder - An Overview

Prevalence and Sex Differences in ADHD. Epidemiologic studies have provided estimates which suggest that ADHD is present in 3 to 9 percent of normal school age children (Anderson et al., 1987; Bird et al., 1988; Szatmari et al., 1989).

Clinic studies have found that ADHD is more prevalent in boys than girls with reported male to female ratios ranging from 2:1 to 10:1 (Barkley, 1990; Glow, 1980; Holborow, Berry & Elkins, 1984). Epidemiologic studies have found ADHD to be three times as prevalent in boys as girls in nonreferred samples (Szatmari et al., 1989; Trites, 1979). The higher rate of boys in clinic populations may be attributed to a referral bias. Studies have demonstrated that teachers frequently rate boys who are overactive, disruptive and conduct disordered as ADHD, but girls who are inattentive yet not disruptive are less often identified. Generally, it is only those girls who present with significant behavioral problems (i.e., aggression), as well as impaired attention, that are referred for assessment (Pascualvaca, 1989). In a school sample, Pascualvaca and coworkers (1988) found that ADHD girls are rated as having fewer behavioral and conduct problems than ADHD boys, however, they do not differ on laboratory measures of attention, impulse control and activity level.

Thus, in general, the epidemiologic data suggest that ADHD girls may have fewer conduct problems than ADHD boys, but on objective measures they demonstrate the same pattern of cognitive impairment. In contrast, data from clinic studies indicates that girls who are referred for evaluation/treatment tend to be as aggressive and conduct disordered as their male counterparts.

History. There has been considerable controversy surrounding the precise nature of the difficulties manifested by children with ADHD. Continual changes and revisions in the diagnostic nomenclature reflect clinicians' uncertainty as to the core deficit(s) involved in the disorder. ADHD has previously been referred to as Minimal Brain Dysfunction (MBD), Hyperkinetic Reaction of Childhood and Attention Deficit Disorder with and without Hyperactivity (ADD with or without H, respectively). MBD encompassed not only what is today considered to be ADHD, but also a host of other developmental disorders including learning disabilities and motor problems. The notion of MBD was based on the belief that these children suffered from neurological damage. The higher incidence of neurological "soft signs" (Wikler, Dixon & Parker, 1970) and of EEG abnormalities in MBD children (Capute, Niedermeyer & Richardson, 1968; Satterfield, 1973) were utilized as evidence to argue for a neurological basis to the disorder. In addition, children with documented central nervous system

(CNS) lesions frequently present with behavioral and attentional problems similar to those seen in ADHD (Naughon, 1971; Shaffer, Chadwick & Rutter, 1975). However, most ADHD children have normal findings on neurological examination (Halperin, Gittleman, Katz & Struve, 1986). Furthermore, many normal children exhibit neurological soft signs or EEG abnormalities (Wikler et al., 1970). At best, evidence of focal CNS abnormality is seen in only a small proportion of ADHD children (Ferguson & Rapoport, 1983). Rutter (1977) found that less than five percent of children with ADHD have documented brain damage. Further, most children with brain damage do not exhibit the symptoms of ADHD.

The second edition of the Diagnostic and Statistical Manual (DSM-II) (APA, 1968) abandoned the etiological formulation of the syndrome based on damage to the CNS and focused instead on the presenting symptom of abnormally high levels of motor activity. DSM-II referred to the disorder as "Hyperkinetic Reaction of Childhood". A decade later, DSM-III (APA, 1980) began to stress the symptoms of inattention and impulsivity, which could occur, according to this system, with or without overactivity. Whereas overactivity was previously believed to be the primary and defining characteristic of these children, with the introduction of DSM-III (APA, 1980), hyperactivity became secondary relative to inattention and impulsivity. A number of studies attempted to determine whether ADD with and

without Hyperactivity were divergently valid diagnostic entities or whether they were variations of the same disorder (Lahey, et al.,1988; Lahey, Shaughency, Hynd, Carlson & Nieves, 1987). The work of Lahey and others (Edelbrock, Costello & Kessler, 1984) indicated that children who received the diagnosis of ADD without Hyperactivity presented with a more sluggish "cognitive tempo" and tended to exhibit coexisting internalizing disorders (i.e., anxiety or depression). In contrast, children who received the diagnosis of ADD with Hyperactivity presented as more behaviorally disturbed, aggressive, and tended to exhibit more externalizing disorders (i.e., conduct disorder).

The introduction of DSM-III-R (1987) abandoned the dichotomy between ADD with and without Hyperactivity. It was replaced with a single polythetic symptom list from which a child had to present with 8 of 14 symptoms. DSM-III-R (1987) nosology reflects the belief that inattention, impulsivity and hyperactivity may contribute equally to the ADHD syndrome. The symptoms are believed to represent core features of ADHD. However, it is notable that it is possible to diagnose a child as ADHD without his or her presenting with symptoms in all three symptom domains. For example, one ADHD child may be primarily impulsive and hyperactive but not inattentive, while another child might present with inattention and hyperactivity but might not be

characterized as impulsive. Thus, children may receive the diagnosis as a result of several combinations of the symptoms. This change in diagnostic criteria has resulted in a larger and more heterogeneous group of children receiving the diagnosis of ADHD (Lahey et al., 1990; Newcorn et al., 1989). The continuing controversy with respect to the core deficits of ADHD is in part due to the broad defining characteristics which identify an extremely diverse group of children. It appears as if the proposed fourth edition of the DSM will return to the earlier conceptualization of ADD with and without hyperactivity with the hope of bringing increased clarity to the distinction between these related disorders (Greenhill, 1992). In addition, the single symptom checklist will likely be replaced with two checklists, one consisting of items relevant to inattention, and a second list with items pertaining to hyperactivity/impulsivity. Furthermore, clinicians will be required to ascertain whether or not these symptoms have led "to impairment or marked distress" in the areas of academic achievement or peer relationships before a diagnosis of ADHD can be made. These descriptors have been included in an attempt to establish a more stringent criteria for the diagnosis of ADHD (Greenhill, 1992).

Characteristics of ADHD Children

Inattention. One of the hallmark features of ADHD is inattention. These children are often described as easily distracted, having difficulty completing tasks, requiring frequent redirection, being disorganized, making careless errors and continually shifting from one activity to another (Barkley, 1990; Greenhill, 1992). There is controversy with respect to the precise definition of the construct of "attention." However, most researchers agree that attention is not a unitary construct, rather it involves several distinct yet related processes (Mirsky, 1989). There are numerous terms and definitions that various researchers have employed while studying the components of attention. The construct of attention includes: arousal and alertness, orienting, sustained attention, selective attention (which encompasses focused and divided attention), alternating attention, and attentional control (Halperin, McKay, Matier & Sharma, in press; Sohlberg & Mateer, 1989). Research on ADHD has focused primarily on three components of attention: arousal, sustained attention, and selective attention. While not directly addressed in the literature, there is some indication that investigations have also begun to explore the nature of an attentional control mechanism which directs and modulates the attentional system as a whole. It has been suggested that the attentional impairments in ADHD

reflect weaknesses in one or all of these attentional mechanisms.

Arousal. Implicit in all theories of attention is the notion of arousal. Arousal refers to the physiological state which sets the stage for information processing to occur. A suitable level of arousal, characterized by a physiological readiness to perceive external stimuli, is believed to be necessary for all levels of information processing. Extreme levels of arousal on either end of the continuum, as in the case of hypoarousal (i.e., drowsiness) or hyperarousal (i.e., severe pain or high levels of anxiety), can impair attention (Halperin, McKay, Matier & Sharma, in press). Arousal is closely linked to the concept of sustained attention or vigilance and is required for further stages of information processing. In fact, Luria (1983) conceptualized arousal as the regulator of "tone" which sets the stage for information processing to occur.

Some researchers have suggested that ADHD children are under-aroused (Satterfield, Cantwell, Lesser & Podosin, 1972; Satterfield & Dawson, 1971) and tend to seek out more stimulating activities in an attempt to reach a more optimal level of CNS activation (Zentall & Zentall, 1983). This hypothesis was based, in part, on the belief that ADHD children have a "paradoxical" reaction to stimulant medication.

Other research employing physiological indices has provided some evidence supporting the under-arousal theory. ADHD children show a greater EEG amplitude, broader range of amplitude and increased EEG slow waves (Satterfield et al., 1973). Furthermore, ADHD children have been found to exhibit a greater amplitude of auditory evoked potential (Satterfield et al., 1973) and a lower basal skin conductance level than normal controls (Satterfield et al., 1973; Satterfield & Dawson, 1971).

Other researchers have found no difference between the arousal level of ADHD children and controls on these physiological measures (Cohen & Douglas, 1972), and some studies have found ADHD children to be over-aroused (Firestone & Douglas, 1975). Other investigators have suggested that ADHD children may exhibit both under-arousal and over-arousal (Zentall & Zentall, 1983). Consistent with this work, Douglas (1983) has suggested that while ADHD children do not appear different from their normal peers in their resting arousal level, they may have difficulty modulating this level in response to various situational demands. ADHD children may have difficulties at both ends of the continuum, for situations which elicit boredom and as well as those involving a high degree of stimulation (Douglas and Peters, 1979). Consequently, these children may appear both as under-aroused and over-aroused, and

either state can result in impaired performance and an increase in disruptive behaviors.

It is clear that arousal is a prerequisite for information processing to occur. However, it is also the case that while arousal is a necessary component of information processing, it is not the only attentional demand placed upon the system. The complex tasks which confront the ADHD child will require an adequate level of arousal, the ability to sustain attention, the ability to screen out irrelevant stimuli and the capacity to formulate, initiate and modulate a response.

Sustained Attention. In contrast to the work in arousal, less variable findings have been demonstrated on tasks measuring vigilance or sustained attention. In fact, the most consistent finding in studies of ADHD children is their documented deficit in sustained attention. Sustained attention or vigilance is closely related to the construct of arousal. This component of attention refers to the ability to maintain a consistent level of performance over time. Incorporated within the notion of sustained attention are two components. The first relates to the duration of time during which a particular behavior or response can be maintained; the second feature is the consistency of performance throughout that period of time (Sohlberg & Mateer, 1989). A large body of literature supports the notion that ADHD children have difficulties sustaining

attention, particularly during long, dull and repetitive tasks (Douglas, 1983; Dykman, Ackerman & Oglesby, 1979; Milich, Loney & Landau, 1982; Ullman, Barkley & Brown, 1978; Zentall, 1985). ADHD children perform more slowly, make more errors and exhibit more variability in their performance as compared to normal controls on tasks which measure sustained attention (Rosenthal and Allen 1978). These attentional problems may not always be apparent in less structured play settings, but are more readily observed in structured settings, such as classrooms (Porrino et al., 1983b). While some researchers (van der Meere & Sergeant, 1988b) have suggested that ADHD children do not demonstrate a sustained attention deficit, these findings were based on a small number of subjects. In general, most investigators agree that ADHD children experience problems with sustained attention or vigilance.

There is some controversy, however, with respect to whether this deficit in sustained attention constitutes the primary symptom of the disorder, or whether it is the result of impairments in other core symptoms such as impulsivity or hyperactivity. Barkley (1990) argues that the impaired ability to maintain vigilance is secondary to problems with behavioral inhibition. In contrast, Halperin and colleagues (Halperin, et al., 1988; Halperin, Sharma, Greenblatt & Schwartz, 1991; Halperin, Wolf, Greenblatt & Young, 1991) have suggested that inattention and impulsivity are distinct

psychological constructs which can be isolated and independently assessed.

The measurement of sustained attention typically involves the use of target detection tasks which are generally lengthy and repetitive with target stimuli presented randomly among a series of non-target stimuli. These types of tasks are referred to as continuous performance tests. Halperin and coworkers (Halperin, et al., 1988; 1991a) developed a continuous performance test (CPT), modelled after the A-X paradigm of Rosvold et al. (1956), in which the child is told to respond whenever he/she sees the letter A followed by the letter X. Traditionally, omission errors on this task were believed to reflect inattention while commission errors were thought to provide an index of impulsive responding (O'Dougherty, Nuechterlein & Drew, 1984; Sykes et al., 1971). However, Halperin's work (Halperin et al., 1988; 1991b) has suggested that commission errors may be subgrouped into different classes of errors which reflect different psychological processes. For example, responses to the X not preceded by an A (X-Only errors) had slower reaction times than hits, and were correlated with teacher ratings of inattention. In contrast, responses to letters other than X preceded by an A, (A-Not-X errors) had faster reaction times and correlated with teacher ratings of impulsivity and hyperactivity. Random errors (responses to a sequence of two letters which

contained neither an A nor an X) and responses to the letter A (A-Only errors) were not found to be related to teacher ratings of behavior. This work indicates that the CPT is not a global measure of sustained attention, rather it provides an index of several different psychological processes which contribute to, and are involved in information processing.

Selective Attention. Unlike the domain of sustained attention, where there is relative consensus that ADHD children exhibit difficulties, there is controversy as to whether they experience difficulty with the ability to remain focussed on a particular task and avoid distraction. Selective or focused attention is the mechanism which enables the individual to attend to relevant information while simultaneously screening out irrelevant material.

Tests which assess selective attention measure the degree to which performance on a central task is disrupted by the presence of distractors. Examples of such measures include central-incidental learning tasks, speeded classification tasks, selective and dichotic listening tasks, time sharing and visual search tasks (Davies et al., 1984). These tasks can involve extra-task distraction, such as might occur when a child working on an arithmetic problem in class is distracted by a conversation going on in the hallway, or intra-task distraction, such as might occur when

a child who is reading a story is distracted by the illustrations and has trouble focusing on the text.

Despite the fact that children are consistently rated as distractible, researchers have been unable to consistently demonstrate that ADHD children have more difficulties with selective attention than other child psychiatric patients or normal controls when using laboratory measures. Studies have shown that ADHD children are no more distracted by extra-task stimulation than normal controls (Cohen, Weiss & Minde, 1972; Rosenthal & Allen, 1980). However, data from studies using tasks involving intra-task distractors have been equivocal; some researchers have found these distractors worsen performance (Rosenthal & Allen, 1980; Sharma et al., 1991) while others found no effect (Aman & Turbott, 1986; Douglas, 1972; van der Meere & Sergeant, 1988a) or even improved performance in the presence of distractors (Zentall, Falkenberg & Smith, 1985). Others have suggested that ADHD children tend to do worse than controls on selective attention tasks only when presented with highly salient or interesting distractors (Rosenthal & Allen, 1980). However, even in the presence of these attractive distractors, differences between ADHD and normal children are not consistently demonstrated (Bremer & Stern, 1976). Thus, the literature does not support the existence of a selective attention deficit in ADHD.

Attentional Control. While not specifically addressed in many studies, there are indications in the literature that ADHD children may have difficulties with attentional control. Attentional control is the mechanism which controls, directs and modulates one's attentional resources. Tant and Douglas (1982) found that when asked to verbalize the rules by which to solve a given task, ADHD children had no difficulty stating the relevant principles. However, these children were unable to consistently apply these rules when engaged in the task. Further, ADHD children have generally not been found to differ from controls on tasks requiring relatively effortless or automatic processing. However, on tasks which require increasing levels of effort, organization and/or memory, ADHD children have been found to perform significantly poorer relative to both reading disabled children and normal controls (August, 1987; Borcherding et al., 1988; Tant & Douglas, 1982).

These studies suggest that ADHD children may have difficulties with the more "executive" components of attention, which have been referred to as the "central executive" (Baddeley & Hitch, 1974) or "supervisory attentional system" (Shallice, 1988) in cognitive models of attention. This component of attention facilitates the regulation and modulation of behavior by enabling the individual to respond appropriately to changes in situational demands. Impairments in the attentional control

mechanism interfere with one's ability to select appropriate behaviors and may also manifest in terms of a cognitive rigidity or failure to shift set in response to changing contingencies. Clinically, a dysfunctional attentional control mechanism may result in behavioral dysregulation and/or a disordered motor output, features which are characteristic of ADHD children. Thus, impairments in the attentional control mechanism may impact on selective attention, sustained attention and/or impulse control, and may contribute to the variable presentation which is characteristic of ADHD children

In summary, there is controversy with respect to the nature of the attentional disruption which occurs in ADHD. While the research literature does not support the notion that these children have selective attention deficits, several studies suggest the presence of an impairment in sustained attention or vigilance. However, it is possible that these deficits, when considered in the context of the diverse symptomatology of ADHD children, can be more accurately conceptualized as resulting from a deficit in attentional control. Impairments in this mechanism would result in a disruption in the ability to formulate goal directed plans and consistently monitor and regulate one's own behaviors.

Impulsivity. As with attention, there is no single definition of the construct of impulse control. This construct refers to a tendency to act before or without thinking; it is a relative inability to "inhibit behavior in response to situational demands" (Barkley, 1990). Clinically, childhood impulsivity manifests in behaviors such as calling out answers in class and failing to wait for one's turn while playing games. Douglas (1983) has described the impulsivity seen in ADHD children as an inability to withhold responding on less complex tasks, or a tendency to respond before having gained a complete understanding of how to solve more complex tasks. Impulsivity may also manifest in terms of a failure to consider the consequences of perilous actions, such as running out in the street without looking or climbing in dangerously high places (Barkley, 1990; Greenhill, 1992).

As with attention, impulsivity is a complex construct which involves several different components. In general, researchers define impulsivity as a pattern of rapid, inaccurate responding to tasks (Brown & Quay, 1970, as cited in Barkley, 1990). Impulsivity in ADHD children may also manifest as a difficulty maintaining inhibition of a response. For example, when instructed to withhold responding in order to receive a reinforcer, ADHD children tended to respond more frequently than normals and consequently received fewer rewards (Gordon, 1979). Other

impairments which have been attributed to problems with impulsivity include difficulty following rules that guide behavior in social situations (Kendall & Wilcox, 1979) and a poor ability to delay gratification (Gorenstein & Newman, 1980; Rapport et al., 1986).

Barkley (1990) argues that impulsivity is the primary defining symptom of ADHD and that the attentional problems are a secondary manifestation of this failure to inhibit responding. He cites evidence that indicates that impulsivity and overactivity are the features which best discriminate ADHD children from other clinic patients. Furthermore, he attributes the failure of factor analytic studies to differentiate between impulsivity and hyperactivity to a lack of discriminant validity, or the ability to differentiate between the constructs. In contrast, other investigators (Halperin et al., 1988; 1991a; 1991b; Reichenbach et al., 1992) suggest that the constructs of inattention, overactivity and impulsivity are discrete functions which can be assessed independently of one another.

Several tasks have been designed in attempts to measure impulsivity. One of the most frequently used measures is the Matching Familiar Figures Test (MFFT) (Kagan, 1966). This task involves the presentation of a standard figure along with six very similar figures. The child is instructed to select the figure which is identical to the

standard. ADHD children tend to exhibit shorter response latencies and to make more errors on the MFFT (Messer, 1976). Impulsivity has also been assessed by examining commission errors on vigilance tasks. Halperin and colleagues (Halperin et al., 1988; 1991a; 1991b) have found on an A-X continuous performance test (CPT) that A-Not-X and long latency A-Only errors provide an index of impulsivity which is distinct from measures of inattention and overactivity.

Overactivity. Excessive or developmentally inappropriate levels of activity constitute the final primary characteristic of ADHD. These children are frequently described as "restless and squirmy," "always on the go," and "fidgety" (APA, 1987). Teachers often complain that ADHD children have trouble remaining seated, talk excessively and make other inappropriate noises.

Activity level is highly variable across settings. For example, normal children are typically more active in less structured settings (i.e., in the cafeteria or at recess) than when in more organized settings (i.e., classrooms). In fact, ADHD children may be indistinguishable from normals in unstructured settings (Porrino et al., 1983b). Research with ADHD children has shown that they are more likely to manifest overactivity in structured settings (Porrino et al., 1983b) than in unstructured settings. Thus, it is

important to consider the setting in which the behavior is being evaluated when assessing hyperactivity.

While it can be argued that the overactivity which is seen in ADHD is the result of behavioral disinhibition and/or distractibility, this reasoning can not explain the finding that some pervasively hyperactive children also manifest overactivity during sleep (Porrino et al., 1983). The overactivity, in this instance, does not appear to be related to information processing and, therefore, it would not be due to distractibility. Furthermore, it would not be related to impulsivity as the movement during sleep is not goal directed (Halperin, McKay, Matier, & Sharma; in press).

The most commonly employed instrument which is used to assess overactivity in children is behavior rating scales. The Revised Conners Teacher and Parent Questionnaires (Goyette et al., 1978) are the most frequently used rating scales, although many similar instruments have been developed (Achenbach, 1983). While these scales all measure activity level to some extent, they are probably a more accurate measure of behavioral disruption. The Conners Teacher's Rating Scale is a 28-item checklist which generates three presumably orthogonal factor scores: conduct problems, inattention/passivity and hyperactivity. While these measures are useful for identifying children who present with behavior problems, it suffers from certain limitations. For instance, although the factor scores are

allegedly orthogonal, they have been found to be highly intercorrelated (for review, see Hinshaw, 1987). Thus, rating scales tend to lack symptom specificity. Furthermore, rating scales are susceptible to "halo effects." For instance, teachers tend to rate disruptive children as overactive even when observational techniques (Abikoff, 1991; Schacher et al., 1985) and objective laboratory measures (Halperin et el., 1990a) do not indicate hyperactivity. Further problems with these rating scales include the fact that parent ratings are often found to be inconsistent with teacher ratings. Additionally, parents have been shown to have poor inter-rater reliability (i.e., mothers and fathers rate their child's behavior differently) and parent tend to rate their children as less disturbed than teachers (Rapoport, Donelly, Zametkin & Carrougher, 1986).

Observational techniques have also been employed as measures of hyperactivity. Direct observations of hyperactivity have been made in classroom (Abikoff et al., 1980) and playroom settings (Milich & Dodge, 1984; Routh 1978). Seemingly valid and reliable observational techniques have been developed. Drawbacks of these measures include the tremendous amount of time required to conduct a behavioral observation and the necessity to have highly trained observers.

Solid state actigraphs have also been used to provide a more discrete and direct measure of movement (Porrino et al., 1983b; Reichenbach et al., 1992). Of importance in these studies is the body placement of the actigraph as well as the setting in which the activity is being monitored. Porrino et al., (1983) used solid state actigraphs to measure truncal motor activity throughout a 1-week period. The data indicated that ADHD children were more active than normal children in almost all settings. While they could not be distinguished from normals in unstructured settings (i.e., play) they were significantly more active than normals in structured settings (i.e., classrooms) and during sleep. In a separate study (Reichenbach et al., 1992), actigraph measures of activity level were found to have excellent test-retest validity, to be age dependent (younger children were more active than older children) and to be significantly related to both parent and teacher ratings of hyperactivity. However, actigraph measures were not found to correlate with CPT measures of inattention or impulsivity.

Associated Features of ADHD. ADHD is frequently associated with other cognitive, behavioral and emotional problems, which generally occur within the context of a normal IQ (Douglas & Peters, 1978; Rosenthal & Allen, 1978; Stamm & Kreder, 1978). Included among these associated features are: poor academic achievement, learning problems,

low self esteem and difficulties with peer relationships. Furthermore, ADHD children frequently have one or more comorbid diagnoses (i.e., conduct disorder or an anxiety disorder). The large number of associated symptoms and the high incidence of comorbidity found among children with ADHD contribute to the heterogeneity of this population. Consequently, these children frequently differ in the pattern of ADHD symptomatology (i.e. inattention, impulsivity and overactivity) as well as in the presentation of associated features and/or comorbidity. The associated symptoms are believed to result from some interaction between the core ADHD deficits and the child's social and academic environment (Paternite, Loney & Langhorne, 1976, as cited in Braswell & Bloomquist, 1991). To this extent, they are considered as secondary to the more primary symptoms of the disorder.

Children with ADHD frequently demonstrate poor academic achievement (Cantwell & Satterfield, 1978) and extreme variability in their school performance (Douglas 1972; Douglas & Peters, 1979; Rapport, Tucker, DePaul, Merlo & Stoner, 1986). These difficulties stem from a combination of their problems with attention, impulse control and hyperactivity, as well as the presence of developmental learning disabilities (LD). Improvement in academic functioning is often seen when children are given stimulant medication (Barkley, 1990). However, this academic

improvement appears to be related more to improved effort and performance rather than a remittance of a specific LD. ADHD children frequently perform 10 to 15 points below their peers on tests assessing academic achievement (Cantwell & Satterfield, 1978; Safer & Allen, 1976). Studies have shown that a large percentage of ADHD children present with a coexisting learning disability (Lambert & Sandoval, 1980). Thus, it is not uncommon for ADHD children to be retained and/or to be placed in special education classes.

Aside from their learning problems, ADHD children also demonstrate difficulties in the area of socio-emotional functioning. Frequently, these children present with low frustration tolerance, poor self-esteem (Weiss & Hechtman, 1986), and difficulty with social interactions (King & Young, 1981; Milich and Landau, 1982). In their review of the literature, Pelham and Milich (1984) reported that mothers, teachers and children are in agreement that ADHD children exhibit poor peer relations. ADHD children are often intrusive and disruptive. They talk more than other children while having difficulty organizing and expressing their thoughts. Furthermore, ADHD children are more likely to exhibit aggressive behaviors and conduct problems (APA, 1987; Barkley, 1982; Mash & Johnston, 1982; Milich, Loney & Landau, 1982; Thorley, 1984) than other children.

Due to the high degree of overlap between ADHD and other childhood psychiatric diagnoses, researchers have felt

it necessary to investigate patterns of comorbidity. While ADHD is a distinct diagnostic category, in actual practice it is rare to find a child who does not present with another comorbid diagnosis (Biederman, Newcorn & Sprich, 1991). In their review of the literature, Biederman and colleagues report that 30 to 50 percent of these children present with another behavior disorder (i.e., Oppositional Defiant Disorder or Conduct Disorder), 15 to 75 percent present with mood disorders (i.e., Dysthymia or Major Depressive Disorder), approximately 25 percent present with an anxiety disorder, and 10 to 92 percent present with comorbid learning disorders (LD). The wide discrepancy among reports of comorbidity of ADHD with LD is most likely attributable to differences in the way the constructs being assessed have been defined and differences in the sensitivity of the measurement instruments. For example, some researchers define LD as a score at least one standard deviation below expectation for the child's age on standard measures of academic achievement (i.e., a standard score of 85 or less on WRAT-R Reading indicating a reading disability). In contrast, other investigators require a 15 point discrepancy between IQ and measures of academic achievement (i.e., IQ score minus WRAT-R Reading score greater than or equal to 15 points). These two procedures for defining an LD could identify very different groups of children.

Children with comorbid diagnoses may present differently than children with either diagnosis alone. For example, Pliszka (1992) found that ADHD-anxious children tended to be less impulsive and/or overactive than children with only ADHD. Furthermore, a trend was reported such that the ADHD-Anxious children tended to demonstrate fewer symptoms of Conduct Disorder than the ADHD only group. This study highlights the importance and relevance of studying differences among ADHD and the various comorbid disorders; as understanding patterns of comorbidity may have important implications in terms of diagnosis, treatment and prognosis of this heterogeneous group of children.

Overall, the literature suggests that ADHD children may present with variable symptomatology. Even the same child may appear/behave differently in various situations. Therefore, when studying the constructs of inattention, impulsivity and overactivity, it may be more useful to isolate and study discrete symptom domains, rather than to classify children on the basis of their categorical diagnosis.

Developmental Course. Retrospective reports suggest that the primary symptoms of ADHD may be present as early as infancy, and that they are expressed in the form of high activity levels, emotional lability, irregular sleep patterns and reduced need for sleep (Pennington, 1991; Ross & Ross, 1982; Wender, 1987). During the toddler years,

children continue to present with overactivity and begin to demonstrate other problems such as failure to comply with parental requests and proneness to tantrums. Parents may report that their children wear out toys and clothing at a faster rate than other children (Cantwell, 1975). During the pre-school years short attention span and difficulties in group settings become apparent (Palfrey et al., 1985). ADHD children have trouble waiting their turn while playing games and responding to questions. Further, they often behave inappropriately with their peers; they may be overly touchy with other children and fail to pick up on social cues.

As children begin school and increased attentional demands are required, the child with ADHD is frequently identified by teachers as having a shorter attention span, and being more active and impulsive than other children his or her age. It is at this time (about six to eight years old), that most ADHD children are initially identified and referred for evaluation and/or treatment. In general, the mean age of onset of the disorder occurs between three and four years of age with the range occurring from infancy to seven years old (Barkley, 1990). Generally, children who present with the symptoms of ADHD after the age of seven do so as the result of some specific neurological event/trauma.

Earlier conceptualizations viewed this disorder as limited to childhood, with a remission of symptoms occurring during adolescence (Laufer & Denhoff, 1957, as cited in Pennington, 1991). However, more current data suggest that this belief, which was thought of as reflecting a developmental lag, is incorrect (Cantwell, 1985; Lambert et al., 1987). While the hyperactivity generally subsides during adolescence, problems including impulsivity and difficulty sustaining attention, as well as associated features such as low self-esteem and poor social skills, are found to persist through adolescence and into adulthood in a large percentage of ADHD children. Studies have found tremendous heterogeneity when examining long term outcomes of ADHD children (Gittleman et al., 1985; Hechtman & Weiss, 1986; Loney, Kramer & Milich 1981). While some adults appear to show a full remission of symptoms, others continue to present with significant problems with impulse control, sociopathy, substance abuse and/or depression. The variability seen with respect to long-term outcome supports the notion that, as currently defined, the diagnosis of ADHD is applied to a diverse and heterogeneous group of children.

Summary. Despite years of attempts to refine the diagnostic criteria, ADHD children remain extremely heterogenous with respect to their clinical presentations, response to treatment and their long-term outcome. Some of this confusion may have stemmed from the instruments which

are used to define/measure the symptoms which are present in ADHD.

Recent research (August & Garfinkel, 1989; Halperin et al., 1990) suggests that children who are classified as ADHD according to current diagnostic criteria represent a heterogeneous group. Some of these children manifest symptomatology which is primarily characterized by impulsivity and behavioral disruptiveness, while others demonstrate symptomatology which is reflected in impairments in attention and other cognitive functions. Furthermore, preliminary data suggest that the symptoms of inattention, impulsivity and overactivity, when objectively assessed, may not be significantly intercorrelated (Reichenbach et al., 1992). This dissociation of symptoms argues for research which aims to better understand the pathological symptom dimensions rather than being wedded to a specific diagnostic category. These clinical laboratory test data suggest that inattention, impulsivity, and overactivity may be dissociable features of ADHD. Further, these findings lend support to the earlier DSM-III conceptualization of Attention Deficit Disorder with and without Hyperactivity, wherein a clearer distinction was made between the behavioral and cognitive features which underlie the disorder.

A Neuropsychological Model of Executive Functioning and ADHD

The similarity between the pattern of deficits seen in ADHD and those seen in adult patients with frontal lobe lesions has led several researchers to suggest a common etiology for the two disorders (Chelune et al., 1986; Mattes, 1980; Pontius, 1973; Stamm & Kreder, 1979). Adult patients with frontal lobe dysfunction frequently present with difficulties in the initiation, maintenance and inhibition of task appropriate behaviors; they are often socially inappropriate, and have a tendency to exhibit poor cognitive flexibility or an inability to "shift set" (Damasio, 1985; Fuster, 1989; Lezak, 1983; Stuss & Benson, 1986). These impairments impact most profoundly on the individual's ability to successfully engage in novel or non-routine activities (Milner & Petrides, 1984; Shallice, 1982; Stuss & Benson, 1986). Furthermore, studies of frontal lobe patients have also documented impairments in focused and sustained attention (Smith, Kates & Vriezen, in press). Additionally, as with ADHD children, frontal lobe patients frequently exhibit behavioral dyscontrol which may manifest as impulsivity, perseveration or an inability to generate plans and monitor behavior (Petrides & Milner, 1982). These deficits typically occur within the context of normal intellectual functioning. Luria (1973) used the term "executive function" to denote the formulation of intention and the orchestration of behaviors necessary to obtain

goals. In adults, these executive abilities are generally believed to be mediated by the frontal lobes.

The frontal lobe hypothesis of ADHD posits that these children have a neurologically-based disorder characterized by impairments in the "executive" or organizational components of cognition; those functions involving the regulation, planning and organization of goal-directed behaviors, and the initiation and inhibition of responses. Thus, according to this model, the ADHD symptoms of inattention, impulsivity and overactivity are manifestations of a generalized impairment in these executive or regulatory functions. For example, Barkley (1990) notes that while ADHD children do not have problems with language per se, they do exhibit difficulties when required to produce "explanatory speech" speech that requires more thoughtful planning and organization. Furthermore, while ADHD children do not demonstrate significant memory problems, difficulties arise when they must apply strategies to organize and integrate material to foster more efficient encoding. Additionally, Barkley (1990) comments on the difficulties with problem-solving and rule generation which characterize many ADHD children. These problem areas may each reflect an impairment in executive functioning.

Development of Executive Functions. Earlier views regarding the development of the frontal lobes suggested that this brain area was "silent" during the first years of life. For example, Luria (1973) argued that the frontal lobes were not mature until four to seven years of age, while Golden (1981) posited that the frontal lobes were immature and essentially non-functional until the child reached adolescence (after the age of 12). However, more recent research involving both animals and young children has provided evidence to the contrary.

Goldman-Rakic and co-workers (1983; Goldman, 1971; Goldman, Rosvold & Mishkin, 1970a; 1970b) have done extensive work documenting the effects of frontal lobe lesions on monkey's performance on delayed response and delayed alternation tasks. In the delayed response task, the monkey is shown two wells and watches as the examiner hides food in one of the wells. The wells are then hidden from the monkey's view for a specified amount of time. After this delay, the monkey is shown the wells and must select the location where the food was hidden. The delayed alternation task is a variation of the delayed response task. In this task the hiding location is alternated in a patterned fashion which the monkey must discern. Goldman's work (1971) demonstrated that early lesions differentially effected monkeys' performance on these tasks and suggested that different areas of the prefrontal cortex become

functionally mature at different times. Specifically, Goldman's work indicates that the orbito-frontal regions are functionally mature earlier than dorsolateral frontal regions.

Diamond and Goldman-Rakic (1989) have sought to generate a human analog of the work with animals in order to provide evidence supporting the notion that the human prefrontal cortex is also functional early in life. This research employed the A-Not-B task as a counterpart of the delayed response task. In this task, a toy is hidden in one of two wells while the child is watching (A). The wells are then hidden from the child's sight for a delay period, after which the child reaches for the well in which the toy has been hidden. The toy is hidden in the same location for a set number of trials (the criterion) after which the location of hiding is reversed (B). If on the subsequent trial the toy is hidden in well B but the child reaches for A, he/she has made the A-Not-B error. Because of the similarities between this task and the delayed alternation task, it has been hypothesized that successful performance on the A-Not-B task is contingent upon intact prefrontal functioning. Children are generally able to perform the A-Not-B task at 12 months of age (Diamond & Goldman-Rakic, 1989). Similar findings were also reported using the delayed alternation task (Diamond & Doar, 1989).

Diamond (1988) has employed the object retrieval task as an alternate means of examining the self-control and planning abilities thought to be mediated by the frontal lobes. In this task a toy is placed in a plexiglass box clearly within the child's view. The only way for the child to obtain the toy is to circumvent the box and inhibit reaching in a direct line with his/her field of vision. Development of this skill parallels the ability to successfully perform the A-Not-B and delayed alternation tasks; children are typically able to successfully complete the object retrieval task at 11 to 12 months of age (Diamond, 1988).

As with the work of Diamond and Goldman-Rakic, research examining the development of behavior attributed to frontal lobe function in older children suggests that these abilities emerge in a progressive, multi-stage process, with some capacities developing earlier than others (Becker, Isaac & Hynd, 1987; Welsh et al., 1988; 1991). One study examined perseveration, performance on verbal and non-verbal conflict tasks, and performance on proactive and retroactive inhibition tasks in children ranging from six to twelve years old (Becker, Isaac & Hynd, 1987). The results of this study indicate that some of these capacities develop prior to age six (i.e., cognitive flexibility in response to verbal conflict), while others are still not fully developed even by age twelve (i.e., the ability to inhibit the effects

of retroactive interference). Similarly, Welsh & Pennington (1988; 1991) reported that by six years of age normal children have developed the capacity to avoid distraction and inhibit maladaptive responding, and by age ten, they are able to demonstrate cognitive flexibility (as assessed by performance on a card sorting test). By age twelve children appear to be capable of more complex planning and behavioral organization.

Overall, the work in this area provides evidence to suggest that at least some components of the behaviors which are considered as "executive" abilities are present as early as infancy and continue to emerge throughout childhood and adolescence. It is less clear, however, whether in the developing child, these behaviors are contingent upon the frontal lobes or other more posterior and/or subcortical brain regions (Smith, et al., in press).

Head Injury and Frontal Lobe Functioning. There have been few studies which have attempted to study the consequences of early brain injury on the development of the cognitive capacities which, in adults, are attributed to the integrity of the frontal lobes. Mateer (1990, Mateer & Williams, 1991) has reported cases of head injury in children where the locus of the lesion was presumed to primarily involve the frontal cortex. These children were described as being perseverative, having impaired attentional abilities, poor cognitive flexibility, and

difficulty modulating behaviors in accordance with task demands. Inappropriate affect, poor peer relations and difficulties with academic achievement were also reported, although general intellectual functioning was found to be intact. The cognitive profile of these head injured children is strikingly similar to the pattern of strengths and weaknesses which characterize ADHD children. However, due to methodological problems in Mateer's study, it is not possible to conclude that the deficits of the head injured children solely reflect an impairment of frontal lobe functioning. In Mateer's studies the locus of lesion was inferred based upon the site of impact (i.e., head or face). Furthermore, even if the primary insult was to the frontal lobes, this does not preclude injury to more posterior regions (i.e., contra coup) or diffuse cortical damage such as frequently occurs as a result of closed head injuries.

Utility of the Frontal Lobe Model. While there are limitations to the frontal lobe model, it does provide a useful framework for studying the deficits of ADHD children. Contrary to earlier theories, there now appears to be evidence supporting the notion that at least some components of executive functioning are present even during infancy. Furthermore, both adults and children with frontal lobe damage present with a pattern of deficits which is remarkably similar to the impairments which characterize ADHD children. Thus, it is reasonable to posit that a

deficit in executive or self-regulatory functions underlies the behavioral difficulties which are typically seen in ADHD children. Furthermore, it would be justified to employ tasks sensitive to frontal lobe damage when assessing the cognitive abilities of ADHD children.

Despite the appeal of this model, there are problems which must also be considered. To begin, issues of development must be addressed. While these executive abilities may be governed by the frontal lobes in adults, it is plausible that other brain regions subserve these capacities in the developing brain. Furthermore, when attempting to assess executive functions in children, it is often necessary to adapt adult tasks, such as the Wisconsin Card Sorting Test and the Tower of Hanoi, to make them suitable for use with children (Diamond & Boyer, 1989; Welsh et al., 1988). However, even if a task has previously been validated as a measure of frontal lobe functioning in adults, once it has been modified, the abilities being assessed are no longer clear (Smith, et al., in press). Thus, one may merely speculate as to whether or not frontal functions are present in young children.

Issues regarding the development of the frontal lobes remain equivocal. However, many investigators would agree that both children and adults with frontal lobe lesions as well as ADHD children exhibit deficits involving self-regulation or executive functioning. Thus, while it is not

clear that ADHD children have an underlying deficit involving the frontal lobes, it is useful to conceptualize them as having a functional disorder which compromises the integrity of their executive or self-regulatory functions.

Studies of Executive Functioning in ADHD. Chelune and co-workers (1986) were among the first investigators to empirically examine the frontal lobe hypothesis of ADHD. Their study included measures of general intellectual functioning (Peabody Picture Vocabulary Test, subtests from the Kaufman Assessment Battery for Children) and tests which were presumed to be indicative of frontal lobe functioning (Wisconsin Card Sorting Test (WCST), the Progressive Figures and Color Forms tests from the Reitan-Indiana Neuropsychological Test Battery for Children). No differences in IQ were seen, however, the ADHD children performed more poorly on measures thought to require frontal lobe abilities. These results were interpreted as evidence to suggest that ADHD children have an impairment in the prefrontal mechanisms which operate and guide attention in response to environmental contingencies.

A subsequent study (Gorenstein et al., 1989), compared the performance of inattentive-overactive children with normal controls on a series of measures presumed to assess frontal functioning and one control measure. The six frontal measures included: the Trail Making Test (Reitan, 1955), the Stroop Color-Word test (Stroop, 1935), the

Sequential Memory test (Gorenstein, 1989), WCST, Sequential Memory Test (Collier & Levy, as cited in Lezak, 1983) and Necker Cube Reversals (Teuber, 1964). The Vocabulary subtest from the Wechsler Intelligence Scale for Children - Revised was used as the control measure. Consistent with the expectations of the investigators, the inattentive-overactive children generally performed more poorly on all measures with the exception of the control task. Gorenstein and colleagues concluded that ADHD children demonstrate a "frontal-like" deficit with particular impairment in the ability to inhibit a competing response.

However, there were several methodological flaws in these earlier studies which Shue (1989, as cited in Smith et al., in press) attempted to improve upon in a subsequent study. First, Shue employed more rigorous criteria for selection of her ADHD subjects than did the previous studies. Yet, she did not control for the effect(s) of comorbid diagnoses which has been suggested as a confound in other studies assessing frontal functioning in ADHD (Barkley, Grodzinsky & Paul, 1992). Shue also limited selection of her frontal lobe measures to those tasks which have been validated in work with adult patients as being sensitive to the effects of anterior dysfunction. Finally, Shue included measures of posterior function, such as memory tasks sensitive to compromise of the temporal lobes in order to examine the degree of specificity of the deficits in ADHD

children. Overall, this study provided evidence suggesting that ADHD children had difficulties inhibiting and alternating motor responses, were less organized, demonstrated poorer problem solving skills and had more difficulty using feedback to guide responses than did normal controls. No differences were seen on the control measures which assessed both verbal and spatial memory. These results were interpreted as providing support for a functional analogy between frontal lobe dysfunction and the impairments seen in ADHD.

The work of other investigators examining the frontal lobe hypothesis of ADHD has yielded less conclusive findings. In comparing the performance of DSM-III-R diagnosed ADHD children with normal controls on a neuropsychological test battery, one study found no between group differences on tests sensitive to frontal lobe dysfunction (WCST and verbal fluency). However, differences were observed on IQ measures and tests of verbal memory such that ADHD children performed more poorly than age-matched controls (Loge, Stanton & Beatty, 1990). Similarly, Grodzinsky (1990) found only partial support for the frontal lobe hypothesis. In this study ADHD children were impaired on some, but not all of the measures sensitive to frontal dysfunction.

Recently, Barkley et al., (1992) reviewed 22 neuropsychological studies which investigated "frontal lobe

functioning" in ADD children with and without Hyperactivity. His group concluded that tests assessing "response inhibition" (i.e., WCST and CPT) most reliably distinguished between ADD children and normal controls. However, the ability to discriminate between ADD and normals on other purported measures of frontal lobe functioning was far less reliable and seemed highly dependent upon the age of the subjects, as well as which particular adaptation of a task was employed. Barkley also discusses the possibility of comorbid diagnoses as a confounding factor which may have contributed to the negative findings of several studies.

Overall, neuropsychological studies examining the frontal lobe hypothesis of ADHD have yielded inconsistent results. These findings may indicate that those abilities believed to be mediated by the frontal lobes are intact in ADHD children. Alternatively, these data may reflect our limited understanding of the development of frontal lobe/executive functions, as well as an inadequacy of our measures to appropriately assess these functions in children (Becker, Issac & Hynd, 1987; Cooley & Morris, 1990; Welsh & Pennington, 1988).

Neuroimaging Studies. Other investigators have sought to examine the frontal lobe hypothesis by utilizing more direct measures of brain functioning, such as neuro-imaging techniques and measures of regional cerebral blood flow. Computerized Tomography (CT) scans have provided no evidence

of structural differences between the brains of ADHD children and controls (Shaywitz, Shaywitz, Cohen & Young, 1983). However, using magnetic resonance imaging (MRI), Hynd et al., (1990) found an absence of the typical right greater than left frontal asymmetry in ADHD children. Lou and colleagues (1984; 1989) reported decreased blood flow to the frontal lobes in ADHD children. However, after administration of a stimulant medication (Ritalin), blood flow to the frontal lobes increased. They also reported a simultaneous decrease in blood flow to the basal ganglia which provide input to the motor cortex. A recent PET scan study has demonstrated metabolic differences in the frontal lobes between adults who were hyperactive as children and normal controls (Zametkin et al., 1990). Findings from this study, however, have been criticized for not being robust and possibly attributable to chance (Wood, 1991). In a similar study, Wood (1991) reported an overall decrement in regional cerebral blood flow which was not specific to the frontal lobes. Furthermore, this study also reported no differences on measures of neuropsychological functioning between ADHD subjects and controls.

Summary. In general, studies evaluating executive functioning in ADHD children have not consistently supported the frontal lobe hypothesis. However, if as was suggested earlier, the diagnosis of ADHD is applied to a heterogeneous group of children, then it is not surprising that results

from studies attempting to apply a unitary model have been inconsistent. For example, in employing the frontal lobe hypothesis, it is possible that only a carefully diagnosed subgroup of ADHD children, characterized by a specific set of symptoms, would demonstrate deficits in executive functions which are reflected by that particular model. While difficulties within the domain of executive functioning are consistently described as reflecting the symptomatology of ADHD children, not all children who are diagnosed as ADHD present with or manifest their symptoms to the same degree.

Cognitive Models of ADHD

An alternate approach to studying the nature of the deficit(s) in ADHD children has been to employ information processing models of attention. Evidence from studies attempting to apply information-processing models to examine the nature of the cognitive deficits in ADHD, suggests that these children may have impairments in the ability to organize a motor output or response (van der Meere and Sergeant, 1988a; 1988b; van der Meere, van Baal & Sergeant, 1989). Thus, research from the domains of both neuropsychology and developmental cognitive psychology suggests that ADHD children may have impairments in the gating, control and/or regulation of motor outputs.

As was previously discussed, investigators may not agree on the mechanisms involved in the maintenance of

attention, but it is generally accepted that attention is not a unitary construct (Mirsky, 1988); it has many facets all of which contribute to one's ability to detect, process and respond to stimuli from the environment. While researchers may propose differing models of attention, the existence of certain components in these models is generally agreed upon. One such construct, sustained attention, refers to the ability to maintain a level of performance over time (van der Meere & Sergeant, 1988a). A separate construct, selective attention, refers to the ability to focus on relevant material while simultaneously screening out irrelevant information (Broadbent, 1971; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). Shiffrin and Schneider subdivided selective attention into two components, divided attention, which involves the parallel processing of information across several channels simultaneously, and focused attention, which can be conceived of as filtering out irrelevant stimuli in favor of processing salient material.

A large body of literature supports the notion that ADHD children have difficulties sustaining their attention (Kupietz, (1976) Dykman, Ackerman & Oglesby, 1979). These children perform more slowly, make more errors and exhibit more variability in their performance as compared to normal controls on tasks which purport to measure sustained attention (Rosenthal & Allen, 1973). Data are equivocal

regarding selective attention deficits in ADHD. While these children are often characterized as distractible (having difficulties selectively attending to stimuli in the environment), most laboratory studies do not support this finding (Sykes, Douglas, Weiss & Minde, 1971).

van der Meere and Sergeant's Model. Recently, in an attempt to more clearly elucidate the processing deficits of ADHD children, van der Meere and Sergeant (1988a; 1988b; 1989) postulated a model which combines elements of Sternberg's (1969) Additive Factor Method (AFM) with Shiffrin and Schneider's conceptualization of selective attention. The AFM, postulates that information processing is comprised of four discrete stages: 1) stimulus input or encoding, 2) memory search, 3) decision, and 4) response organization. According to this model, reaction time (RT) is the sum of the time needed to process information at each stage, and the integrity of a particular stage can be assessed by systematically altering task demands to affect processing at one stage while holding all other contingencies constant. Van der Meere and Sergeant suggest that sustained attention, as defined by Shiffrin and Schneider, involves stages two and three of Sternberg's model (memory search and decision).

Through an elegant series of experiments, van der Meere and Sergeant manipulated a set of task demands in such a manner as to impact upon only one stage of processing.

Using the AFM coupled with Shiffrin and Schneider's model, it was found that ADHD children performed more slowly, made more errors and exhibited more variability than controls, despite having received several practice trials (van der Meere & Sergeant, 1988a). These decrements in performance were not found to be attributable to deficient encoding (Sergeant & Scholten, 1985), problems with focussed attention (van der Meere & Sergeant, 1988a), divided attention (van der Meere & Sergeant, 1987) or sustained attention (van der Meere & Sergeant, 1988b). Therefore, by process of elimination, it was hypothesized that the poor performance of ADHD children on their task was attributable to problems with the organization of a motor output (Sergeant & van der Meere 1988a; van der Meere & Sergeant, 1988b). In a subsequent study (van der Meere, van Baal and Sergeant, 1989), comparing the performance of ADHD and learning disabled (LD) children, both groups were found to perform the experimental task more slowly and with greater variability than did age matched controls. However, a dissociation was found between the LD and hyperactive group when analyzing the locus of the difficulty in terms of stage of processing. LD children were found to have an impairment in central processing or selective attention (Stages two and three in Sternberg's model), while ADHD children were found to be impaired in stage four (Output).

The elegance of this model is the manner in which the investigators were able to selectively manipulate various stages of information processing. However, this work has been criticized for the small number of subjects which were employed as well as the failure to more directly assess output organization in ADHD children.

Shallice's Model. As noted by van der Meere and colleagues (1989), the notion of motor output/response organization, is a complex construct which may itself be comprised of discrete stages of information processing (Frowein, 1981). The model developed by Shallice (1988, Norman & Shallice, 1980; 1986) draws on research from the domains of both neuropsychology and cognitive psychology and is useful in addressing issues of information processing as they relate to the organization and output of behavior.

Shallice proposes a model of information processing where a "Supervisory Attentional System" (SAS) is responsible for selecting and initiating highly specialized routines or schemas. These schemas are activated by perceptual triggers and several of these routines may be activated at any given time. The choice of which routine or schema to initiate is determined by the SAS and by "Contention Scheduling". Contention scheduling is decentralized, involved in more automatic processing, and responsible for the selection of schemata based on the strength of the perceptual triggers. Contention scheduling

therefore, modulates behavioral programming when automatic processing is operative. In contrast, the SAS is involved in more effortful, controlled processing. The SAS has the capacity to override the more routinized programming of contention scheduling.

An example illustrating the operation of this system can be seen in the processing required to complete the Stroop Test (Stroop, 1935), a classic measure of frontal lobe functioning. In this test, subjects are presented with color names which have been printed in different colors of ink. Subjects are asked to read the words, ignoring the color of the ink, a relatively automatic task for fluent readers. Subsequently, the subjects are asked to name the color ink in which the words are printed. This latter activity is more difficult and requires the ability to inhibit a prepotent response (reading the word). When engaged in the Stroop Test, the contention scheduling system would favor the more routine schema of reading the words. The SAS would be needed in order to overcome this more automatic response and successfully name the color of the ink.

Shallice likens failures of the SAS to the deficits seen in patients with frontal lobe dysfunction who present with impairments in the "programming, regulation and verification" of behaviors. The behavior of the patient, who is governed solely by contention scheduling, is based

entirely on the salience of perceptual triggers. This may present in either of two apparently contradictory ways. In circumstances where the perceptual trigger is strong, the patient's behaviors may appear extremely rigid and perseverative, demonstrating little cognitive flexibility. In this instance, the high saliency of the perceptual trigger would cause contention scheduling to initiate a single, routine trigger; no alternate behaviors would be initiated. In contrast, if the perceptual trigger is weak, these patients may present as highly distractible and impulsive, frequently moving from one activity to another. In the absence of a strong perceptual trigger, attention would be easily drawn to irrelevant stimuli in the environment. Therefore, impairments in the SAS can cause the same individual to appear to present with these contradictory features, either rigid and perseverative or distractible and impulsive.

While Shallice bases his model on the clinical presentation of adult patients with frontal lobe dysfunction, the similarities between this group and ADHD children are compelling. The inattention, behavioral dysregulation and difficulties in the programming of behaviors typically seen in ADHD could result from a failure of the SAS. Additionally, this model could account for the variability in performance which often characterizes these children. Finally, impairment in the SAS would manifest in

terms of a generalized deficit in self-regulatory functions which is suggested by the neuropsychological models and is alluded to in the ADHD literature.

Douglas' Model. Virginia Douglas (1988) has developed a model which specifically addresses the self-regulatory deficits seen in ADHD children. Douglas argues that this deficit impacts upon the organization of information processing as well as the inhibition of inappropriate responding. She believes that this self-regulatory deficit impinges on processing across all domains: visual, auditory, perceptual and visual-motor. Furthermore, as with Shallice's model, Douglas views self-regulation as modulating the organized and effortful attention which she believes is an integral element of all stages of information processing. Failures in this self-regulatory mechanism may result in one of two behaviors, an inability to withhold inappropriate responses, or a failure to inhibit responses to inappropriate stimuli.

According to Douglas' model, there are three primary domains involved in self-regulation, 1) the organization of information processing, 2) the mobilization of attention, and 3) the inhibition of responses. The first component includes the regulation of arousal and alertness, planning, executive functioning, set maintenance, metacognition and self-monitoring. The second component is involved in the mobilization of attention and refers to the ability to

deploy and maintain attention over time. Inhibition refers to the ability to withhold inappropriate responses.

In reviewing the literature addressing the cognitive functioning of ADHD children, Douglas arrived at a similar conclusion as van der Meere, van Baal and Sergeant (1989); stating that ADHD children demonstrate competencies in the encoding, storage and retrieval of information (Sternberg's stages one to three) but have difficulties organizing and regulating their responses. Douglas asserts that this self-regulatory deficit contributes to the confusion surrounding diagnostic issues. ADHD children are highly variable and erratic in their performance, and they can be easily influenced by subtle alterations in assessment techniques. Therefore, these children may present with different problems at different times, making it extremely difficult to specify and define the precise nature of their disorder. Douglas comments on the fact that the erratic and variable performance of ADHD children contributes to what is often observed as a large discrepancy between the ADHD child's capacity and his/her level of performance.

Douglas (1988) also reported on a study conducted by Shue (unpublished doctoral dissertation) which specifically addressed the motor control deficits observed in ADHD children. In this study ADHD children were found to be impaired relative to normals on a conflictual motor responding test (Luria, 1973), a "Go-No-Go" task (Drewe,

1975, as cited in Douglas, 1988) and an Incompatible Compatible discrimination test (Drewe, 1975, as cited in Douglas, 1988). This latter task requires the subject to name or point to a response card which was either the same color or different than the stimulus card. The findings from this study indicate that ADHD children exhibit deficits in the execution and control of motor responses. Furthermore, they present with difficulties inhibiting an opposite or competing response, as well as an impairment in the ability to inhibit or terminate ongoing response tendencies (i.e., perseveration). Douglas comments on the parallels between these deficits and those observed in frontal lobe patients and suggests that if Shue's findings are replicated, these motor control tests should become a standard component of the evaluation of ADHD children.

Assessment of Executive Functions

Data from both the neuropsychological and cognitive domains suggest that ADHD children may have an impairment in the organization and output of responses. The neuropsychological literature suggests that tasks sensitive to frontal lobe dysfunction are valid measures of these outputting or executive capacities. Similarly, measures of executive functioning, which by definition require effortful, organized responses, also appear to have face validity in terms of their ability to examine the information processing deficits of ADHD children. Thus,

there is convergent validation from both the cognitive and neuropsychological literatures which indicates that measures of executive functioning are uniquely suited to assess the underlying symptomatology of ADHD.

The classic means of evaluating executive functions was developed by Luria (1966; 1973), who created a series of measures to discriminate the cognitive deficits associated with frontal lobe pathology in adult populations. He described these tests as assessing "executive functions" which were defined as the capacity to plan, initiate, program and monitor complex motor sequences. These tasks were designed to specifically evaluate "cognitive flexibility," as reflected by one's ability to shift set when confronted with changing contingencies, and "output organization," as reflected in one's ability to learn and perform complex motor sequences. To assess cognitive flexibility, he designed a competing motor programs task where the patient was instructed to tap once in response to the examiner tapping twice and to tap twice when the examiner tapped once. Another variant of this activity requires the patient to give a short hand squeeze in response to the examiner's long hand squeeze and vice versa. Patients with frontal lobe pathology tend to "mirror" the examiner's movement and are unable to inhibit this response in favor of a competing one. In order to assess output organization, Luria asked his patients to perform complex

sequential hand movements. One such sequence "edge-palm-fist" requires the individual to repeat a succession of hand movements. Patients with frontal lobe pathology have great difficulty performing these movements, and often perseverate, despite adequate comprehension of the task instructions. Thus, for both competing motor programs and sequential hand movements, patients with frontal lobe pathology can accurately repeat the instructions, but they cannot perform the task, despite the fact that they do not have a primary deficit in motor functioning.

As previously discussed, developmental psychologists have only recently begun to study the maturation of "executive functions" believed to be mediated by the frontal lobes, in children. Their measures are frequently adapted from tasks which have traditionally been employed for the assessment of adults. Therefore, it is necessary to develop and validate new measures which are appropriate for the study of executive abilities in children. The developmental data which have been collected thus far are preliminary and inconclusive (Becker, Isaac & Hynd, 1987; Cooley & Morris, 1990; Passler, Isaac & Hynd, 1988; Welsh & Pennington, 1988; Welsh, Pennington & Groisser, 1991). However, these studies consistently indicate that these functions are not fully developed until early adolescence.

Pilot Study

There is evidence to suggest that the children who receive the diagnosis of ADHD represent a heterogeneous group. Several investigators have proposed that these children can be subgrouped in order to delineate more distinct and homogenous diagnostic categories (August & Garfinkel, 1989; Halperin et al., 1990). Halperin and co-workers have argued that some ADHD children present as inattentive and more cognitively impaired, while others present as impulsive and more behaviorally disturbed. An alternate hypothesis regarding ADHD posits that these children have impairments in executive functioning, those abilities which involve the planning, initiation, organization and monitoring of goal directed behaviors. According to this model, an underlying deficit in executive abilities could explain the tremendous variability seen in ADHD children. The purpose of this pilot study was to examine the relationship between inattention, ADHD, and executive functioning in a sample of children who met DSM-III-R criteria for ADHD.

Method

Subjects. All children were recruited from an urban parochial school. The initial sample consisted of 73 non-referred school children, 32 boys and 41 girls who ranged in age from 6 to 14 years old. The majority of the sample was Hispanic (61.1%) or Black (34.2%), and all children were

English-speaking. Socioeconomic status was not determined individually for each child, however, the sample consisted primarily of children who were of a lower socioeconomic status. The sample was of average intelligence, with a mean (SD) WISC-R Full Scale IQ of 99.9 (13.84).

Materials and Procedures. There were two independent variables in this study: (1) presence or absence of teacher ratings of ADHD, and (2) presence or absence of attentional dysfunction. The subjects were divided into two groups based on teacher ratings on the Children's Behavior Questionnaire, which is comprised of DSM-III-R ADHD items. Children who were rated by teachers as having 8 of 14 symptoms present were classified as ADHD, while children with fewer than 5 symptoms were placed in the control group. Individuals who were rated as having 5 to 7 symptoms present were dropped from the study in an effort to clearly delineate between groups. This procedure classified 26% of the sample (N = 19) as ADHD and resulted in a final sample of 63 children.

Attention was objectively evaluated on the basis of subjects' performance on a computerized continuous performance test (CPT) modeled after the A-X task of Rosvold et al. (1956). The stimulus set contained 12 letters in all. A total of 400 stimuli were presented quasi-randomly on a Commodore 64 computer. Stimulus duration was 200 milliseconds with a 1.5 millisecond interstimulus interval.

The task duration was 12 minutes. Children were instructed to respond as quickly as possible with their preferred hand whenever the target, an X preceded by an A, appeared on the video monitor. An inattention score was calculated based on the number of omission errors (missed targets) plus the X-only commission errors (responding to X when not preceded by an A). Previous research with this instrument (Halperin et al., 1988) indicated that these error types provide an accurate index of inattention and also suggest that children who commit 4 or more such errors are exhibiting significant deficits in attention. Thus, children who committed greater than 3 inattention errors were placed in the inattentive group. Children were divided into inattentive and non-inattentive groups in order to explore the possibility of meaningful distinctions between these subgroups.

The dependent measure in this study was performance on a competing motor programs test which was employed as a measure of executive functioning. The task was programmed to run on a Commodore 64 computer. Children were seated in front of a video monitor on which two center keys were clearly labelled as "1" and "2." Children were told to use only their dominant hand to respond. A random sequence of 1's and 2's were delivered for a total of 150 trials, distributed evenly across five conditions. The task was self-paced, that is, the stimuli remained on the screen until the child responded. This was an effort to minimize

the effects of inattention since transient lapses of attention would thus not interfere with performance. In the baseline condition, directions were presented on the screen instructing children to press a "1" whenever they saw a "1" on the screen and to press "2" whenever a "2" appeared. After the baseline trials, the contingency was changed such that the children were instructed to press "2" whenever a "1" appeared and to press "1" whenever a "2" was presented. After 30 trials, the contingency was again shifted. Children were instructed to press "2" when a "1" appeared and to do nothing when a "2" was presented. In condition four, subjects were told to do nothing whenever they saw a "1" and to press "1" whenever they saw a "2." The final 30 trials were administered in the same manner as the baseline condition. Task duration, including instructions, was approximately five minutes.

Results and Discussion

Figure 1 shows the frequency of objectively-assessed inattention in the ADHD and Control groups. As assessed using the CPT, 52.6% of the children in the ADHD group were inattentive, as compared to 20.4% of the controls (Chi Square = 5.08, $p < .05$). Thus, significantly more ADHD children were assessed as inattentive, but about half of the ADHD children were not found to be inattentive. The dependent measure was assessed as follows: a regression equation which accounted for 49% of the variance was

computed using age, IQ and the number of errors in the baseline condition, to predict total number of expected errors in the "competing" conditions. For each child a difference score was calculated by subtracting his/her expected score form his/her actual score. A 2-way ANOVA (ADHD x CPT-Inattention) comparing these difference scores yielded a significant main effect for CPT-inattention [$F(1,59) = 4.64$, $p < .05$], but not for ADHD or the ADHD x Inattention interaction (See Figure 2).

Thus, these pilot data suggest that children rated by teachers as meeting DSM-III-R criteria for ADHD do not necessarily exhibit attentional dysfunction nor deficits in executive functioning. However, it does appear that the symptom dimension of inattention is related to an impaired executive functioning as assessed by the abilities to shift set and/or to resist responding to interfering stimuli. Based on the findings of the pilot study it was concluded that it might be advantageous for future research to focus on the neuropsychological correlates of inattention as well as the diagnostic category of ADHD when studying executive functions in ADHD children.

Rationale for the Present Research

This dissertation consists of two experiments. Experiment I was designed to assess the relationship between executive functions, as measured using tests of cognitive flexibility and output organization, and the ADHD symptom

dimensions of inattention, impulsivity and activity level. This first experiment was conducted on a large sample of non-referred children. The primary goal was to more clearly determine whether the behavioral dimensions of attention, impulse control and activity level are differentially related to executive function. This will facilitate a better understanding of the underlying brain-behavior relationships which mediate these functions in normal children. According to the frontal lobe hypothesis, ADHD is a unitary syndrome characterized by deficits in executive function. These impairments in executive abilities are thought to result in inattention, impulsivity and hyperactivity, each of which should be related to this measure of cognitive flexibility. However, if these behavioral dimensions are mediated by distinct neural substrates, they may be differentially related to measures assessing executive function.

Experiment II was designed to evaluate executive functions in ADHD and non-ADHD patients referred to a child psychiatry outpatient clinic. The goal was to determine whether deficits in executive functioning are specific to all ADHD children, a subgroup of children who receive the diagnosis of ADHD, or whether these deficits are more closely associated with the clinical presentation of attentional problems, irrespective of diagnosis.

Should the results of this study indicate that all ADHD children show executive function deficits, it would lend support to a unitary "frontal lobe" model of ADHD. If, however, only a subset of children diagnosed as ADHD show deficits in executive functioning, these data would lend further support to the notion that ADHD children, as currently diagnosed, represent a heterogeneous group with diverse underlying neural determinants. Finally, if non-ADHD patients groups who are characterized as having attentional deficits are also found to have impaired executive functions, it would suggest that these functions may be impaired in a wide range of child psychiatric patients. This would indicate that these symptoms are not a unique feature of any specific diagnostic category. Rather, it would suggest that attention, as clinically defined, may be related to those aspects of cognition which are involved in executive functioning irrespective of diagnosis. Such a finding would suggest that it may be advantageous for further research evaluating the neural substrates of psychopathology in children to focus on empirically measured dimensions of behavior, rather than clinically defined psychiatric diagnoses.

Experiment I

Rationale. The purpose of this experiment was to examine the relationship of executive functions to the behavioral dimensions of attention, impulse control and activity level

in a non-referred sample of children. The dimensions were assessed using teacher and parent ratings, as well as objective laboratory measures.

Hypothesis:

The frontal lobe hypothesis of ADHD posits that these children have deficits in executive or self-regulatory functions. The pilot data indicate that among ADHD children, some may be characterized as inattentive while others appear to have intact attentional functioning. Furthermore, there appear to be distinct neuropsychological correlates of these two subgroups such that only inattentive ADHD children present with impaired executive functioning. Therefore, it is hypothesized that executive function, as assessed by measures of cognitive flexibility, output organization and sequential motor movements, will be positively correlated with CPT attention but not with CPT impulsivity or actigraph measures. That is, children who demonstrate poor executive functions will appear inattentive, but not necessarily impulsive or overactive.

Method

Subjects

The sample consisted of 123 non-referred boys between the ages of seven and twelve years with a mean (SD) age of 9.4 years (1.4 years). Only boys were included because

ADHD is far more prevalent in boys than in girls (Szatmari et al., 1989; Trites, 1979) and because research suggests that ADHD symptoms manifest themselves differently in boys and girls (Pascualvaca, 1989). The sample was recruited from four elementary schools in a single town located in a suburb outside of New York City. All parents whose seven to twelve year old boys attended these schools were mailed consent forms along with a letter describing the purpose of the research and the testing procedure. Only those children for whom parental consent was received were included in the study. Approximately 30% of the parents who were mailed letters agreed to allow their child to be involved in the study. Participation was voluntary and individual results were kept confidential. Parents were provided with feedback upon request.

Socioeconomic status was not individually assessed, but the children were primarily from middle class families. Further, although primarily Caucasian, the sample was ethnically and culturally diverse. It consisted of 110 Caucasian children, 2 Black children, 10 children of Asian heritage and 1 child of Hispanic descent. All subjects were English speaking. Children with known neurological disorders (such as epilepsy or Tourette's syndrome) or other physical handicaps which impair motor functioning were excluded from the study. Additionally, children who were receiving psychotropic medications were excluded.

Measures

Behavior Rating Scales

Each child's behavior was rated by his classroom teacher using the Revised Conners Teacher's questionnaire (CTQ) and by his parent using the Children's Behavior Checklist (CBCL).

Conners Teachers Questionnaire (CTQ). The CTQ (Goyette et al., 1978) is a 28-item checklist which samples a number of behavior problems which are typically observed in the classroom (e.g., "disturbs other child", "restless in the "squirmy" sense", "uncooperative with classmates"). The questionnaire is scored on a four-point scale ranging from zero ("not at all" a problem) to three ("very much" a problem). A clinically derived Hyperactivity Index as well as three empirically derived factor scores, Conduct Problems, Inattention-passivity, and Hyperactivity, are derived from the CTQ. This scale has been useful in discriminating ADHD children from normals (McGee, Williams & Silva, 1984) and treated from untreated ADHD children (Barkley et al.,1989).

Achenbach Child Behavior Checklist (CBCL). The CBCL (Achenbach, 1976) is a 113-item checklist which is completed by parents. This questionnaire has been used to assesses a wide range of behaviors associated with psychopathology (e.g. "can't sit still, restless or

hyperactive," "too fearful or anxious," "sees things that aren't there" "talks about killing self"). Items on the checklist are scored on a scale ranging from zero ("not at all" present) to two ("pretty much" present). Standardized T-scores are generated for several factors. The "broad band" factors, (i.e., Internalizing and Externalizing) and the Total Behavior Problems score were used as measures of behavioral disruption.

Neuropsychological Test Battery

Each child was administered a 1-hour neuropsychological test battery consisting of tests of cognitive and academic functioning, as well as specific tests designed to assess attention, impulse control, cognitive flexibility, the organization of motor output and activity level. Specifically, the battery consisted of the following measures, which were administered in the following order to all subjects. The test order was designed to reduce fatigue and maintain maximal interest:

1) Peabody Picture Vocabulary Test - Revised (PPVT-R);
2) Raven Coloured Progressive Matrices (RCPM);
3) Competing Motor Programs Test:
4) Reading Subtest of the Wide Range Achievement Test - Revised (WRAT-R);

5) Reading Comprehension Subtest of the Peabody Individualized Achievement Test - Revised (PIAT-R);

6) Continuous Performance Test (CPT);

7) Revised Neurological Examination for Subtle Signs - hand patting, arm pronation-supination, finger tap, and finger sequences (NESS);

8) Hand Movements Subtest of the Kaufman Assessment Battery for Children (K-ABC);

9) Activity Level.

The RCPM and PPVT served as estimates of general intellectual functioning and the WRAT-R and PIAT-R provided indices of academic achievement. The CPT generated objective measures of attention and impulse control. Hand patting and finger tapping provided a measure of motor functioning as it relates to the degree of neurodevelopmental maturation. The remaining measures, including Competing Motor Programs, arm pronation-supination, finger sequencing and the K-ABC served as measures of executive functioning. Activity level was objectively measured during the testing session. Each of these measures is described below.

1) Peabody Picture Vocabulary Test - Revised (PPVT-R). The Peabody Picture Vocabulary Test - Revised (Dunn & Dunn, 1981) was used to provide an estimate of overall cognitive

function. The PPVT-R is a test of receptive vocabulary at the single word level. The child is required to point to one of four pictures that depicts the word spoken by the examiner. The PPVT-R has been found to predict Full Scale IQ, and like standard IQ measures, the PPVT-R yields a standard score with a mean of 100 and a standard deviation of 15. The PPVT-R provided a verbal measure of intellectual functioning.

2) Raven Coloured Progressive Matrices. The Raven Coloured Progressive Matrices (Raven, Court & Raven, 1985) is a culture-fair measure of perceptual organization and nonverbal reasoning. The child is required to choose, among six alternatives, the item which best completes an incomplete perceptual pattern. It was necessary to select a culture-fair IQ measure in order to diminish biases which impact on test performance, particularly when comparing individuals of differing socioeconomic status. A future study, involving an inner-city sample comprised primarily of lower SES children, was anticipated. Thus, to facilitate comparison between the present group of children and the inner city children, it was important to include an IQ measure which was less sensitive to cultural differences. The RCPM was included as it has been found to reliably predict IQ. Scores obtained on the RCPM may be converted to standard scores with a mean of 100 and a standard deviation of 15.

3) Competing Motor Programs. Cognitive flexibility, defined as the ability to inhibit interference from a competing or previously learned or routinized response, was assessed using a computerized task modelled after Luria's competing motor programs (Luria, 1966; 1973). The test was programmed to run on an IBM-compatible laptop computer. Luria used similar measures in his clinical assessment of adults with brain injury. He found these measures to be particularly sensitive to damage of the frontal lobes. In one version of Luria's task, the patient was given the following "conflicting" instructions: "When I raise my fist, you raise your finger. When I raise my finger, you raise your fist." Patient's with frontal lobe lesions typically had difficulty performing this task; they tended to imitate the examiner rather than follow the command. However, when questioned, these patients were able to state the task instructions, thus suggesting that their poor performance was not the result of a memory deficit. These patients had similar difficulties when instructed to tap once in response to two taps and to tap twice in response to one tap, or when asked to give a short hand squeeze in response to a long squeeze and a long squeeze in response to a short squeeze. Furthermore, Luria (1973) found this group of patients to be most impaired when presented with a motor program which conflicted with stereotyped (previously learned and mastered) routines and behaviors. Luria felt that the

difficulties with this task, which are characteristic of patients with frontal lobe disorders, reflected impairments in the organization, regulation and execution of motor programs.

The cognitive flexibility measure used for this study was designed to be analogous to Luria's competing motor programs tasks. Children were seated in front of a computer on which two central keys were clearly labelled as "1" and "2." A random sequence of 120 " 1's" and "2's" was presented in the center of the video monitor.

The 120 trials were distributed evenly across four conditions. During the first, "non-competing" condition, children were instructed to press the key labelled "1" whenever they saw a "1" on the screen and to press the key labelled "2" whenever a "2" appeared. After 30 trials, the test stopped and the contingencies changed to the "competing" condition; the child was instructed to press "2" whenever a "1" appeared and to press "1" whenever a "2" was presented. After an additional 30 trials, the children were again instructed to press "2" whenever a "1" appeared and to press the "1" whenever a "2" was presented. Following another 30 trials, the contingencies changed back to the non-competing task used in the first condition.

All children were instructed to respond as quickly as possible using the index finger on their dominant hand. Reaction times (RTs) for each correct response, as well as

the total number of correct responses and mean RT for each set of 30 trials was computed.

The task was self-paced in an effort to minimize the effects of inattention, since transient lapses of attention would thus not interfere with performance accuracy. Therefore, the number remained on the screen until the child responded. The next number was presented 200 msecs following the response. Total task duration was approximately five minutes.

The perceptual processing demands, attentional demands, memory load and motor response for the competing and non-competing conditions in this task are identical. It was believed that the competing condition, however, would be more difficult because it required a greater degree of executive control/cognitive flexibility, since a correct response requires the inhibition of an overlearned, routinized one.

In addition to the total number correct and RT data, several scores were generated from the competing motor programs test. These computed scores were used in the data analyses. A single score (N-Compete) was derived for the non-competing condition by summing the number correct x RT for sets one and four and dividing this number by the total number correct for sets one and four combined. This same procedure was employed using sets two and three in order to calculate a competing score (Y-Compete). Thus, a mean RT

for correct responses was computed for each condition. Additionally, an overall index of performance on the Competing Programs Task was derived by subtracting the N-Compete score from the Y-Compete score. The resulting score was called the Compete Index. This index was used as a measure of executive function; higher values indicate increased difficulty in the competing as opposed to the non-competing condition and thus reflect poorer cognitive flexibility.

Children with high error rates were eliminated from the data analyses as the meaningfulness of their RT data is of questionable validity (van der Meere & Sergeant, 1988a). The cutoff for a "high" number of errors was determined through a visual inspection of the error rates in the entire sample.

4) Reading Subtest - Wide Range Achievement Test Revised (WRAT-R). The reading subtest of the Wide Range Achievement Test - Revised (Jastak & Wilkenson, 1984) is a measure of decoding which requires children to read a series of progressively more difficult words aloud. It was included in order to assess the presence of a reading disability in the children. Investigators have differed in the manner in which they have defined learning disabilities. However, it is generally accepted that for a child to be classified as learning disabled his/her academic achievement should be low relative to both his/her age and level of intellectual

functioning. Comparison of WRAT-R and RCPM scores to generate an index of LD is facilitated by the fact that both measures yield standardized scores with a mean of 100 and a standard deviation of 15.

5) Reading Comprehension Subtest - Peabody Individual Achievement Test - Revised (PIAT-R). This test was also included to assess the presence of a reading disability. The reading subtest of the WRAT-R assesses decoding skills, which constitute only one component of reading ability. Many children with reading disabilities are able to decode, however they fail to comprehend the material which they have read. The reading comprehension subtest was included to decrease the likelihood of false negatives with respect to reading disability.

The reading comprehension subtest of the PIAT- R (Markwardt, 1989) requires the child to silently read a sentence and then to point to one of four pictures which best illustrates the ideas presented in the passage. Like the WRAT-R, the PIAT-R yields a standardized score with a mean of 100 and a deviation of 15.

6) Continuous Performance Test (CPT). Attention and impulse control were assessed using a computerized continuous performance test (CPT). The CPT was initially developed (Rosvold et al., 1956) to assess differences in the attentional capacities of normal and brain injured patients. It was believed that due to the rapid nature of the stimulus

presentation and the lengthy task duration, that the CPT would be sensitive to lapses in attention. Historically, the number of missed targets was considered to be an index of inattention, while false alarms were believed to reflect impulsivity. More recently, it has become apparent that the CPT measures a wide range of cognitive functions in addition to attention and impulse control. However, it is still useful as a clinical research tool for the assessment of attentional and impulse control disorders in children.

Researchers working with children have found that CPT performance can be utilized to reliably discriminate a variety of patient groups from normals. Specifically, differences have been found between normal controls and children with conduct disorders (Klee & Garfinkel, 1983; Shapiro & Garfinkel, 1986), attention-deficit hyperactivity disorder (O'Dougherty, Nuechterlein & Drew, 1984; Rosenthal & Allen, 1978; Sykes, Douglas, Weiss & Minde, 1971), learning disabilities (Dykman, Ackerman & Oglesby, 1979; Swanson, 1981) and children at high risk for schizophrenia (Cornblatt & Erlenmeyer-Kimling, 1985; Nuechterlein, 1983; Rutschmann, Cornblatt & Erlenmeyer-Kimling, 1977). However, CPT performance has not been shown to differentiate between various psychiatric populations.

Recently, through modifications of the CPT, it has been possible to develop somewhat purer objective measures of inattention and impulsivity which are uncorrelated with each

other and IQ, reliable over an extended period of time, and for which several forms of construct validity have been ascertained (Halperin et al., 1988; 19901a; 1991b).

This revised version of the CPT, which was used in the present study, was modelled after the A-X task of Rosvold et al. (1956) and run on laptop computers (Toshiba, Model # T1200). It consisted of 11 letters which were presented in a quasi-random order for a total of 400 stimuli. Each letter was presented for a duration of 200 msec. with a 1.5 sec. inter-stimulus interval. There was a 10% target frequency and the entire task lasted approximately 12 min. The CPT generated three measures; inattention, impulsivity and dyscontrol; which are described in more detail elsewhere (Halperin et al., 1988; 1991a; 1991b). The inattention measure was the number of omission errors plus the number of responses to "X" not preceded by "A" (X-Only Commission errors) with reaction times (RTs) longer than the child's mean hit RT. The CPT measure of impulsivity was the number of responses to "A" just prior to the onset of the next letter (A-Only errors) plus the number of responses to an "A-not-X" sequence with a RT faster than the child's mean hit RT. These inattention and impulsivity scores have been reported to have greater test-retest reliability and construct validity than the more commonly used omission and commission errors (Halperin et al; 1988, 1991a; 1991b). The less specific measure of dyscontrol, which is made up of a

combination of all the other forms of commission errors, has been found to correlate with behavior problems in children, but the precise function it assesses is less clear and its test-retest reliability is considerably lower than the measures of inattention and impulsivity (Halperin et al., 1991).

7) Revised Neurological Examination for Subtle Signs (NESS). Subjects were administered portions of the Revised Neurological Examination for Subtle Signs (Denkla, 1985). The NESS is a neurological screening battery which consists of a variety of motor tasks. These tasks can be divided into those that are repetitive in nature, and those that require the execution of more complex motor sequences. Luria (1973) suggested that the ability to perform complex sequential movements is related to the ability to organize a motor output (output organization). Thus, the sequential movements of the NESS may provide a measure of this executive function and was used as a measure of such in this study. In contrast, stereotyped or repetitive movements should not be impaired in individuals with higher order executive deficits. Therefore, the repetitive items from the NESS served as control measures, and assisted in determining the development of appropriate levels of motor functioning.

Subjects were asked to perform 4 items from the NESS, 1) repetitive hand pat, 2) arm pronation-supination, 3)

repetitive finger movements, and 4) successive finger movements. Repetitive hand pat requires the child place his open hand palm down upon his thigh, and then repeatedly pat his leg with his hand as quickly as he can. Arm pronation-supination is a variation of the first activity; the child begins by patting his hand on his thigh once and then turns his hand over and pats his leg using the upper side of his hand. Repetitive finger movements involves touching the index finger to the thumb while keeping other fingers of the hand immobile. Finally, successive finger movements requires that the child touch first his index finger, then middle finger, then ring finger and pinky to his thumb, and then begin the sequence again.

Initially, the examiner demonstrated each movement and the child was asked to model the activity using his preferred hand. The child was then given feedback regarding the accuracy of his performance. Once the child demonstrated a clear understanding of the task, as assessed by his ability to accurately perform the motor movement, he was instructed to perform the movement as quickly as possible until the examiner signaled him to stop. The examiner recorded the time to perform 20 movements to the nearest tenth of a second. There were two trials for each movement and children were required to perform the movements separately using their left and right hands. The mean time

per 20 movements was then calculated for each task administered.

8) Hand Movements - Kaufman Assessment Battery for Children (K-ABC). The ability to organize and execute a complex motor program was further assessed using the Hand Movements subtest of the Kaufman Assessment Battery for Children (Kaufman, 1983), which requires the child to perform sequences of hand movements such as those described by Luria (1966; 1973). Luria reported that even normal adults had some difficulty mastering the "fist-edge-palm" sequence of hand movements. However, with some training, normal adults were able to perform the task efficiently. In contrast, patients with lesions involving the frontal lobes demonstrated significant impairments in their ability to perform this sequence of skilled movements. They often perseverated the first movement and had trouble moving on through the sequences. Luria described these patients as having difficulties in the "dynamic organization of movements...[they do] not form the complex kinetic melody requiring the inhibition of the series once begun and return to the first movement." (p. 422-424 Luria, 1966).

The Hand Movements subtest of the K-ABC, which was used in this study, is normed for ages 2 years, 6 months through 12 years 5 months, and is clearly age appropriate for these subjects. Initially, the subjects were asked to imitate each of the three movements after it had been

modeled by the examiner; palm, side and fist, as originally described by Luria. The child was then asked to imitate the sequence palm-palm as a practice item. The test consisted of the child imitating a series of hand movements which were demonstrated by the examiner. The sequences varied in length from 2 to 6 movements and became increasingly complex as the task progressed. The total number of correctly executed sequences (prior to a ceiling) was calculated. This score was converted into a standard score with a mean of 100 and a standard deviation of 15, based upon published norms (Kaufman, 1983), to facilitate more direct comparison with other measures.

9) Motor Activity. Activity level was automatically and continuously recorded from all children during approximately the first 50 minutes of the assessment. It was measured using solid state actigraphs (Ambulatory Monitoring , Inc; Cat. # 20.100) which count truncal body movements in 4-minute epochs. This monitor, which weighs approximately 3 ounces, was placed in a money pouch and secured around the child's waist. The belt was positioned so that the monitor rested near the small of the child's back. The monitor was removed for the last portion of the assessment when the Hand Movements and NESS items were administered, as these tests may have contributed to artificially increasing the activity scores. Previous research has shown actigraphs to have good test-retest reliability and to generate measures which are

correlated with both parent and teacher ratings of hyperactivity (Reichenbach et al., 1992). Furthermore, actigraph measures have been found to distinguish ADHD children from normal controls and stimulant from placebo-treated ADHD children (Porrino et al., 1983a; 1983b).

Procedure

All children were tested at school during normal school hours. Every effort was made to minimize disruption of the child's school day. Testing was conducted in vacant offices or classrooms. The order of task presentation remained consistent for each subject.

Data Analysis

A. Validation of Cognitive Flexibility Measure. To validate the competing motor programs measure, two one-way repeated measures analyses of variance comparing the four sets were computed. If the task worked as it was originally designed and conceptualized, sets two and three should contain significantly more errors and have significantly longer RTs than sets one and four.

B. Hypothesis Testing. The hypothesis was evaluated through the formation of a single measure of executive function. This measure was calculated based upon performance on the four measures believed to assess executive functions: competing motor programs, K-ABC, arm pronation-supination and finger sequencing. Scores for each test were converted to Z-scores and then combined to form a single measure. The

relationship of this measure of executive function to CPT-attention, CPT-impulsivity and activity level was determined using partial correlations controlling for age and IQ. One-tailed tests of significance were used since the hypothesized relationship is highly specific with regard to the direction of the relationship.

C. Secondary Analysis. A principal components factor analysis with varimax rotation was conducted to examine the inter-relatedness of the objective and behavioral measures, and to generate hypotheses regarding possible cognitive mechanisms underlying functions. Most major variables in this study, including K-ABC, CPT-attention, CPT-impulsivity, NESS-repetitive and sequential scores, compete scores, mean activity level, CTQ-Hyperactivity Index and CBCL-Total Behavior Problems score, were statistically adjusted for age and IQ and entered into a factor analysis.

Results

Sample Characteristics

As shown in Table 1, the sample was found to be of average intelligence as estimated by both the PPVT-R and RCPM. Overall level of academic achievement, as estimated by the Reading subtest of the WRAT-R and the Reading Comprehension subtest of the PIAT, was also found to be within the average range. Four children, 3.3 percent of the sample, were found to have a learning disability (LD). The determination of LD was based upon the child obtaining a

score on the WRAT-R or PIAT-R which was at least 1 SD (15 points) below the mean for his age, and there being a discrepancy of at least 15 points between his IQ (RCPM + PPVT/2) and either the WRAT-R or PIAT-R standard scores.

Teacher ratings of behavior were obtained for all but one subject. Factor scores summarizing the sample's behavior ratings on the Conners Teacher's Questionnaire are presented in Table 2. Mean factor scores of Hyperactivity, Inattention/Passivity, Conduct Problems and the Hyperactivity Index were all within normal limits. Parent ratings of behavior were obtained for 119 of the subjects using the Child Behavior Checklist. T-scores generated for the Internalizing, Externalizing and Total Behavior Problems scales of the CBCL are summarized in Table 3. These scores were also well within the normal range. Thus, the sample appears to be normal with respect to cognitive, academic and behavioral functioning.

Validation of the Competing Motor Programs Test

If this task functions as it was initially conceived and designed, subjects should have longer reaction times and make more errors in sets two and three (the competing conditions) than sets one and four (the non-competing conditions). Therefore, validity of the competing motor programs test was assessed using separate repeated measures analyses of variance comparing number correct and RT across the four sets. The mean number of correct responses across

conditions (sets one to four) are summarized in Table 4. As shown in Table 4, a significant main effect was found for total number correct, $F(3,336)=8.79$; $p < .0001$.

These findings are further depicted in Figure 3. Subjects made fewer correct responses in the competing condition (sets two and three) than the non-competing condition (sets one and four). Paired t-tests comparing the number of correct responses across sets one to four indicate that subjects' performance on set one differed significantly from set two [$t(122)=5.72$, $p < .0001$], set three [$t(122)=4.51$, $p < .0001$] and set four [$t(122)=3.33$, $p < .001$]. There was no significant difference in the number of correct responses between sets two and three, but there was a tendency [$t(122)=-1.85$, $p < .07$] for performance to improve between sets three and four.

In order to increase the likelihood of obtaining meaningful RT data from the competing motor programs test, subjects with high error rates need to be eliminated from the analyses (van der Meere & Sergeant, 1988a). This is due to the fact that when a subject makes many errors, it is unclear whether or not RT differences reflect aspects of the experimental manipulation, a failure of the subject to fully comprehend the task instructions, or a lack of compliance with the task demands.

The sample distribution of total number correct on the competing motor programs test is presented in Figure 4.

After a visual inspection of these data, it was decided that only children with at least 106 correct responses (88% correct) would be included for further data analyses. This resulted in the elimination of eleven subjects (9% of the original sample). Thus, the final sample included 112 boys. As illustrated in Tables 5 - 7, this elimination process did not significantly alter the sample characteristics, which remained within the normal range with respect to cognitive, academic and behavioral functioning.

As with the error rate, analyses of the more sensitive RT data indicate that the task had the desired effect (see Figure 5). A repeated measures analysis of variance comparing RT across the four sets yielded a significant effect for RT, $F(3,333) = 130.32$; $p < .0001$. As depicted in Table 8, RTs were fastest during set one, while the greatest response latency was observed during set two. RTs decreased significantly (relative to performance on set two) during set three and RTs became faster on set four though not returning to the level obtained during the baseline condition (set one). Paired t-tests comparing RTs on sets one to four were all significant (See Table 9).

Thus, these data support the construct validity of the competing motor programs test as subjects made more errors and obtained significantly longer RTs in the competing conditions (sets two and three) as compared with the non-competing condition (sets one and four).

Further analyses were conducted to examine the relationship between number correct and RT on the competing motor programs test. A difference score was computed between the number correct in the non-competing versus the competing conditions. Partial correlations controlling for age and IQ were then conducted utilizing the entire sample (N = 123). A significant relationship was found between this difference score and the Compete Index ($r = .24$, $p < .01$). When subjects who committed a high number of errors on the task were eliminated from the data analysis, the magnitude of the relationship between the difference score and compete index increased ($r = .34$, $p < .001$).

The relationship of these measures (RT and number correct) was also examined in the subjects who made a high number of errors on the competing motor programs test. In this group, no relationship was found to exist between the difference score and the Compete Index ($r = .11$, $p > 05$). Thus, in children who do not make a high number of errors on the competing motor programs test, RT and error rate appear to be related and provide indices of similar constructs.

Reliability. Split-half reliability was assessed by comparing Rts in sets one and four ($r = .63$, $p < .0001$) and RTs obtained in sets two and three ($r = .84$, $p<.0001$). The Spearman-Brown formula was used to adjust the split-half correlation (Anastasi, 1988; Pp. 121) and the resulting split-half reliabilities were in the acceptable range for

both sets one and four (r_u = .78) and sets two and three (r_u = .91).

Test-retest reliability of the Competing Programs Test was assessed in 27 children. Reliability coefficients were significant for the N-Compete and Y-Compete scores (r = .75, p < .0001 and r = .76, p < .0001, respectively) but not for the Compete Index or the total number correct. The effect of practice was also assessed for the four measures using paired t-tests. Significant practice effects were found for both the N-Compete and Y-Compete scores, which decreased significantly upon repeat testing. There were no practice effects for the Compete Index or total number correct (see Table 10).

Age and IQ Effects. Age and IQ effects of the competing motor programs test were examined by calculating the correlations between these variables and the Compete Index. A significant age effect was found (r = -.21, p < .01) as well as a significant IQ effect for the RCPM (r = -.23, p < .006), but not for the PPVT (r = .05, NS).

Continuous Performance Test

Objective measures of inattention, impulsivity and dyscontrol were obtained for the entire sample using the CPT. The mean (SD) number of inattention, impulsivity and dyscontrol errors is presented in Table 11. For a discussion of reliability and validity of the CPT see Halperin et al., 1991.

Age and IQ Effects. Significant age effects were found for the inattention ($r = -.39$, $p < .0001$) impulsivity ($r = -.20$, $p < .02$) and dyscontrol ($r = -.19$, $p < .02$) errors. Furthermore, IQ as estimated by the RCPM was related to the total number of dyscontrol errors ($r = -.23$, $p < .008$), but not to inattention or impulsivity ($r = -.05$ and $r = .007$ respectively, NS). There was no effect of IQ as estimated by the PPVT on any of the three error scores derived from the CPT.

Activity Level

An activity score was generated for 103 subjects; data for nine subjects were lost due to technical problems. The activity score was calculated by averaging the actigraph counts for each of the four-minute epochs which transpired while the child was wearing the actigraph. The first and last epochs were omitted in order to minimize error variance related to putting on or removing the device. This resulted in approximately 12-15 four-minute epochs being used for each child. The mean (SD) activity score for the sample was 29.68 (14.80). Activity level was not significantly correlated with age ($r = -.10$, NS), RCPM ($r = -.10$, NS), or PPVT ($r = -.10$, NS).

NESS Hand Movements

The mean time to execute each of the four NESS movements with the left and right hand is shown in Appendix A. Test-retest reliabilities were assessed separately for

the left and right hand by comparing performance on trials 1 and 2 for each type of movement. Correlations were significant for all categories of movement (r's ranged from 0.77 to 0.87, all $p < .0001$). Furthermore, correlations assessing the degree of relatedness between right and left sided performance on each category of movement were also highly significant ($r = .53$ to $r = .87$, $p < .0001$). Due to both the good test-retest reliability and the strong relationship found between left and right hand performance, a single measure was computed for each category of movement.

Age and IQ Effects. As would be predicted on the basis of neurodevelopment, age was found to be highly related to each of the four movements (see Table 12). There was no relationship between any of the NESS movements and IQ as estimated by either the RCPM or PPVT (see Table 12). Thus, the NESS appears to be a reliable and age related measure suggesting that it is probably a valid indicator of developmental motor functioning.

Based on a priori hypotheses that the arm pronation-supination and finger sequencing movements would provide an index of response organization, these two measures were averaged to yield a single measure of executive/sequential motor functioning. The remaining movements were hypothesized to reflect more basic motor functioning and degree of neurodevelopmental maturation. Thus, these latter measures were combined to yield a measure of non-executive/repetitive

motor functioning. The resulting mean (SD) time to complete the executive movements was 8.62 (1.9) seconds, while the mean (SD) time to complete the non-executive RT was 4.98 (.56) seconds.

K-ABC Hand Movements

The raw score and standard score from the Hand Movements subtest of the K-ABC was calculated for each subject as specified by Kaufman (1983). The mean (SD) raw score was 13.79 (2.8) and the mean (SD) standard score was 103.97 (12.38). Thus, overall the sample performed at an average level on this measure.

Hypothesis Testing

It was hypothesized that the measures of executive function (arm pronation-supination, finger sequences, the Compete Index and the K-ABC) would be positively correlated with CPT-attention, but not CPT-impulsivity or measures of activity level. Z-score transformations were performed on the Compete Index, mean time to complete the NESS executive/sequential movements (arm pronation-supination, finger sequences) and K-ABC Hand Movements score. On the basis of a priori hypothesis that these tasks each require executive abilities, the three scores were combined and averaged to generate an overall index of executive functioning.

As hypothesized, partial correlations controlling for age and IQ yielded a significant relationship between

executive functioning and CPT attention ($r = .28$, $p < .001$). No significant correlation was found between executive functioning and impulse control ($r = .07$, NS) or activity level ($r = .01$, NS). Correlations examining the relationship between parent and teacher ratings of behavior and executive functioning were also not significant ($r = .02$, NS and $r = -.01$, NS, respectively).

To further examine the degree of relatedness among the executive function measures and their individual relationship with attention, partial correlations controlling for age and IQ were computed between each of the relevant pairs of variables. No relationships were found between ratings of behavior and laboratory measures with the exception of a significant correlation between teacher ratings of hyperactivity and objectively assessed activity level ($r = .22$, $p < .01$) (see Table 13). While the Compete Index and the K-ABC Hand Movements were found to be highly related to each other ($r = -.26$, $p < .003$), neither measure is related to the NESS executive/sequential movements. Furthermore, while both the Compete Index and the Hand Movements were related to CPT attention ($r = .25$, $p < .003$, and $r = -.18$, $p < .03$, respectively) the NESS executive/ sequential movements were found to be unrelated to attention ($r = .11$, NS) (See Table 14). An unexpected relationship was found between the NESS non-executive/repetitive

movements and CPT attention ($r = .21$, $p < .01$), but this measure was unrelated to the Compete Index and the K-ABC.

Similarly, the relationships among the CPT-attention, CPT-impulsivity and actigraph measures of activity level were evaluated using partial correlations controlling for age. CPT-attention and CPT-impulsivity were found to be unrelated to each other ($r = 0.07$, NS) and to activity level ($r = .09$ and $r = .003$ respectively, NS). This finding supports the notion that these three behavioral constructs, as defined and assessed in the present study, are relatively independent of each other.

Overall, these data support the hypothesis that children who demonstrate poor executive functioning are inattentive, but not necessarily impulsive or overactive. The data only partially support the a priori hypothesis that the Compete Index, K-ABC Hand Movements and NESS executive/sequential movements measure related functions. While the Compete Index and K-ABC are highly related, the data do not support the inclusion of the NESS executive/sequential movements as a third measure of executive ability. Additional analyses were conducted in an attempt to clarify the inter-relationships among the variables.

Exploratory Factor Analysis

To further explore the relationship among the measures, a principal components factor analysis with varimax rotation

was applied to scores that were corrected for age and IQ. The following variables were included: teacher and parent ratings of behavioral disruptiveness, CPT-attention, CPT-impulsivity, activity level, K-ABC, Compete Index and mean time to complete each of the 4 categories of NESS movements. The CPT-dyscontrol score was omitted from this factor analysis as this measure provides a non-specific index of CPT performance and relationships between this measure and other variables would be difficult to interpret. A Factor loading of .50 was considered to be significant for the purpose of this analysis.

The factor analysis yielded 4 independent factors accounting for 58.2% of the variance (see Table 15). Factor 1, which accounted for 20.1% of the variance, consisted of significant loadings from the NESS hand patting, arm pronation-supination and finger sequencing and a weak loading (.40) from finger tapping. Thus, factor 1 could be considered a motor factor. Factor 2, which consisted of activity level and parent and teacher ratings of behavior, accounted for 14.4% of the variance. This factor seems to be assessing disruptive behavior. Factor 3, which included CPT attention, the Compete Index and K-ABC Hand Movements accounted for 13.5% of the variance. This factor seems to represent executive functioning. The fourth factor consisted of only CPT Impulsivity along with a weak loading from K-ABC and thus could be considered an impulsivity

factor; however, it is always difficult to interpret a factor which consists of only one loading. This latter factor accounted for 10.1% of the variance.

In order to assess the effects of age on the relationships between the measures, the subjects were divided in half on the basis of age (younger versus older children). Separate factor analyses were conducted to examine the relationship of the variables in these groups. In both cases, a five factor solution was obtained. In the younger children, the executive factor remained (CPT attention, Compete Index and K-ABC). However, in older children, the Compete Index loaded with the K-ABC and CPT impulsivity. CPT attention loaded on a separate factor together with the K-ABC. Thus, in older children, performance on the competing motor programs test may be more related to laboratory measures of impulsivity than inattention.

Brief Discussion

This experiment was designed to examine the relationship of attention, impulse control and activity level to measures of executive functioning in a large, non-referred sample of school age boys. Executive functioning was assessed using three distinct measures: 1) the Hand Movements subtest of the K-ABC, 2) the arm-pronation-supination and finger sequencing from the NESS, and 3) a

computerized adaptation of Luria's competing motor programs test.

The Hand Movements subtest is a well normed and standardized measure modeled after the "edge-palm-fist" task employed by Luria (1973) in his assessment of executive functions. The abilities assessed by this measure have been documented to be impaired in adults with frontal lobe lesions (Luria, 1973). The NESS movements have been normed in a large sample of children (Denkla, 1985). The inclusion of the arm pronation-supination and finger sequencing as measures of executive functioning was based on the fact that these items appear to require the organization and output of more complex, sequential and alternating movements; capacities which may reflect self-regulatory or executive abilities. The competing motor programs test is an experimental measure. While this measure was also based upon a task used by Luria to assess frontal lobe functioning, this computerized adaptation of the task has not been previously used. Thus, there is no empirical evidence to support its use as a measure of executive functioning. Therefore, before discussing the results in relationship to the hypotheses, it is important to discuss the construct validity of both the NESS measures and the competing programs test.

The data with regard to the NESS provide no evidence supporting the notion that these movements assess any

capacity other than basic motor functioning. The arm pronation-supination and finger sequencing movements were highly correlated with the other NESS items. However, no relationship was found between these movements and other tasks which are purported to be measures of executive and/or frontal lobe functioning.

In contrast, analysis of the competing motor programs test supports the construct validity of this task as a measure of executive functioning. The data were examined to ensure that the task had the desired effect (competing conditions more difficult, as indicated by longer RTs, than non-competing conditions). The findings indicated that subjects had the most difficulty, made more errors and had longer response latencies, in the competing (sets two and three) as opposed to the non-competing conditions. As previously discussed, the memory load, encoding and processing demands of the two conditions were the same (Sternberg, 1968), only the response organization demands were varied. Therefore, it can be inferred that differences in performance across the conditions can be attributed to the increased response organization demands of the competing, as opposed to the non-competing condition. Further, performance on the competing programs test was significantly related to the K-ABC hand movements.

Thus, these data only support the inclusion of two of the three purported measures of executive functioning (Hand

Movements and competing motor programs). The NESS movements may be associated with executive functioning, however, they are not associated with the component of executive functioning which is being assessed in the present study.

With regard to the specified hypothesis, the data support the notion that objective measures of attention are related to executive functioning. In contrast, both ratings and measures of impulsivity and hyperactivity were unrelated to measures of executive functioning. This finding does not imply that impulsivity and hyperactivity are not related to self-regulatory functions, but rather, that they are not related to these capacities as assessed in the current study. Given the functional (Diamond & Goldman-Rakic, 1989) and neuro-anatomical (Goldman-Rakic, 1971) diversity of the executive functions believed to be mediated by the frontal lobes, it is possible that differential relationships between these behavioral constructs and measures of executive ability may be found.

Thus, these data suggest that in normal children, dissociations can be found among the various ADHD symptom dimensions. Objectively assessed inattention, but not impulsivity or overactivity appears to be related to executive functions as assessed in the present study. The frontal lobe hypothesis of ADHD would posit that inattention, impulsivity and overactivity are all attributable to a dysfunction in self-regulatory functions.

While one must use caution when making inferences between normal children and patient groups, the present findings are consistent with recent investigations (August & Garfinkel, 1989; Halperin et al., 1990) which have suggested that ADHD children may be divided into meaningful subgroups on the basis of inattention/cognitive functioning. Similarly, the present data suggest that only a subgroup of ADHD children, those characterized by inattention, will exhibit poor executive functions.

Experiment II

Rationale: This experiment was designed to evaluate ADHD and non-ADHD child psychiatric patients and normal controls in order to determine whether impaired cognitive flexibility is specific to the diagnosis of ADHD, or whether it is related to the symptom dimension of inattention, irrespective of diagnosis.

Hypothesis:

Data suggest that not all children who meet criteria for ADHD are inattentive, and that other groups of child psychiatric patients present with attentional problems. Furthermore, data from Experiment I indicate that inattentive children manifest impairments in executive functioning. Therefore, it is hypothesized that deficits in executive functioning, as assessed by the competing motor programs test, will be associated

with objectively assessed attentional problems in children, irrespective of diagnosis.

Method

Subjects

The sample consisted of 62, unmedicated boys, between the ages of 6 and 12 years, who were consecutively referred to the child psychiatry outpatient clinic of a major metropolitan medical center. Eighteen normal controls were recruited from a nearby parochial school, thus, increasing the overall sample size to 80 children. The mean (SD) age of the sample was 9.7 years (1.8 years). Each child's behavior was rated by his teacher using the CTQ and by his parent using the Achenbach CBCL. In addition, patients were evaluated by a clinician through the use of a series of clinical interviews with the parent and child both separately and together. The clinician was blind to all psychometric data.

Upon completion of the patient's assessment, using clinical interview and rating scale, but not psychometric data, the clinician was asked to complete a 70-item scale containing the DSM-III-R items for ADHD, conduct disorder, oppositional defiant disorder, avoidant disorder, overanxious disorder, separation anxiety disorder, dysthymia and major affective disorder. Symptoms pertaining to each disorder were listed in random order, and the clinician rated each symptom as either absent or present (Halperin et

al., 1992; Matier et al., 1992). In cases where the clinician felt uncertain about his/her assessment of a particular symptom, he/she was asked to schedule an additional session wherein the presence or absence of the symptom could be ascertained. Research diagnoses were then generated using a computer algorithm based upon DSM-III-R criteria. Children presenting with possible psychosis and/or neurologic disorders were dropped from the study. These diagnostic procedures resulted in the classification of 24 patients as ADHD and 38 as non-ADHD.

Materials

Psychometric Measures. Psychological testing consisted of the following tests administered in the following order, all of which were described in Experiment I.

1) Peabody Picture Vocabulary Test - Revised (PPVT);
2) Raven Coloured Progressive Matrices (RCPM);
3) Competing Motor Programs;
4) Reading Subtest of the Wide Range Achievement Test - Revised (WRAT-R);
5) Reading Comprehension Subtest of the Peabody Individualized Achievement Test - Revised (PIAT-R);
6) Continuous Performance Test (CPT);
7) Activity Level.

The NESS was omitted from this test battery as the data analysis conducted in Experiment I suggested that this measure did not provide an index of executive ability. Further, due to the time constraints, the K-ABC Hand Movements subtest was not administered in Experiment 2. The total duration of the psychometric assessment was approximately one hour.

As in Experiment I, the PPVT and RCPM provided an estimate of general intellectual ability, while the WRAT-R and PIAT-R were used to provide an index of academic achievement. Objective measures of attention and impulse control were obtained from the CPT and activity level was measured using solid state actigraphs. The competing motor programs test served as the sole index of executive ability in Experiment II.

Procedure

All patients were tested in a quiet office at the hospital. Testing was generally conducted during normal school hours. Controls were tested at their school during normal school hours. The order of task presentation remained consistent for each subject.

Data Analyses. Children were divided into three diagnostic groups, ADHD patients, non-ADHD patients and normal controls. The subjects were also divided into groups based upon the presence or absence of inattention, as measured using the CPT. Individual subject's performance on

the CPT was compared with the age norms which were generated from Experiment I; children under age seven were eliminated as no norms were collected for this age group, whereas children older than eleven were compared against the eleven year-old norms. The older children were combined with the eleven year-old group because the normative data suggest that by age eleven children rarely make errors on this task (Halperin et al., 1991). Thus, the performance of twelve year olds was unlikely to differ from that of the eleven year olds. In contrast, it was not felt the seven year-old norms would be meaningful in assessing the performance of six year olds.

Children were considered to be inattentive if their CPT inattention score was greater than 1.5 SD above the mean for their age, as compared to the large normal group used in Experiment I. Subjects were considered to be non-inattentive if their CPT inattention score was less than 1 SD above the mean for their age. Those with scores between 1 and 1.5 SD above the mean for their age were eliminated from the analyses to provide a clear distinction between the groups. When used in the past, similar procedures for identifying inattentive and non-inattentive children have been useful in differentiating between distinct groups of children within a non-referred sample (Halperin et al., 1990a). This procedure resulted in the elimination of 10 subjects (11% of the sample) and reduced the sample size to

70 children. Three children were eliminated because they were younger than seven years old and the remaining six children were eliminated on the basis of their CPT performance (i.e., between 1 and 1.5 SD below the mean).

A 2 x 3 Chi Square analysis was initially used to examine the distribution of inattentive and non-inattentive children across the three diagnostic groups. Subsequently, the hypothesis that inattentive children would demonstrate difficulties in executive functioning, irrespective of diagnosis, was evaluated using a three-way analysis of variance. There were two between group variables, Diagnosis (ADHD versus non-ADHD versus controls) and Attention (inattentive versus non-inattentive). There was one within group variable, Condition (competing versus non-competing). A main effect for Condition would again, as in Experiment I, indicate that the task is functioning as it was originally conceived and designed. The hypothesis would be supported by a significant Attention x Condition interaction.

Results

Sample Characteristics

As shown in Table 16, the three groups did not differ significantly in age [$F(2,77) = 2.09$, N.S.]. There was, however, a significant group difference [$F(2,67) = 20.98$, $p < .0001$] on the RCPM. Post hoc Tukey HSD indicated that all three groups differed significantly from each other. Thus,

the controls scored significantly higher than the ADHD group who scored higher than the non-ADHD patient group (see Table 16). On the less culture-free PPVT, there was also a significant group difference [$F(2,77) = 3.70$, $p < .03$]. As illustrated in Table 16, post hoc analysis indicated that the non-ADHD patients scored significantly lower than the control group.

The control group was found to be achieving at age appropriate levels on both the WRAT-R and PIAT-R (mean standard scores of 99.9 and 101.2, respectively). In contrast, both patient groups performed at least 1 standard deviation below the mean for their age on the WRAT-R (see Table 16). ADHD and non-ADHD patients were found to be achieving at significantly lower levels than the control group on the Reading subtest of the WRAT-R [$F(2,75) = 5.87$, $p < .004$)], but the two patient groups did not significantly differ in their performance on this measure. Furthermore, only the non-ADHD patients performed at a significantly lower level than controls on the PIAT-R [$F(2,55) = 3.87$, $p < .03$]. Performance of the ADHD group did not differ significantly from that of either the controls or non-ADHD patients on the PIAT-R.

Thus, on tests assessing general intellectual functioning and academic achievement, the control group was found to be performing well within the Average range. In

contrast, the two patient groups were generally found to be performing within the Low Average range on these measures.

Behavior Rating Scales

Teacher ratings of behavior were obtained for the entire control group but were not obtained for 8 non-ADHD patients and 3 ADHD patients. Factor scores summarizing the sample's behavior ratings on the Conners Teacher's questionnaire are presented in Table 17. There were significant group differences on all three factors of the CTQ as well as the Hyperactivity Index. Post hoc analyses indicated that the two patient groups were rated as significantly more impaired than controls on the Conduct Problems and Inattention-Passivity factors, as well as on the Hyperactivity Index. Only the ADHD group was rated significantly higher than the normal controls on the Hyperactivity factor.

Parent ratings of behavior were obtained for only nine children in the control group due to a failure of half of the parents to return the CBCL. Furthermore, parent ratings were not available for two non-ADHD patients and for four ADHD patients. Table 17 shows the group comparisons on the CBCL. There were no significant group differences for the Internalizing scale of the CBCL, but on the Externalizing scale, ADHD children scored significantly higher than both the non-ADHD patient group and the normal controls.

Furthermore, on the Total Behavior Problems scale, the ADHD group scored significantly higher than the control group.

Objective Measures of Attention

As shown in figure 6, the distribution of objectively determined inattention differed significantly across the diagnostic groups (Chi-Square = 8.24, $p < .05$). However, the frequency of inattention did not differ across the two patient groups. Whereas 53 percent of the ADHD group was found to be inattentive, 42 percent of the Non-ADHD children were also found to be inattentive. Only one normal control, .07 percent, was found to be inattentive.

Hypothesis Testing

Since only one child from the control group was found to be inattentive, the hypothesis could not be evaluated using the three groups. Therefore, only the two patient groups were used to assess the hypothesis using a 2 x 2 x 2 ANOVA. As in Experiment I, in order to increase the likelihood of obtaining meaningful RT data, it was important to eliminate those children who made a high number of errors on the competing motor programs test. Therefore, again, those children with fewer than 106 correct responses were eliminated. However, as is shown in figure 7, this procedure resulted in an unequal elimination of subjects across the groups. Whereas .07 percent of the normal group would have been eliminated, 33.3 percent of the Non-ADHD children and 47.3 percent of the ADHD children would have

been eliminated (Chi-Square = 6.57, p = .05). Thus, this process not only would differentially and systematically alter the groups, but it would also result in a substantially reduced number of subjects, thereby diminishing the power of the statistical analysis. Therefore, it was decided to use the less sensitive measure of errors, rather than RT, since the latter measure would have been of questionable validity.

The hypothesis stated that deficits in cognitive flexibility would be associated with CPT assessed attentional problems, irrespective of diagnosis. The three-way (Group x Attention x Condition) ANOVA yielded main effects for Condition ($F = 23.23$, $p < .001$), Group ($F = 7.52$, $p < .01$) and Attention ($F = 14.32$, $p < .001$). However, there were no significant interactions between any of the independent variables. Figure 8 depicts the main effect for group, figure 9 depicts the main effect for attention and figure 10 shows the lack of a significant interaction when the sample was subdivided by both grouping variables (i.e., Diagnostic group and Attention). Thus, the hypothesis was not supported; ADHD children performed more poorly than non-ADHD children, and children with objectively assessed inattention performed more poorly than those who were not inattentive, this decrement in performance is not attributable to the executive component of the competing motor programs test. In other words, both the ADHD group

and the Inattentive group displayed a performance decrement on this task which can not be attributed to the experimental manipulation.

Further analyses were conducted to discern whether the poorer performance of ADHD and inattentive children on the competing motor programs test was due solely to a performance decrement or if some other factor contributed to lowering their scores. The control group was included in this analysis in order to provide an index of normal functioning. Figure 11 compares the performance of the inattentive, non-inattentive and control groups across all four sets of the competing programs test. The inattentive group was found to have significantly ($p < .05$) fewer correct response across all four sets relative to the other groups. Similarly, figure 12 shows the performance of the ADHD, non-ADHD and control groups across the four sets. The three diagnostic groups did not differ significantly ($p > .10$) in their performance during Sets one and two. However, the ADHD group made significantly more errors during Sets three ($F= 6.78$, $p < .002$) and 4 ($F = 3.28$, $p < .05$). Post hoc analyses using Tukey HSD indicate that during set three, the ADHD children made significantly fewer correct responses than both the non-ADHD group and the normal controls. By set four, ADHD children did not differ significantly from non-ADHD patients, but still differed significantly from the normal controls.

Further post hoc analyses were conducted by dividing the sample into five distinct groups: inattentive/ADHD (N = 10), non-inattentive/ADHD (N = 9), inattentive/non-ADHD patients (N = 15), non-inattentive/non-ADHD patients (N = 21) and normal controls (N = 18). The five groups were compared on their performance across the four sets of the competing programs test. As shown in figure 13, the inattentive/ADHD children performed significantly worse than all other groups during Set one ($F = 4.14$, $p < .005$). There were no group differences during Set two, and the inattentive/ADHD group performed significantly poorer than both the non-inattentive/non-ADHD patients and the normal controls during Sets three ($F = 6.69$, $p < .001$) and four ($F = 3.19$, $p < .05$).

Brief Discussion

Experiment II was designed to test the hypothesis that child psychiatric patients presenting with objectively assessed inattention would also exhibit impairments in executive functioning. It was hypothesized that these impairments would not be specific to ADHD children, but rather, would be found in inattentive patients, irrespective of diagnosis.

Unlike Experiment I, where RT was employed as the dependent measure on the competing motor programs test, it was necessary to use the less sensitive measure of errors, in Experiment II. When using RT data, it is necessary to

eliminate those subjects who make a high number of errors in order to ensure the meaningfulness of the data. However, this procedure would have systematically altered the sample, by eliminating unequal proportions of subjects across the three groups (normals, non-ADHD patients and ADHD patients). Thus, errors were used as the dependent measure in Experiment II. Additionally, while data were collected on normal controls, these children were not included in the analysis examining the main hypothesis, that inattentive children would demonstrate impairments in executive functioning. This was due to the fact that only one normal control was found to be inattentive by CPT performance. Thus, only one subject would be in the cell containing inattentive controls and this would limit the ability to make inferences from the data. Therefore, only the patient groups were included in further data analysis.

The data indicate that inattentive children had more trouble than non-inattentive children and ADHD had more difficulty than non-ADHD children on the competing programs test. However, the lack of a significant interaction (Group x Condition) indicates that the poorer performance is not due to the shift from non-competing to competing conditions. Rather, the inattentive and ADHD children performed more poorly in both competing and non-competing conditions. Thus, there is evidence of an overall performance decrement

in these groups of children that cannot be accounted for by the experimental manipulation.

A closer examination of the data indicate that the ADHD children were able to make the shift from the non-competing to competing conditions as well as non-ADHD patients and controls. However, once they had successfully shifted set, they were unable to maintain their performance, particularly during the more difficult, competing condition. This suggests that the difficulties in the ADHD children may more accurately characterized by a deficit in the ability to maintain effortful processing, such as required during the competing conditions. Additionally, their inability to maintain a consistent level of performance may be indicative of deficits in sustained attention. In contrast, inattentive children, as defined using the CPT, performed more poorly throughout the entire task.

General Discussion

This study was designed to examine the hypothesis that ADHD children have impairments in executive/self-regulatory functions. There is convergent evidence from the domains of both developmental neuropsychology and cognitive psychology which suggests that the impairments in attention, impulse control and activity level which characterize ADHD children reflect a general impairment in self-regulation. Because these models represent different levels of analysis, they

specify different mechanisms which may be responsible for the disruption in functioning.

Neuropsychological models are derived from investigations of brain behavior relationships and attempt to delineate a neuroanatomical substrate which is responsible for mediating the observed behaviors. In the case of ADHD, the neuropsychological model is derived from studies examining frontal lobe functions in adults. While direct comparisons cannot be made between the mature adult brain and the developing brain, the frontal lobe hypothesis does provide a useful conceptual framework for studying the deficits seen in ADHD children.

Cognitive models represent another level of analysis. This literature has provided theories which attempt to explain the role of attention in the various stages of information processing. Early cognitive models focused primarily on the earliest stages of information processing (Broadbent, 1958) and were concerned with notions such as stimulus perception, and selective attention. More recently, attentional models have begun to address the end point in information processing. Researchers in this field have specified the nature of an attentional mechanism which is capable of the planning, initiation, organization and monitoring of non-routine behavioral programs (Douglas, 1988; Shallice, 1988). According to the cognitive models, impairments in these "supervisory attentional mechanisms",

or "central executives" (Baddely & Hitch, 1974) can result in the variable, dysregulated behavior which often typifies children with ADHD. Thus, despite the different levels of analysis evoked by neuropsychology and cognitive psychology, research in both domains suggest that an impairment in the ability to modulate and organize motor outputs (van der Meere, van Baal & Sergeant, 1989) is central to the deficits seen in ADHD children.

The purpose of Experiment I was to examine the relationship between executive functions and the ADHD symptom dimensions of inattention, impulsivity and overactivity. A pilot study indicated that executive functions would be related to objective measures of attention, but not impulse control or activity level. The results of Experiment I supported the hypothesis and provided further evidence supporting the subgrouping of ADHD children into those with and without impairments in attention. No relationship was found between behavior ratings and measures of executive functioning, or between behavior ratings and laboratory measures of attention and impulse control. The only significant relationship was found between actigraph measures of activity level and teacher ratings of hyperactivity. This suggests that teachers focus primarily on overactivity when rating disruptive behaviors. This finding was further substantiated by a factor analysis which yielded a factor

consisting of activity level as well as parent and teacher ratings of behavior.

If there is a significant relationship between executive functioning and attention, one would predict that children who exhibit poor executive abilities would be rated as inattentive, and would also demonstrate poor attentional skills on objective measures. The failure to find a significant relationship between executive functioning and behavioral ratings in the present study may indicate that the CPT does not provide an ecologically valid measure of attention. Alternatively, it is possible that parent and teacher ratings of attention more accurately reflect behavior problems rather than true inattention (Schachar, et al., 1985). Additionally, the low incidence of behavioral disruptiveness in the normal sample may have precluded the possibility of finding significant relationships between the behavioral and objective measures.

In summary, the findings from Experiment I support the notion that children with impairments in attention also exhibit faulty executive/self-regulatory functions. This finding lends partial support to the neuropsychological model of ADHD. According to the frontal lobe hypothesis, one would predict that impairment in attention, impulse control and activity level would each be related deficits in executive abilities. However, in this experiment, only a limited number of executive function were assessed. The

frontal lobes subserve many disparate functions, many of which are considered to reflect executive functioning (i.e., verbal fluency, recency memory and time estimation). Perhaps relationships would have been found to exist between measures of executive functioning and measures of impulsivity and activity if a more comprehensive battery of "frontal lobe" tasks had been employed. These data, however, support the notion that at least some aspects of executive functioning are disrupted in children with poor attentional skills.

With regard to the cognitive models, the findings of Experiment I indicate that impairments in attention are associated with concomitant difficulties in the area of response organization and the ability to inhibit a competing response. This is consistent with the predictions of the cognitive models (van der Meere, van Baal & Sergeant, 1989; Douglas, 1988) and provides evidence to support the notion that the deficits seen in ADHD may reflect a disruption in the "supervisory attentional system" (Shallice., 1988).

Experiment II was conducted using a patient population in order to determine if impairments in executive functioning, as assessed by the competing motor programs test, are specific to ADHD children or are more closely related to inattention, irrespective of diagnosis. Based on the results of Experiment I, it was hypothesized that children who presented with impairments on objective

measures of attention would exhibit poor executive functioning. This hypothesis was not supported in the patient group. The data indicate that both ADHD children and children with poor attention manifest difficulties on the competing motor programs test. However, the lack of a significant Group x Condition interaction indicated that poor performance of the ADHD and the inattentive children on the competing motor programs test was not due to difficulties in response organization (shifting set between the non-competing and competing instructions).

Consistent with the findings of other investigators (Douglas, 1988), ADHD children demonstrated an overall performance decrement on this task; they made more errors and performed more variably then either non-ADHD patients or controls. When attempting to analyze the stage of information processing (Sternberg, 1968; van der Meere & Sergeant, 1989) wherein the faulty processing occurred, it was clear that ADHD children did not exhibit impairments in response organization as assessed by the competing programs test. The data indicate that ADHD children had no more difficulty than controls in making the shift from the non-competing to the competing condition. Thus, they understood the task instructions and were, at least initially, able to make the shift and inhibit a previously learned response in favor of a competing response.

Surprisingly, the ADHD children were found to be most impaired in their performance during set three, which requires the maintenance of the competing response. There are several possible explanations of this finding. Perhaps, as often described by teachers and parents, ADHD children are able to initially understand and carry out more complex behaviors. However, difficulties arise when these more complex activities, which require increased effort, must be performed over an extended period of time. Thus, this impairment may reflect problems with sustained attention.

It is also possible that in non-ADHD children, those activities which require effortful processing are more readily learned and converted into automatic processes, which require less effort and less conscious control. Thus, when viewed in terms of the present research, normal children show a tendency to improve their performance between sets two and three, which may be attributable to the task becoming less effortful and more automatic. In contrast, ADHD children, who demonstrated more difficulties in set three relative to set two, may fail to develop this more automatic processing strategy and may be continually engaged in effortful processing. ADHD children may, therefore, become more fatigued and appear to demonstrate sustained attention deficits.

Another possibility is that factors such as motivation and/or the saliency of the reinforcers impact upon the ADHD

child's ability to successfully perform this task. However, the current study provided no means of assessing these latter two factors. Finally, since many of the ADHD patients also had comorbid diagnoses, it is possible that the findings were confounded due to issues of comorbidity.

Experiment II does not provide support for the notion that either inattentive or ADHD children demonstrate particular deficits in executive functioning as measured by the competing motor programs test. In contrast, in a non-referred sample, it appears that objective measures of attention are related to executive functioning. Furthermore, as children become older, it seems that impulsivity may be more strongly related to deficits in executive functioning.

There are several possible explanations for the disparate findings of Experiment I and Experiment II. To begin, the subjects differed across several meaningful dimensions. Subjects in Experiment I were generally from the middle class. In contrast, subjects in Experiment II were of lower SES. Furthermore, while the subjects in Experiment I were of Average to Above Average intelligence, the subjects in Experiment II were generally of Low Average intelligence. Additionally, while the subjects in Experiment I were found to be achieving at or slightly above grade level, the patient groups were achieving 1 SD below expected levels. In fact, there was more than a 20 point

discrepancy between the achievement scores of the non-referred sample and the patient groups. The two patient groups did not differ from one another in terms of academic achievement and thus, differences between their performance on the competing motor programs test can not be attributed to this factor. However, it is possible that the results of Experiment II were confounded by the higher incidence of learning problems within the patient population (only 3% of the non-referred sample was found to be LD).

The subjects in the two experiments also differed in terms of the two major factors being examined, ADHD and inattention. Although ADHD children are characterized as inattentive, impulsive and overactive, diagnosis of the disorder is not dependent upon laboratory measures assessing these symptom dimensions. Rather, the diagnosis of ADHD is based upon observations of behavior and as such, is closely related to teacher and parent ratings of behavior. The findings of Experiment I indicate that measures of executive functioning are not related to behavior ratings. Therefore, it is consistent with the results of the first experiment to find that children diagnosed as ADHD are not impaired on a measure of executive functioning.

On the other hand, the lack of a relationship between CPT-measured attention and executive functioning in the patient groups is inconsistent with the results of Experiment I. Both experiments employed the same objective

measure, performance on the CPT, as an index of attentional functioning. However, despite the fact that the same measure was employed, the CPT attention score may reflect differing capacities in the two samples. When examining the relationship of CPT-inattention to CPT-impulsivity and activity level in Experiment I, no interrelationships were found. Thus, these measures are believed to reflect relatively independent functions in a non-referred sample. In contrast, in the patient groups, CPT-inattention and CPT-impulsivity were found to be related ($r = .30$, $p < .005$) as were CPT-inattention and activity level ($r = .39$, $p < .0001$). This finding raises the possibility that the specificity of the cognitive process associated with CPT-inattention in a non-referred sample, may be confounded by other processes in a patient population. For example, it is possible that an ADHD child may demonstrate impaired performance on the CPT due to hyperactivity; if the child can not sit still and is continually moving around, it is likely that he will appear inattentive on the CPT. Thus, the construct of inattention as was operationally defined in this study may differ as a function of group (non-referred children versus patients).

Another possible explanation for the differences in findings between the two experiments is that the measure of executive functioning was assessing somewhat different capacities in the two samples. In Experiment I, RT was used

as the dependent measure. A significant relationship was found between number correct and RT in children who did not make a high number of errors on the competing motor programs test. Further, both of these measures were found to be related to CPT-inattention ($r = .25$, $p < .005$ and $r = .23$, $p < .01$, respectively). Thus, the two dependent measures, RT and number correct, appear to relate to similar functions in a non-referred sample. In contrast, in children who made a high number of errors on the competing motor programs test, no relationship was found between the accuracy and RT measures. In Experiment II, several children made a high number of errors on the task. Therefore, it was decided to use number correct instead of RT as the dependent measure, as it is difficult to interpret RT data in subjects who commit a high number of errors (van der Meere & Sergeant, 1988a). However, it is possible that the dependent measures (RT in the non-referred group and number correct in the patient group) are not measuring equivalent abilities. In Experiment I, the relationship between performance on the competing motor programs test and the K-ABC suggested that these two tasks measured similar capacities thought to reflect executive functioning. As the competing motor programs test was the only measure of executive functioning employed in Experiment II, it is difficult to assert with certainty precisely what function the task was assessing. If the K-ABC had been included in Experiment II, it would

have been possible to confirm the relationship between measures of executive functioning and better determine what function was being assessed by the competing motor programs test in the patient group.

Data from Experiment II indicate that ADHD children do not have difficulty in shifting cognitive set, an area of impairment which is frequently seen in adult patients with frontal lobe dysfunction. However, the relevance of the frontal lobe model cannot be dismissed on the basis of these results alone. While ADHD children did not have trouble shifting set, this capacity is only one aspect of executive functioning. Perhaps it is not useful to employ the term executive functioning, as it refers to a broad group of behaviors (i.e., problem solving, time estimation, sequencing, cognitive flexibility) which are likely to have distinct neural substrates within the frontal lobes. It may be more meaningful to examine the relationship of certain specific capacities to ADHD. For example, while ADHD children may not be impaired in their ability to shift set, it is possible that they would demonstrate impaired problem solving abilities. The tasks selected as measures of executive functioning in this study were extremely limited in terms of the scope of the self-regulatory functions they assessed. Even within the category of measures of response organization/ability to inhibit a competing response tendency, other tasks such as an auditory competing programs

test and/or the Stroop Test (1935) would provide a useful comparison for the competing motor programs test. Perhaps a more comprehensive battery of neuropsychological tests would be better able to assess the degree of impairment and the specificity of deficits in executive functioning which may characterize ADHD children.

Additionally, although ADHD children did not have trouble shifting set, their poor performance on the competing motor programs test can be attributed impairments similar to those seen in adult patients with frontal lobe dysfunction. Patients with massive lesions involving the frontal lobes will manifest a full frontal lobe syndrome which may be manifest in terms of a complete inability to shift set (perseveration) (Luria, 1966; 1973). However, Luria (1966) describes patients who present with only a partial frontal lobe syndrome as initially being able to shift set. However, these patients begin to manifest problems over time, especially when they are engaged in tasks requiring effortful processing. Thus, in these patients there appears to be a build-up of interference of the competing or prepotent response over time.

This description of Luria's is similar to the pattern of performance of the ADHD group on the competing motor programs test. Initially, these children were able to perform the task at the same level as normals. It was only when they were required to maintain their performance over

time that deficits emerged. Unlike the inattentive patients who were impaired across all four sets of the competing motor programs test, the ADHD children were selectively impaired on the conflicting condition. Thus, the impaired performance of the ADHD group on the competing motor programs test is compatible with the frontal lobe hypothesis of ADHD.

With regard to the cognitive models, unlike the findings in the normal sample, research with patient groups suggest that ADHD children do not demonstrate selective impairments in response organization as would be predicted by van der Meere and Sergeant's model (1989). ADHD children may be most accurately described as having deficits in the maintenance of effortful processing. Shallice (1988) describes the SAS as being involved in effortful processing and indicates that when the SAS is impaired, the result may be a tendency to evoke more automatic or routinized responses.

Similarly, these data support Virginia Douglas' model (1988) of self-regulatory deficits in ADHD. The second element in her model refers to the ability to mobilize attentional resources over time. Data from this study indicate that ADHD children are impaired in this capacity.

Finally, ADHD children are heterogenous with respect to their presenting symptoms, associated features and comorbidity, treatment response and long-term outcome.

Similarly, the children who are identified as inattentive on the basis of their performance on the CPT are also a heterogenous group. Children can perform poorly on the CPT for many reasons, thus, this may not be the most useful measure on which to base group placement.

It would be advantageous to study ADHD children in terms of symptom dimensions as well as associated comorbidities. For example, work by Halperin et al., (1990a) suggests that some ADHD children present with inattention and cognitive problems (LD), while others present with impulsivity and more behavioral problems (i.e., conduct disorder). Thus, it may be useful to study ADHD-LD children and ADHD-CD children to compare their performance on measures of executive functioning. In the present study, attempts to subgroup children resulted in small N's and thus decreased the statistical power of subsequent analyses. Alternatively, efforts should be made to study a group of "pure" ADHD children as this would ensure that the findings were not due to the presence of some other pathological condition.

Future Studies. In order to more fully test the frontal lobe hypothesis of ADHD, it would be useful to design a study which employed a broad and comprehensive battery of tests assessing executive functions. These tasks should be selected on the basis of the functions measured and, when possible, the location within the frontal lobes

which is responsible for mediating a given task. Additionally, developmental considerations should be taken into account (i.e., when are children able to perform the task?). Subjects selection should include a rigorous diagnostic procedure in order to make statements regarding pure disorders and the effects of comorbidity. Additionally, ADHD children should be compared with other child psychiatric patient groups in order to make statements with regard to specificity of executive impairments if they are found.

It may be also be useful to employ performance on measures of executive functioning as an independent variable which could be used to discriminate between subgroups of ADHD children with and without impairments in executive functioning. It would then be interesting to study response to various treatment modalities as a dependent measure. If differences in treatment efficacy as a function of group were found, this would lend further support to the notion that at least some ADHD children can best be characterized by deficits in executive/self-regulatory functioning.

Furthermore, as the results of Experiment II suggest that ADHD children have a deficit in the ability to maintain effortful processing, it would be interesting to re-design the competing motor programs test in order to further test this hypothesis. The test could be restructured so that it alternated from non-competing to competing to non-competing

and then finally competing. This would be an attempt to minimize the sustained effort required in the present version of this task. If, as was found in Experiment II, ADHD children have no more difficulties than normals shifting set, then one would predict to find no difference between normals and ADHD children on this task. This result would support the notion that the performance decrement seen in Experiment II, was in fact, due to this sustained effort component. Further research would be necessary to study whether this impairment reflects a failure of effortful processing to become automatized or whether it reflects other issues such as motivation.

The results of this study indicate that ADHD children do not appear to be characterized by deficits in response organization/capacity to shift set. While this finding does not support a unitary frontal lobe hypothesis of ADHD, one cannot rule out the possibility of deficits in other executive abilities. Furthermore, the data provide support for a dissociation between the diagnostic category of ADHD and the symptom dimension of inattention. Although both ADHD and inattentive children had difficulty on the competing programs test, they showed distinct patterns of impaired performance. This suggests that a different neural substrate may underlie the deficits seen in distinct subgroups of ADHD children and raises the question as to whether inattention should be considered the primary

defining characteristic of all children who present with hyperactive behavior disorders.

Table 1
Sample Characteristics
N = 123

	Mean	SD	Minimum	Maximum
PPVT-R	106.45	14.40	40	138
RCPM	106.69	10.43	81	131
WRAT-R	107.35	11.99	68	131
PIAT-R	105.56	12.84	59	133

Table 2
Teacher Ratings of Behavior
on the Conners Teacher's Questionnaire
N = 122

	Mean	SD	Minimum	Maximum
Conduct Problems	.33	.47	.00	2.00
Hyperactivity Factor	.57	.70	.00	3.00
Inattention/Passivity	.60	.65	.00	2.75
Hyperactivity Index	.33	.47	.00	2.00

Table 3
Parent Ratings of Behavior Using
the Children's Behavior Checklist*
N = 119

	Mean	SD	Minimum	Maximum
Total Behavior Problems	48.61	10.41	30.0	75.0
Internalizing	49.53	9.63	35.0	75.0
Externalizing	48.67	10.39	31.0	75.0

* T-scores

Table 4
Sample Performance on the Competing Motor Programs Test*
(N = 123)

Set	Mean # Correct	SD
1	29.07	1.57
2	27.99	2.51
3	27.45	4.03
4	28.17	3.03

*$F = 8.79$, $p < .0001$

Table 5
Final Sample Characteristics on Measures
of Cognitive and Academic Functioning
N = 112

	Mean	SD	Minimum	Maximum
PPVT-R	106.96	14.24	40	138
RCPM	107.99	9.99	81	131
WRAT-R	108.10	11.81	68	131
PIAT-R	106.35	12.71	59	133

Table 6
Teacher Ratings of Behavior
on the Conners Teacher's Questionnaire
Reduced Sample
N = 111

	Mean	SD	Minimum	Maximum
Conduct Problems	.30	.45	.00	2.00
Hyperactivity Factor	.53	.67	.00	3.00
Inattention/Passivity	.56	.60	.00	2.50
Hyperactivity Index	.46	.55	.00	2.20

Table 7
T-Scores of Parent Behavior Ratings Using
the Children's Behavior Checklist - Reduced Sample
N = 109

	Mean	SD	Minimum	Maximum
Total Behavior Problems	48.68	10.37	30.00	75.00
Internalizing	49.94	9.66	35.00	75.00
Externalizing	48.58	10.23	31.00	72.00

Table 8
RT Performance on the Competing Motor Programs Test*
(N = 112)

Set	Mean RT	SD
1	785.69	229.01
2	1104.08	298.38
3	1058.70	285.86
4	838.82	204.54

*F = 130.32, $p < .0001$

Table 9
t-Tests Comparing RT
Sets 1-4 Competing Motor Programs Test
(N = 112)

	RT 1	RT 2	RT 3	RT 4
RT 1	------	-14.11**	-11.39**	-3.02*
RT 2	------	------	2.88*	14.77**
RT 3	------	------	------	12.06**

* $p < .01$
** $p < .0001$

Table 10
Test-Retest Reliability and Practice Effects
on the Competing Motor Programs Test
(N = 27)

Variable	*Time 1 Mean	SD	Time 2 Mean	SD	Reliability r	p	Practice t	p
N-Compete (RT in msecs.)	822	244	748	174	.75	< .0001	2.41	< .02
Y-Compete (RT in msecs.)	1048	259	962	242	.76	< .0001	2.57	< .02
Compete Index	226	173	214	125	.32	< .05	.35	> .05
Total # Correct	114.7	4.6	115.3	5.9	.38	< .05	-.49	> .05

*Time measured in milliseconds

Table 11
Sample Performance on the CPT
N = 112

	MEAN # of ERRORS	SD
INATTENTION	2.76	2.76
IMPULSIVITY	3.27	4.74
DYSCONTROL	2.54	4.27

Table 12
Correlations Between the NESS, Age
and Measures of IQ
N = 112

	AGE	PPVT	RAVEN
Hand Patting	-.48*	.17	.05
Finger Tapping	-.56*	.06	.14
Arm Pronation-Supination	-.53*	.15	.05
Finger Sequencing	-.70*	.15	.02

*p < .0001

Table 13

Partial Correlations Between Behavior Ratings and Objective Measures Controlling for Age and IQ

(N = 112)

	Parent Ratings CBCL Total Behavior Problems	Teacher Ratings CTQ Hyperactivity Index
CPT Inattention	-.08	.05
CPT Impulsivity	-.09	.10
Activity Level	.10	.22*

*p < .01

Table 14

Partial Correlations Between Executive Measures and CPT Attention Controlling for Age and IQ

	NESS Non-Exec	K-ABC	Compete Index	CPT-Attention
NESS Executive	.38*	-.10	.04	.10
NESS Non-Executive	----	-.15	.14	.21**
K-ABC	----	----	-.26*	-.17*
Compete Index	----	----	-----	.25**

*p < .05
**p < .003

Table 15

Principal Components Factor Analysis with Varimax Rotation

	Factor 1	Factor 2	Factor 3	Factor 4
CPT Attention	.08327	-.00686	**.75180***	-.27065
CPT Impulsivity	-.04913	.02077	-.00654	**.86022***
Activity level	.01696	**.56427***	.08598	-.15773
Hyperactivity Index	-.08174	**.81886***	.13410	.15106
CBCL Total Behavior Problems	.12955	**.69941***	-.16654	.01210
Compete Index	-.00806	.10396	**.71133***	.11185
Hand Pat	**.67593***	.07728	.25195	.00102
ARM Pro/Sup.	**.84006***	-.14314	.04709	.05138
Finger Tap	.39605	.23987	.09501	-.25996
Finger Sequencing	**.83886***	.05667	-.14561	-.00434
K-ABC	.18681	-.09220	**.58246***	**.47102***

The four factor solution accounts for 58.2% Of the variance.

Table 16

Characteristics of ADHD, non-ADHD patients and normal control groups

	ADHD (N = 24)		Non-ADHD (N = 38)		Normals (N = 18)			
Variable	Mean	SD	Mean	SD	Mean	SD	F	p
Age (in mos.)1	114.5	23.1	120.7	20.7	108.4	20.9	2.09	N.S.
Ravens[1]	95.4	11.2	88.3	9.2	107.2	9.5	20.98	< .0001
PPVT[2]	82.5	19.5	80.5	19.5	94.7	15.3	3.70	.03
WRAT-R[2]	80.9	16.9	82.3	23.2	99.9	14.4	5.87	< .004
PIAT-R[3]	89.9	17.1	86.3	16.8	101.2	14.0	3.87	< .03

[1] All groups differed significantly from each other, $p < .0001$

[2] Both patient groups significantly different from normals, $p < .03$

[3] Non-ADHD patient groups differed significantly from normals, $p < .03$

Table 17

Parent and teacher ratings of ADHD, non-ADHD patients and normal controls

	ADHD		Non-ADHD		Normals			
Variable	Mean	SD	Mean	SD	Mean	SD	F	p
CTQ (factor score)								
Conduct Problems[1]	1.69	11.2	1.49	0.98	0.63	0.84	7.59	< .0001
Inattention/Passivity[1]	1.69	19.5	1.49	0.98	0.63	0.84	10.42	< .0001
Hyperactivity Factor[2]	1.99	16.9	1.37	1.05	0.96	0.83	6.36	< .003
Hyperactivity Index[1]	1.96	17.1	1.46	0.91	0.86	0.75	9.54	< .0002
CBCL (T-Score)								
Externalizing[2]	72.45	6.52	65.42	11.71	57.11	8.62	7.71	< .001
Internalizing[2]	67.55	9.64	65.78	9.79	58.89	9.00	2.57	N.S.
Total Behavior Probs[1]	71.90	10.16	67.16	12.43	58.22	8.69	4.51	< .01

[1] ADHD and Non-ADHD patients differ significantly from Controls.
[2] ADHD differs significantly from Controls

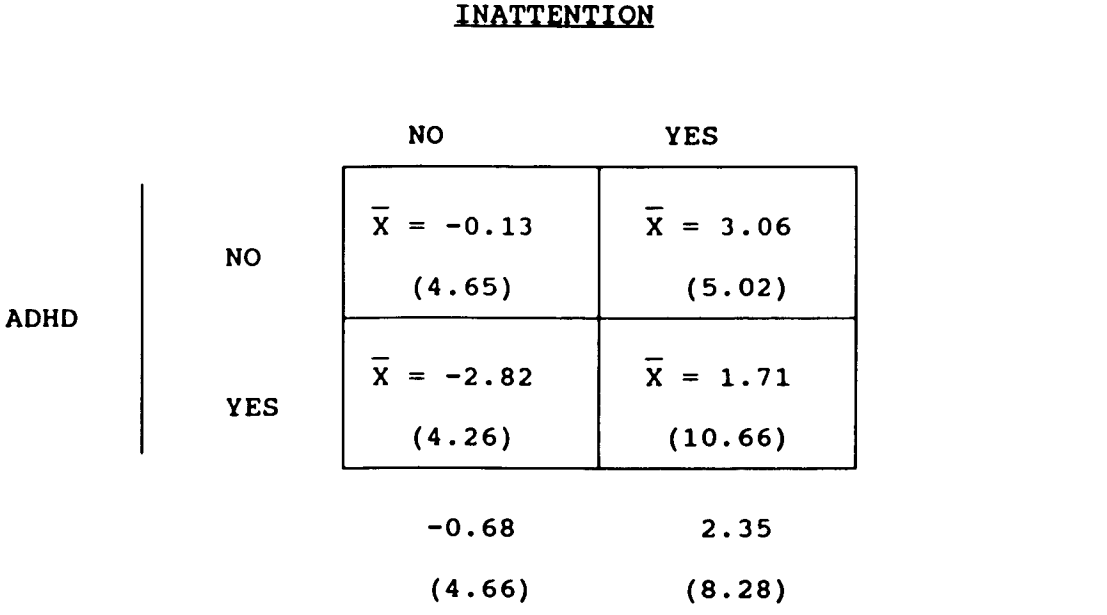
Figure 1

INATTENTION

ADHD		NO	YES
	NO	35	9
	YES	9	10

$X^2 = 5.08, P < .05$

Figure 2



ADHD Main Effect: F (1,59) = 1.55, p > .10
Inattention Main Effect: F (1,59) = 4.62, p < .04
ADHD X Inattention Interaction: F (1,59) = 0.14, p > .10

Figure 3

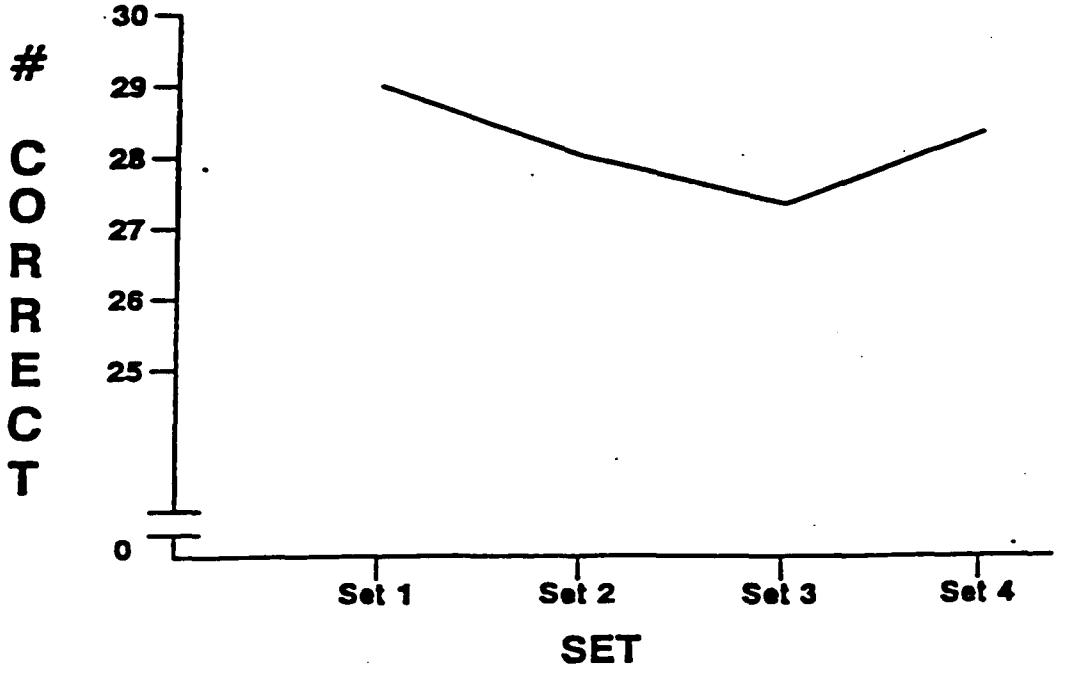


Figure 4

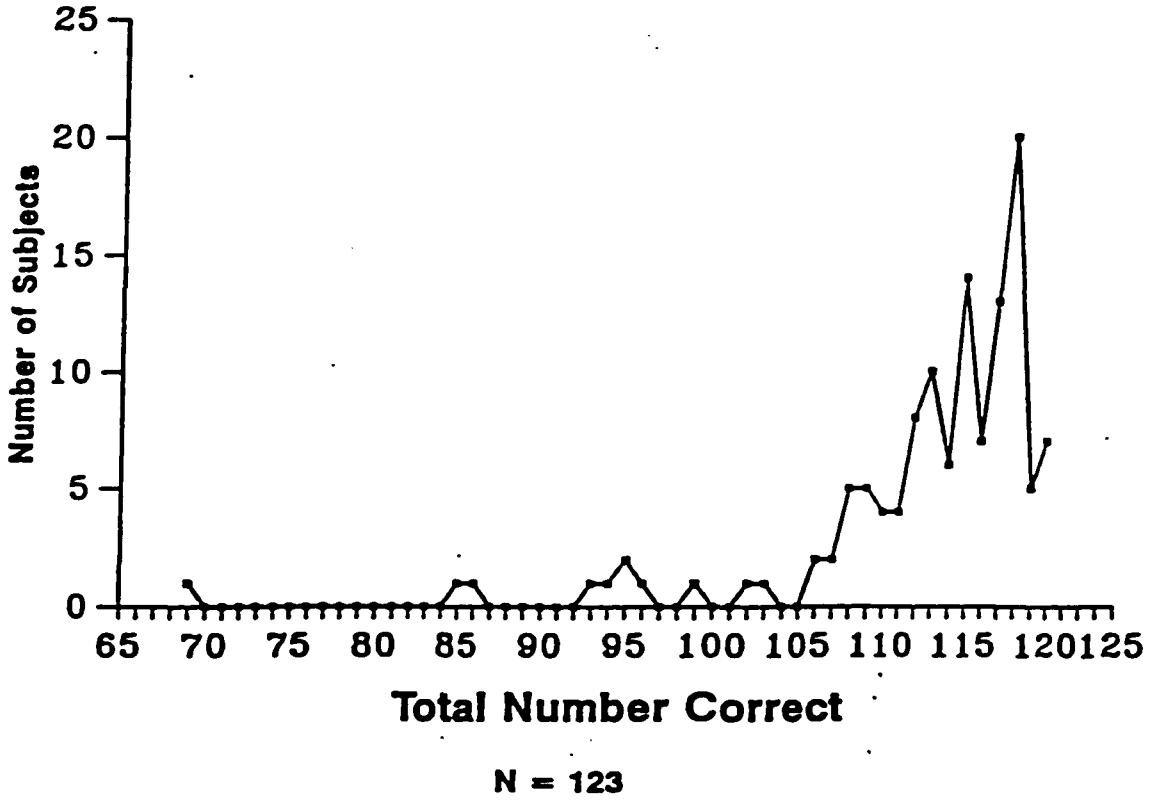
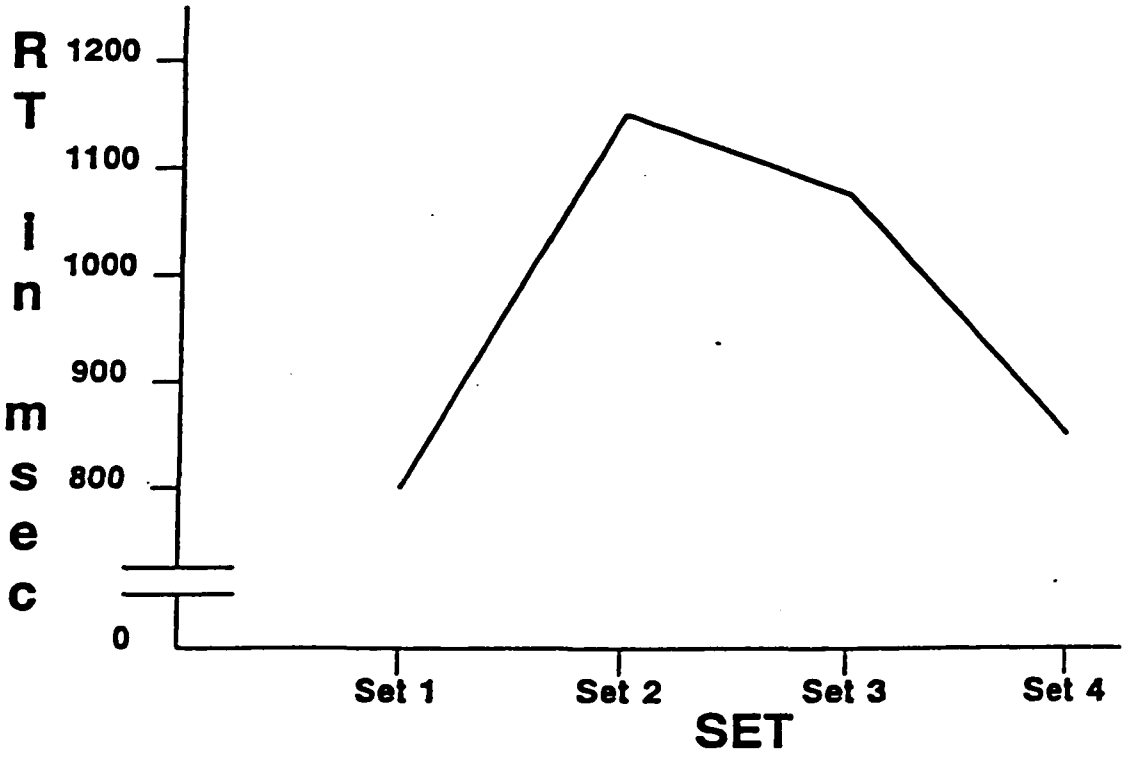

25
20
15
10
5
0
Number of Subjects
65 70 75 80 85 90 95 100 105 110 115 120125
Total Number Correct
N = 123

Figure 5



Paired t-test between each set, $p < .005$

Figure 6

	Attentive	Inattentive	
Normal Controls	14	1	15
Non-ADHD Patients	21	15	36
ADHD Patients	9	10	19
Total	44	26	70

*Chi-Square = 8.24, $p<.05$

Figure 7

	Greater than or equal to 106 Correct	Less than 106 Correct	
Normal Controls	14	1	15
Non-ADHD Patients	24	12	36
ADHD Patients	10	9	19
Total	48	22	70

*Chi-Square = 6.57, p <.04

Figure 8

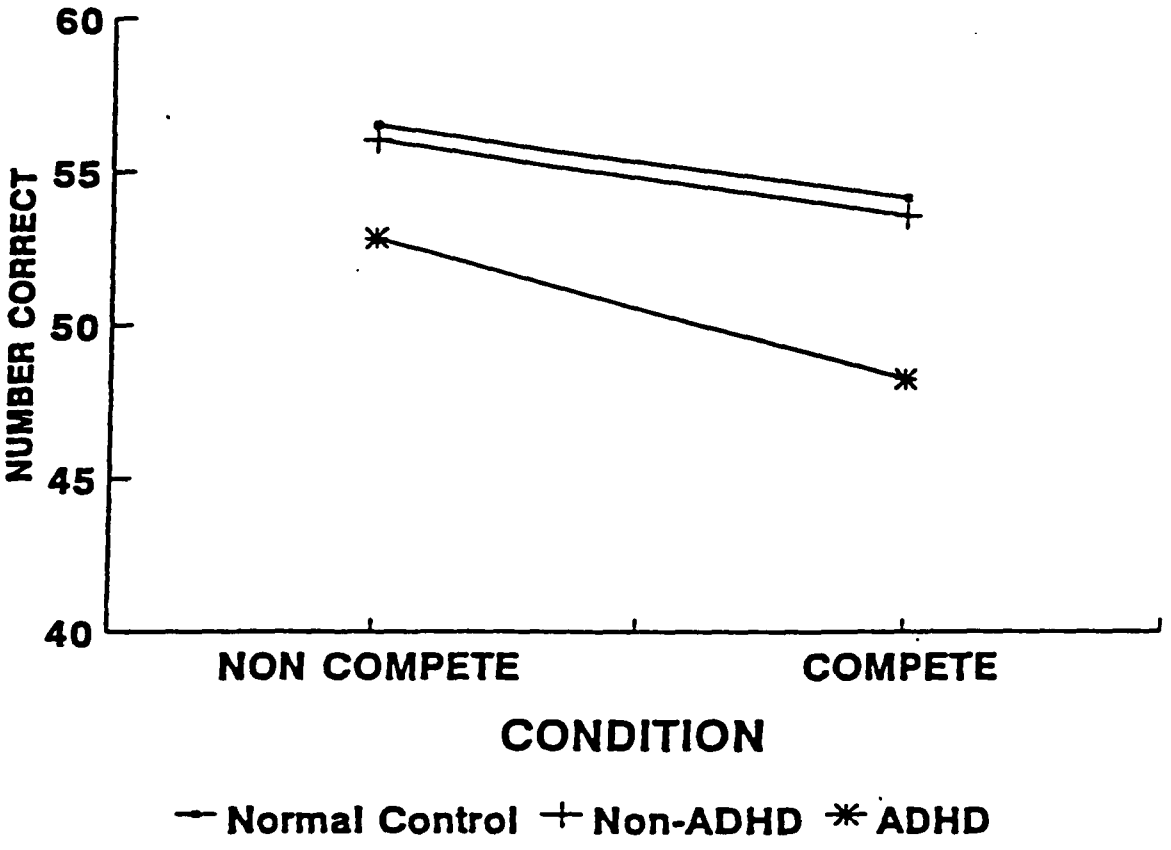

60
55
50
45
40
NUMBER CORRECT
NON COMPETE
COMPETE
CONDITION
Normal Control
Non-ADHD
ADHD

Figure 9

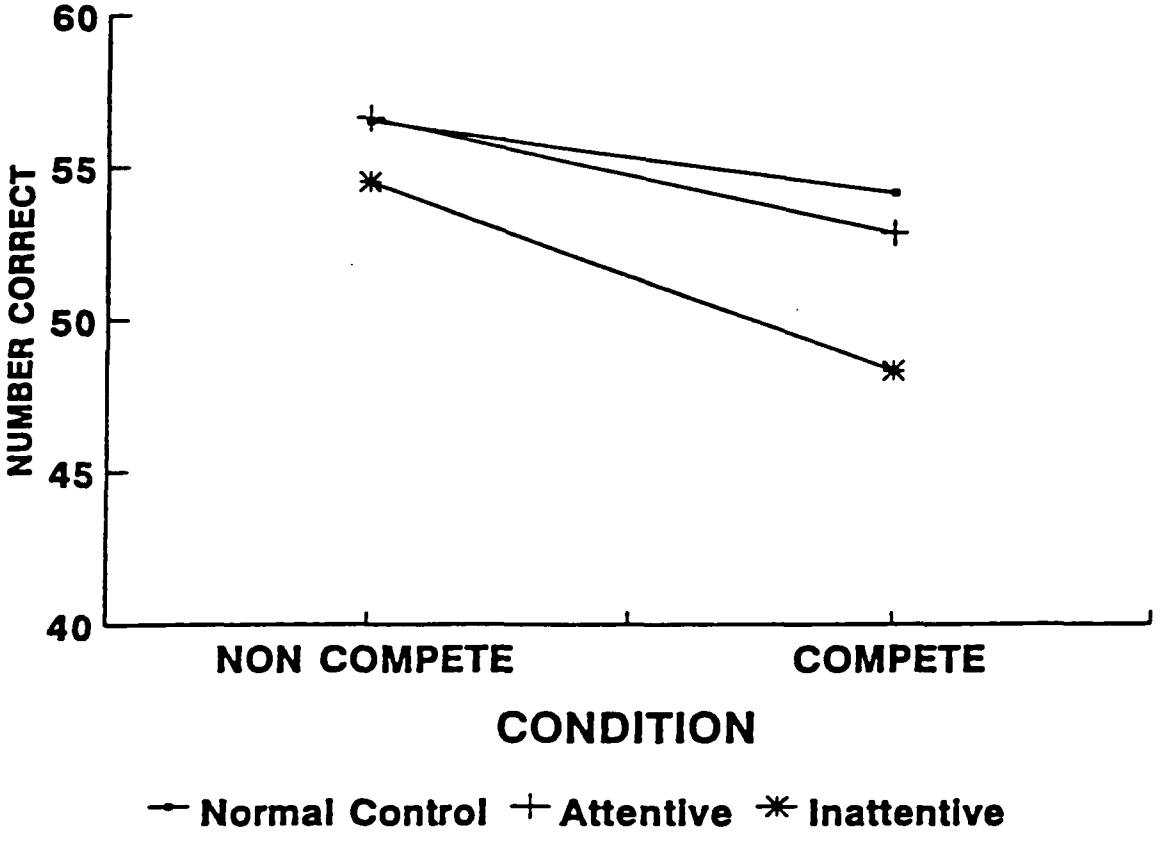

60
55
50
45
40
NUMBER CORRECT
NON COMPETE
COMPETE
CONDITION
Normal Control
Attentive
Inattentive

Figure 10

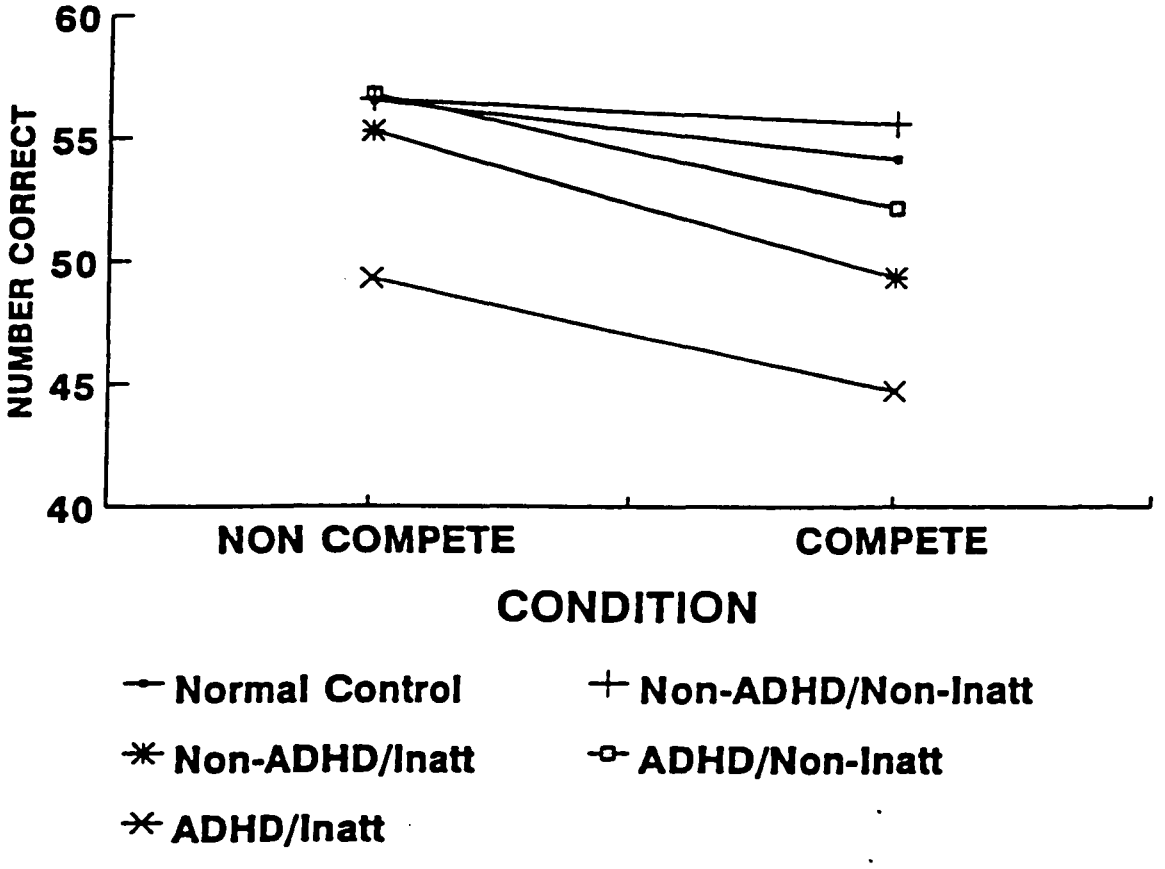

60
55
50
45
40
NUMBER CORRECT
NON COMPETE
COMPETE
CONDITION
Normal Control
Non-ADHD/Non-Inatt
Non-ADHD/Inatt
ADHD/Non-Inatt
ADHD/Inatt

Figure 11

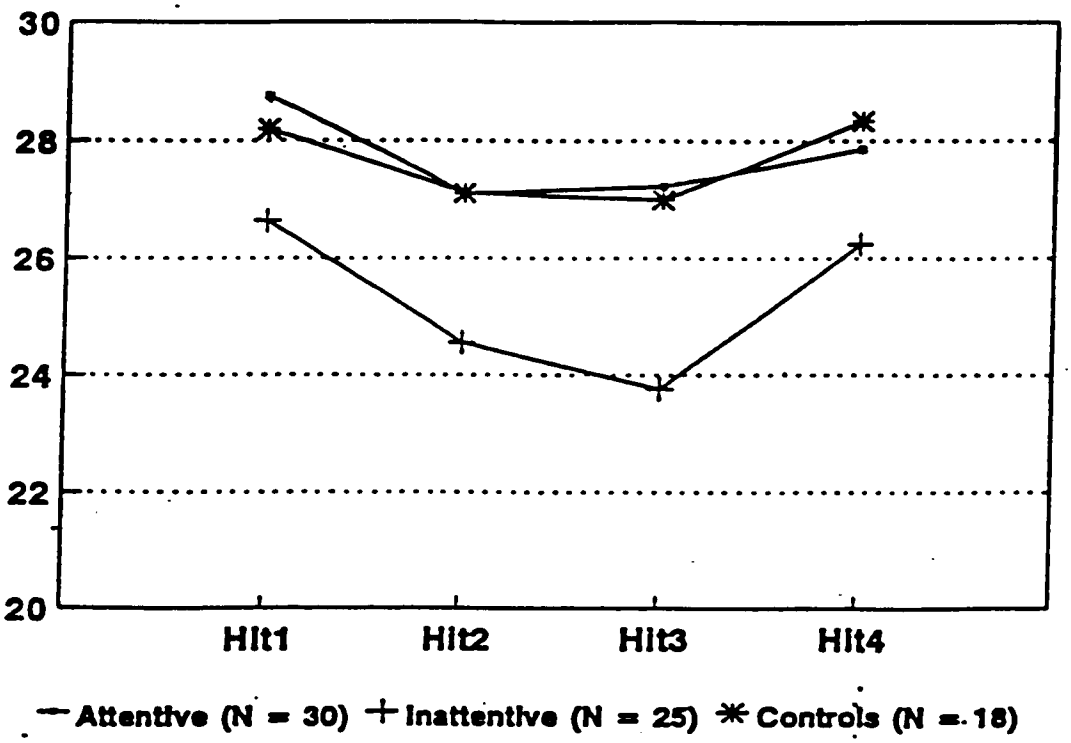

30
28
26
24
22
20
Hit1
Hit2
Hit3
Hit4
Attentive (N = 30)
Inattentive (N = 25)
Controls (N = 18)

Figure 12

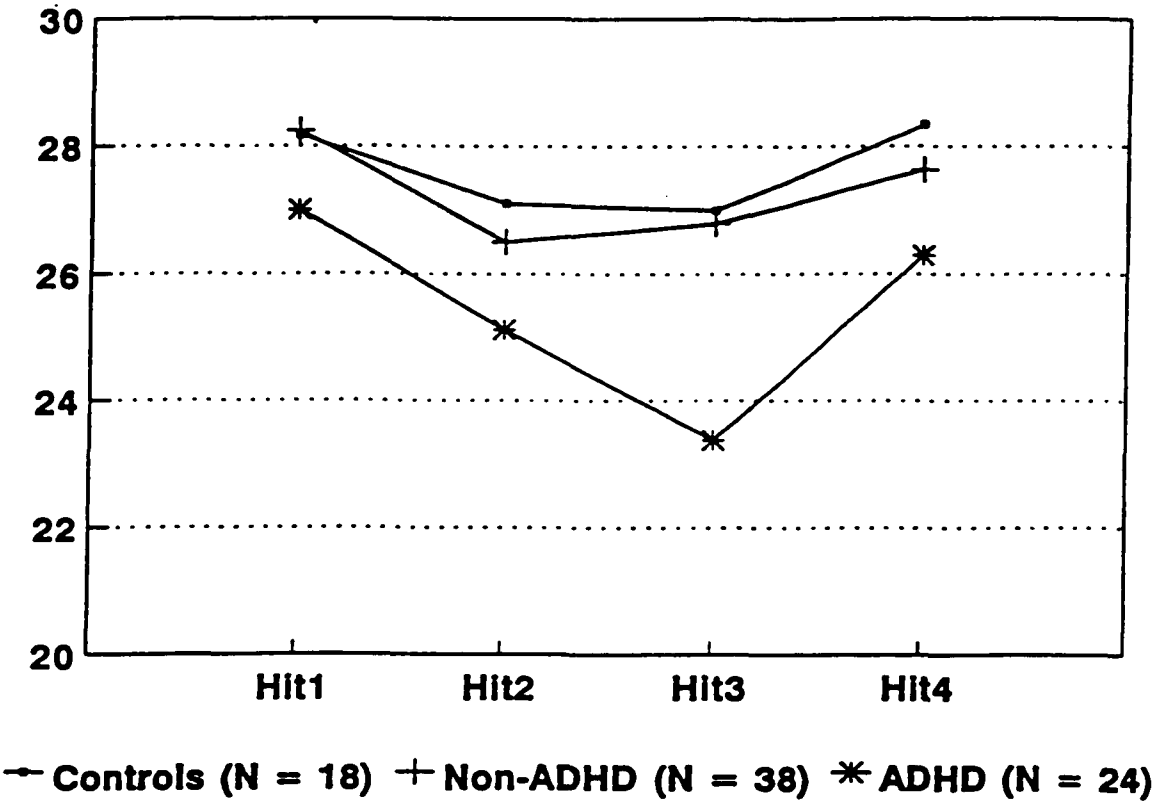
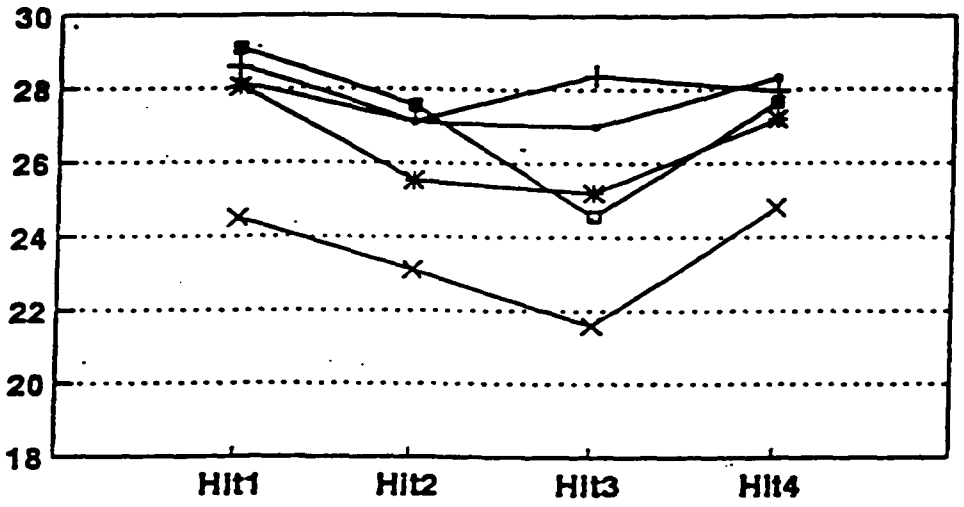

30
28
26
24
22
20
Hit1
Hit2
Hit3
Hit4
Controls (N = 18)
Non-ADHD (N = 38)
ADHD (N = 24)

Figure 13



Controls+ (N=18
Non-ADHD+ (N=21)
Non-ADHD- (N=15)
ADHD+ (N=9)
ADHD- (N=10)

+ not inattentive
- inattentive

Appendix A

Performance on the NESS
N = 112
Mean (SD) Time in Seconds
to Complete 20 Movements

	$\bar{X}$	SD
Right Hand Pat Trial 1	3.93	.74
Right Hand Pat Trial 2	4.06	.68
Left Hand Pat Trial 1	4.18	.77
Left Hand Pat Trial 2	4.37	.78
Right Finger Tap Trial 1	5.39	.81
Right Finger Tap Trial 2	5.67	.84
Left Finger Tap Trial 1	5.95	.83
Left Finger Tap Trial 2	6.30	.94
Right Arm Pronation-Supination Trial 1	6.45	1.31
Right Arm Pronation-Supination Trial 2	6.61	1.34
Left Arm Pronation-Supination Trial 1	6.83	1.35
Left Arm Pronation-Supination Trial 2	7.02	1.37
Right Finger Sequencing Trial 1	10.54	3.53
Right Finger Sequencing Trial 2	10.41	2.73
Left Finger Sequencing Trial 1	10.68	3.06
Left Finger Sequencing Trial 2	10.41	2.73

Performance on NESS by Category of Movement
N = 112

Mean (SD) Time in Seconds
to Complete 20 Movements
by Category of Movement

	$\bar{X}$	SD
Hand Patting	4.13	.66
Finger Tapping	5.82	.73
Arm Pronation-Supination	6.73	1.22
Finger Sequencing	10.52	2.82

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