

Attention Deficit Hyperactivity Disorder
and the Frontal Lobe Syndrome

Karen L. Shue

A thesis submitted to the Faculty of Graduate Studies
and Research in partial fulfillment of the requirements
for the degree of Doctor of Philosophy

© Karen L. Shue, 1989
Department of Psychology
McGill University, Montreal
July 1989

Abstract

The usefulness of frontal lobe (FL) dysfunction as a conceptual model for Attention Deficit Hyperactivity Disorder (ADHD) was investigated. Twenty-four ADHD and 24 normal control (NC) children were tested using tasks sensitive to FL deficits in motor control and problem solving skills and memory tasks sensitive to temporal lobe (TL) dysfunction. ADHD children differed significantly from NCs on measures of FL function, but not on tests of TL functions. Wherever norms were available for normal children on the same FL tests, ADHD subjects performed like 6 to 7 year olds, in spite of their mean age of 10 years and minimum age of 8 years. The differential performance of ADHD children on tasks sensitive to FL and TL damage supports the conceptualization of ADHD deficits as analogous to FL dysfunction and implies that deficits are not explained by reference to generalized impairment.

Résumé

L'utilité de la dysfonction des lobes frontaux (LF) en tant que modèle conceptuel des troubles attentionnels d'hyperactivité (DAH) a été étudiée. Vingt-quatre enfants DAH et un groupe témoin de 24 enfants normaux (EN) furent testés à l'aide de tâches sensibles aux déficits des LF dans les domaines du contrôle moteur et de la résolution de problèmes, ainsi qu'à l'aide de tâches mnémiques reliées, elles, à la dysfonction des lobes temporaux (LT). Les enfants DAH différaient de façon significative des EN quant aux mesures des fonctions des LF, mais pas quant aux mesures des fonctions des LT. Là où des normes étaient disponibles pour les enfants normaux pour les mêmes tests des LF, les sujets DAH se comportèrent comme des enfants de 6 ou 7 ans bien que l'âge moyen était de 10 ans, et l'âge minimum de 8 ans. La performance différentielle des enfants DAH aux tâches sensibles au dysfonctionnement des LF par rapport à celles sensibles au LT supporte l'hypothèse d'une analogie entre les déficits des DAH et la dysfonction des LF, et implique que ces déficits ne s'expliquent pas par une dysfonction généralisée.

Acknowledgements

I would like to express my deepest appreciation to my advisor, Dr. Virginia Douglas, who contributed advice, criticism, and encouragement when each was needed. I also wish to thank the other members of my committee, Drs. Keith Franklin and Michael Petrides, for their helpful comments throughout.

Special thanks go to all the children who participated in the research as well as to their schools and teachers who provided the space and time for testing, and to the staff of the ADHD clinic at the Montreal Children's Hospital Research Institute. I also thank Honours students Karen Eselson and Joy Etcovitch for their assistance in testing the children.

I am also grateful to Rhonda Amsel for her statistical advice, to Dr. Denis Raymond for translating the abstract into French, and to the many friends and colleagues who kept me going. I especially thank Dr. Richard Verbeek for his on-going support and tolerance of long hours and missed vacations.

This research was supported in part by a Medical Research Council of Canada Studentship to the author, as well as by Grant MA6913 from the Medical Research Council of Canada to Dr. V.I. Douglas.

Attention Deficit Hyperactivity Disorder
and the Frontal Lobe Syndrome

TABLE OF CONTENTS

Introduction	
Overview.....	1
Frontal Lobe Syndrome and ADHD--The Hypothesis.....	3
The Present Investigation.....	7
Study 1: Performance of ADHD children on tests measuring motor control.....	
	13
Motor Control	
Simple Motor Inhibition.....	13
Inhibition of Echopraxic Responses.....	18
Response Alternation.....	22
Verbal-Motor Dissociation.....	26
Plan for Study 1.....	34
Method.....	37
Subjects.....	37
Selection Criteria.....	38
Procedure.....	39
Test Materials and Administration.....	39
Results.....	41
Discussion.....	44
Study 2: Performance of ADHD children on tasks measuring problem-solving skills.....	
	48
Problem-Solving	
Trial and Error Learning.....	48
Stimulus Organization.....	51
Response Organization.....	55
Concept Discovery.....	57
Wisconsin Card Sorting Test.....	65
Plan for Study 2.....	69
Method.....	70
Subjects.....	70
Procedure.....	71
Test Materials and Administration.....	71
Results.....	73
Discussion.....	75

(continued)

Study 3: Performance of ADHD children on tasks measuring memory performance.....	80
Memory	
Increased Processing Demands.....	80
Depth of Processing.....	85
Sensitivity to Stimulus Characteristics.....	89
Plan for Study 3.....	93
Method.....	97
Subjects.....	97
Procedure.....	97
Test Materials and Administration.....	97
Results.....	99
Discussion.....	102
 General Discussion and Conclusions.....	 105
 Statement of Original Contribution.....	 121
 References.....	 122

Introduction

Overview

Attention Deficit Hyperactivity Disorder (ADHD), as described in the Diagnostic and Statistical Manual III-Revised (DSM III-R; American Psychiatric Association, 1987), is a syndrome consisting primarily of deficits in attention, activity level, and impulse control. It is commonly referred to in the literature as "hyperactivity" and these terms are used interchangeably in the present discussion. In order to make the diagnosis according to the DSM III-R, at least eight of fourteen listed behaviors must be present. These behaviors include specific examples of restlessness, distractibility, impulsiveness, poor sustained attention, excessive talking, poor social skills, and failure to consider consequences of behaviors. The prevalence of the disorder, reported to be three percent of school age children (DSM III-R, 1987), makes it one of the most commonly occurring behavior problems in the pediatric population.

For this reason, a great deal of clinical and research interest has been focused upon these children. Progress has been made in diagnosis (e.g., Barkley, 1981; DSM III-R, 1987), definition of the underlying cognitive deficits (e.g., Douglas, 1983) and in the area of treatment, including pharmacological (e.g., Barkley, 1977; Pelham, Milich & Walker, 1986), behavioral (e.g., Lahey, 1979), and cognitive training approaches (e.g., Kendall & Braswell, 1985).

Although a number of psychological and physiological causes have been proposed, the etiology of the syndrome has not been identified. Recent

theoretical, empirical and technical developments in neuropsychology have led to increasing interest in the neurological and neuropsychological status of children with ADHD. Some investigators have searched for evidence of general neuropsychological impairment. Others have attempted to describe specific areas of cognitive deficit or to relate specific deficits to neuropsychological profiles of patients with identified brain damage.

Several authors have identified behavioral features which ADHD children share with adults having damage of the frontal lobes (Gualtieri & Hicks, 1985; Mattes, 1980; Pontius, 1973; Stamm & Kreder, 1979). Most authors have focused on behavioral descriptions and theorizing based on the effects of stimulant medication. Only a few have provided experimental evidence of parallels between FL patients and ADHD children (e.g., Chelune, Ferguson, Koon & Dickey, 1986; Gorenstein, Mammato & Sandy, in press). Also, many reviewers have pointed to the frontal lobe system as the probable neurological site of ADHD (e.g., Mattes, 1980; Pontius, 1973). This position cannot be verified without direct physiological evidence.

Prior to speculating about ADHD as a manifestation of frontal lobe dysfunction, it is necessary to demonstrate clearly both the accuracy and specificity of the analogy. This has not been done to date. In addition, because of the maturational gap between frontal lobe adults and ADHD children, it is important to incorporate developmental information regarding the sequence and rate of skill development on measures associated with frontal lobe functions.

The present investigation will explore the parallels between behaviors associated with frontal lobe dysfunction and those associated with ADHD.

Three studies designed to provide evidence of an analogous relationship between the two clinical disorders in major areas of cognitive functioning will be presented. Performance will be measured across a range of cognitive skills and, in order to establish the specificity of the comparison, measures sensitive to both frontal and nonfrontal lobe functions will be included.

FRONTAL LOBE SYNDROME AND ADHD -- THE HYPOTHESIS

As Kenny (1980) has observed: "The effort to identify a neurologic basis for...observed hyperactive behavior is the most pervasive theme in the research literature (p. 442)." From the earliest reports of children presenting with the constellation of symptoms found in ADHD, an organic etiology has been overtly discussed or implicitly assumed (e.g., Still, 1902).

There have been two lines of evidence connecting ADHD and brain damage. The first involves identification of hyperactive patterns of behavior in populations with overt evidence of brain damage. Groups in which characteristics of ADHD have been described include survivors of encephalitis (Ebaugh, 1923; Hohman, 1922; Strecker & Ebaugh, 1924), epileptic children (Ounsted, 1955) and children with brain tumors (Hirsch, Renier, Czernichow, Benveniste & Pierre-Kahn, 1979; Knights & Hinton, 1973; Kun, Mulhern & Crisco, 1983) or head injuries (Boll, 1983; Rutter, 1981).

The behavioral and cognitive abnormalities associated with these disorders have been used to contend that similar abnormalities in ADHD children denote organic brain dysfunction. This argument depends on the assumption that a symptom associated with a particular disorder is always

attributable to that disorder. Yet, the disturbances seen in ADHD children may be attributable to sources other than brain damage. More importantly, no single, well-specified syndrome of "brain damage" has been identified. Effects of central nervous system (CNS) disruption vary greatly depending on the locus, type, extent and progression of the damage, as well as on characteristics of the individual and the environment (Boll & Barth, 1981).

Other authors have attempted to link ADHD and brain damage by searching for biological correlates reflecting CNS vulnerability in ADHD children (Dubey, 1976; McMahon, 1981; Rapoport & Ferguson, 1981; D. M. Ross & S. A. Ross, 1982; Rutter, 1982; Schierberl, 1979). Investigators have studied genetic and familial factors (Cantwell, 1975; Morrison & Stewart, 1971, 1973), frequency of pre- and perinatal complications ((Millichap, 1977; Pasamanick & Knobloch, 1966), minor physical anomalies (Waldrop, Bell, McLaughlin & Halverson, 1978; Waldrop & Goering, 1971) and psychophysiological abnormalities (Ferguson & Pappas, 1979; Feuerstein, Ward & LeBaron, 1978; Hastings & Barkley, 1978). Some investigators have attempted to isolate "harder" evidence of CNS dysfunction, i.e., biochemical abnormalities (Coleman, 1971; S. E. Shaywitz, Cohen & B. A. Shaywitz, 1978; Wender, 1971), regional differences in cerebral blood flow (Lou, Henriksen & Bruhn, 1984) and structural abnormalities of the brain as measured via CAT scans (B. A. Shaywitz, S. E. Shaywitz, Byrne, Cohen & Rothman, 1983; Thompson, Ross & Horowitz, 1980).

Neuropsychological tests also have been used in attempts to establish presumed CNS damage or dysfunction in ADHD children (Feuerstein et al., 1978; Johnston, 1986). Many investigators have attempted to identify tests

which could reliably differentiate hyperactive from non-hyperactive children. Most researchers have used either general screening tests (i.e., tests for "brain damage") or single tests tapping only discreet functions (e.g., perceptual, visual-motor). Typically, in spite of the emphasis on differential diagnosis, comparisons are made between hyperactive and normal control children, without including a clinical control group. Thus, one cannot conclude that differences found are specific to ADHD. Feuerstein et al. (1978) concluded that studies using a differential diagnostic approach have been of questionable value, as deficits, when observed, are not consistent across studies and are not specific to ADHD.

In many of these investigations, comparisons are made between "minimal brain dysfunction" (MBD) and "brain damaged" and/or normal control groups. Others assess frequency of occurrence of "organic" features in hyperactives. However, as Rutter (1982) has pointed out, there is no general behavioral, psychiatric or cognitive profile of brain damage. Hence, examination of global so-called "organic" features cannot result in valid distinctions. Similarly, the MBD label has failed to identify a group of children with specific cognitive or behavioral characteristics. Taylor (1983) described MBD as a "prediagnostic classification" which identifies group members on the basis of exclusionary rather than inclusionary criteria. He argued that there is no evidence to support an "MBD syndrome" and suggested that the "primary basis for the placement of such diverse disorders [as learning disabilities, ADHD, language disorders, motor deficiencies, etc.] into a common category is the shared suspicion of constitutional influences (p. 281)." Thus, the heterogeneity of both MBD and brain damaged groups may

obscure any similarities or consistent differences between them.

More recently, researchers have speculated on relationships between the behavioral effects of a localized brain lesion and the behavior of ADHD children. An increasing number of authors have related characteristics of ADHD children to particular behavioral and/or cognitive sequelae of damage to the frontal regions of the brain (Gualtieri and Hicks, 1985; Mattes, 1980; Pontius, 1973; Stamm and Kreder, 1979).

As yet, however, there are few direct experimental studies supporting this hypothesis (e.g., Chelune et al., 1986; Dykman, Ackerman & Oglesby, 1980; Gorenstein et al., in press). This makes it difficult to be sure that any parallels between ADHD and the frontal lobe syndrome result from the disruption of common neural processes rather than superficial behavioral similarities.

The nature of the relationship these authors attempt to establish between ADHD and frontal lobe dysfunction also raises concern. Investigators have consistently described the frontal lobes as the neurological site of ADHD (Chelune et al., 1986; Gualtieri and Hicks, 1985; Mattes, 1980; Pontius, 1973; Stamm and Kreder, 1979). Anatomical hypotheses, however, cannot be verified without direct physiological evidence, which is difficult to produce in a pediatric population. It would be more advantageous, for clinical and theoretical purposes, to clarify the cognitive consequences associated with a dysfunctional anatomical locus and to compare these characteristics to those of the child with ADHD (e.g., Fletcher & Taylor, 1984).

In addition, neuropsychological performance of ADHD children should be

interpreted within the context of normal development. That is, even if ADHD children approximate the performance of FL patients on certain tasks, does this pattern represent a disruption of normal developmental processes? If so, and this disruption is consistent with what is known about maturation of the frontal lobes, it would add to the strength of the analogy.

It is important, however, not to overinterpret findings based on neuropsychological assessment. Neuropsychological measures are validated by the performance of patients with known brain dysfunction. However, poor performance does not confirm dysfunction of the associated area. Thus, speculations regarding the frontal lobes as the site of brain dysfunction in ADHD children are premature. In this study, neuropsychological tasks will be used only to establish whether there is sufficient evidence of parallels between the performance patterns of patients with FL dysfunction and ADHD to merit continued investigation of the extent and meaning of the association.

THE PRESENT INVESTIGATION

Previous authors describing similarities between ADHD children and frontal lobe damaged (FL) patients have concentrated on behavioral and personality characteristics such as impulsivity, unpredictability, and lack of social inhibitions. Although these comparisons could reflect only superficial similarities, it is interesting to note the similarity in personality "styles" associated with the two disorders.

Early investigators delineated two general patterns of "frontal lobe personality" (Blumer & Benson, 1975; Greenblatt & Soloman, 1966; Walsh, 1978). The first represents Blumer and Benson's (1975) "pseudo-depressed" group. This type was described as showing apathy, lack of drive or

intrinsic motivation, an inability to plan ahead and lack of concern with events around them. It was associated with lesions of the dorsolateral convexity.

The second pattern, the "pseudo-psychopathic" group, was thought to consist of impulsive, disinhibited behavior and a lack of concern for others and was most frequently reported in association with orbital foci and following frontal lobotomy. Most patients, however, show some mixture of the attributes of these "pure" types.

Luria (1966) proposed that the observed changes were not shifts in personality per se. He suggested that these alterations reflected a combination of attention and concentration disturbances and an inability to handle complex mental sequences. For example, an inability to remain on-task would have been described as a lack of motivation or drive.

Several authors have pointed to similarities between descriptions of children with ADHD and those of FL patients (Gualtieri and Hicks, 1985; Mattes, 1980; Pontius, 1973; Stamm and Kreder, 1979). Among the diagnostic characteristics of ADHD children listed on the Conners' Parent Rating Scale (1969) are: restless, impulsive, disturbs others, demands must be met immediately, unpredictable. These have been said to resemble the impulsive and disinhibited "pseudo-psychopathic" group of FL adults with orbital lesions.

Elements of the "pseudo-depressed" (dorsolateral lesion) group also have been noted in ADHD children. They do not plan ahead and have been described as lacking intrinsic motivation or drive (Douglas, 1984). As Luria suggested for frontal lobe disorders, however, the apparent boredom

and lack of drive of ADHD children may reflect their inability to stay on-task due to attentional problems and/or the "pull" of competing, more salient activities.

Experimental evidence of an association between ADHD and the FL syndrome has been limited. Although several investigators have administered tests associated with frontal lobe functions to ADHD children (e.g., Clarkson & Hayden, 1971; Parry, 1973), only Chelune et al. (1986) and Gorenstein et al. (in press) have directly addressed the possible relationship between frontal lobe symptoms and ADHD.

Chelune et al. (1986) compared the performance of ADHD and normal control children on a battery of tests which included the Peabody Picture Vocabulary Test, four subtests from the Kaufman Assessment Battery for Children (K.ABC), the Wisconsin Card Sorting Test (WCST), and the Progressive Figures and Color Form tests from the Reitan-Indiana Neuropsychological Test Battery for Children. Significant differences were reported on the Number Recall test of the K.ABC, errors on the Color Form test, and three WCST measures: total percent of correct responses, categories achieved, and number of perseverative errors. The authors concluded that these results provide partial support for a hypothesized frontal lobe dysfunction underlying ADHD because the ADHD children showed "a relatively distinct and circumscribed pattern of neuropsychological deficits on tests presumed to measure frontal lobe functioning..." (p.232). It is difficult, however, to interpret the findings of Chelune et al. Although the WCST has proven consistently sensitive to FL damage (e.g., Heaton, 1981; Milner, 1963), studies demonstrating the validity of the Color Form test and

the K.ABC Number Recall task as measures of frontal lobe function have not been reported (Reynolds & Kamphaus, 1986).

Gorenstein et al. (in press) also have attempted to confirm a functional analogy between FL dysfunction and ADHD. They used six tests which included the Trail-Making test, Parts A and B (TM-A; TM-B), the Stroop Color-Word test, the Sequential Matching Memory Test (SMMT), the Necker Cube illusion, the WCST, and the Sequential Memory Test for Children. This last test was designed to measure proactive and retroactive interference effects similar to those reported by Passler, Isaac, and Hynd (1985) in normal children. They found significant ADHD-NC differences on time to complete TM-B, WCST perseverative errors, SMMT errors, and both noninterference and interference conditions of the Sequential Memory Test. In addition, ADHD children made more errors on the Stroop in both the baseline (color-naming) and distraction conditions. ADHD children also reported a marginally significant ($p < .07$) greater number of reversals of the Necker Cube. Gorenstein et al. concluded that these findings support a functional similarity between ADHD and FL dysfunction.

Of the six measures Gorenstein et al. (in press) used, however, only TM-B and the WCST have shown reliable impairments in FL subjects. The Stroop test has yielded inconsistent results (Perret, 1974; Stuss, Benson, Kaplan, Weir & Della Malva, 1981); the Sequential Memory Test designed by Gorenstein et al. (in press) has not been validated on FL patients; and the SMMT has been used only in one study with lobotomized schizophrenic patients (Collier & Levy, undated, cited in Lezak, 1983). Reliability of reporting may be a complicating factor on the Necker Cube test. In addition,

Gorenstein et al. did not include tests sensitive to deficits resulting from dysfunction of other brain areas. Consequently, it is difficult to establish whether ADHD impairments resemble a specific pattern of FL dysfunction.

The present investigation will include three studies focusing on motor control, problem-solving skills, and memory performance. The first two studies will use clinical and experimental measures which have been used to demonstrate cognitive impairments in FL patients. The third study is intended to demonstrate that expected ADHD deficits on FL tasks cannot be attributed to general failure to perform at a normal level. It will focus primarily on tests which have shown memory difficulties in patients with temporal lobe damage, but on which FL patients typically are not impaired. By comparing the cognitive performance of ADHD children in these different areas, the appropriateness and specificity of the FL analogy of ADHD will be evaluated.

Reviews of the literature in each of the three areas will include studies of normal child development in addition to ADHD and FL research. The importance of these normal developmental studies is twofold: first, they establish whether the performance of children who have difficulty with "FL tests" resembles that of FL adults; and second, they help in determining ages at which children would be expected to have mastered these tasks; i.e., the rate of development of FL abilities.

Most of the developmental evidence cited will be drawn from three studies investigating the maturation of FL functions. Passler et al. (1985) and Becker, Isaac, and Hynd (1988) used a number of tests from the FL

literature to assess the developmental sequence in the emergence of FL functions. Chelune and Baer (1986) established developmental norms for the Wisconsin Card Sorting Test. All three studies used groups of children aged from 6 to 12 years and reported comparable findings in terms of ages at which FL tasks were mastered. Thus, two related questions regarding ADHD performance will be asked: Is there anything unusual about the cognitive development of ADHD children in these areas and, if so, does their performance resemble adult frontal lobe pathology?

Study 1: Performance of ADHD children on tests measuring motor control

Patients with FL damage, normal young children, and children with ADHD demonstrate difficulties on a wide variety of tasks requiring motor control. These will be discussed in four subsections, examining problems in simple motor inhibition, inhibition of echopraxic (imitative) responses, response alternation, and verbal-motor dissociation. Motor deficiencies of the three subject groups will be compared on the same tests wherever possible. Tasks which appear to have similar behavioral demands also will be discussed.

Simple Motor Inhibition

FLS. FL patients are impaired on tasks requiring inhibitory motor control, as demonstrated by Ivanova (1953; reported in Luria & Homskaya, 1964) using a "go right-go left" test. Patients were instructed to press a key with their right hand in response to a red light and to respond with their left hand to a green light. Within two to three trials, FL patients began to either respond to all signals with one hand, respond alternately without regard to the signals, or respond randomly, although they still could repeat the instructions correctly. Ivanova found similar results when patients were instructed to respond to one color and refrain from responding to another ("go-no go"). Brain-damaged patients without FL damage did not show these difficulties.

Drewe (1975) also administered go-no go (GNG) and right-left tests to patients with circumscribed brain damage following surgery. In the GNG test, subjects were instructed to push a response key when a red light flashed and to refrain from pressing when a blue light flashed. FL patients

made significantly more errors than did non-FL patients.

In the right-left task, there were two keys on which subjects placed their right and left hand. They were instructed to press the right hand key upon seeing a red light and to press the left key following a blue light. Contrary to Ivanova's (1953) findings, FL damage was not associated with increased errors. This difference may be attributable to the more restricted nature of the FL lesions of Drewe's subjects. Ivanova's subjects were hospitalized patients with extensive tumors and gunshot wounds. Thus, damage probably extended beyond the frontal region.

There also are important differences between the GNG and right-left tasks. GNG tasks require either an immediate response or the inhibition of a response. Thus, subjects must withhold a "primed" movement. In the right-left test, the primary requirement is to respond according to an arbitrary signal. Subjects must remember the meaning of the signal and respond accordingly; however, they are not "primed" by task instructions to respond primarily in one direction. Both Ivanova's and Drewe's samples showed disinhibition of primed responses, while Drewe's patients did not show a deficit in right-left performance.

Gitton, Buchtel, and Douglas (1982) reported another form of motor disinhibition in FL patients on a task assessing the role of the frontal lobes in the control of eye movements. Subjects were required to report a signal in the visual field opposite from the field in which a brief distractor was flashed. FL patients were less likely than non-FL patients or NC subjects to inhibit reflex-like saccadic eye movements toward the distractor. Again, FL patients had difficulty inhibiting a "primed"

response.

Normal Child Development (ND). Luria (1969) demonstrated that normal young children show developmental changes in their ability to inhibit simple motor actions. In one task, children aged 3 to 3-1/2 were instructed to press a ball whenever a red light flashed and to refrain from pressing to a blue flash. These requirements are the same as those of the GNG task used with adult FL patients by Ivanova (1953). The children responded correctly to the red ("go") light, but failed to inhibit responding to the blue ("no go") light.

In a study of the development of non-verbal behaviors associated with FL functioning, Becker et al. (1988) tested children on two GNG tasks. In the first, children were instructed to press a response bar as quickly as possible every time they saw two stars and not to press if only one star appeared. In the second, they were instructed to respond as quickly as possible whenever they saw two identical shapes and to refrain from responding if they saw only one shape. Results revealed that 6 year olds made significantly more responses to the "no go" stimuli and showed more variable response times than any of the older groups. While 8 year olds consistently performed better than 6 year olds, they were inferior to 10 and 12 year olds in their ability to make speeded decisions, as reflected by their slower reaction times for correct responses.

Kendler (1972) assessed developmental changes on a right-left task by teaching children to push a left response button upon viewing one visual pattern and a right button upon viewing another. The learning criterion was 10 consecutive correct responses. Results revealed a significant difference

in mean number of trials to criterion between groups of children aged 5-1/2, 7-1/2, and 10 years and university students. Kendler did not analyze differences between age groups, but group means show that the 5-1/2 year olds required two to three times as many trials to reach criterion (26.5) than did 7-1/2 year olds (11.2) or 10 year old children (8.2). University students required only 1.1 trials to achieve criterion.

In summary, on both GNG and right-left tasks, children appear unable to control motor performance consistently until approximately 7 to 8 years of age. Although further development of response speed and accuracy is seen following 8 years, 10 to 12 year old children perform similarly.

ADHD. ADHD children have not been tested on the GNG or right-left paradigms. Findings have been reported, however, from tasks which make similar demands for motor inhibition.

Hoy, Weiss, Minde, and Cohen (1978) tested hyperactive and control adolescents on a task in which subjects were asked to tap only when they heard words containing an "s" and to refrain from tapping to non-"s" words. Consistent with Ivanova's (1953) and Drewe's (1975) descriptions of FL patients, hyperactives responded significantly more often than control children to non-s ("no go") words. This difficulty also resembles the motor inhibition difficulties of 6 year old children on the GNG tasks described by Becker et al. (1988). It is particularly noteworthy that the mean age of the hyperactive adolescents in Hoy et al.'s (1978) study was 14.7 years.

Vigilance tasks, frequently used to assess attentional performance, also require the inhibition of inappropriate responses. Typically, children are instructed to push a response key when they see a specified stimulus or

stimulus sequence (e.g., "push when you see an X followed by an A") and to withhold responses to any other stimuli (e.g., an X not followed by an A). ADHD children make more errors of both omission (failing to respond to correct stimuli) and commission (responding to incorrect stimuli) than do normal control (NC) children (Douglas & Peters, 1979; Nuechterlein, 1983; O'Dougherty, Nuechterlein & Drew, 1984). Thus, as well as demonstrating attentional deficits, the children fail to inhibit inappropriate responses.

Sergeant and Scholten (1985b) used a high speed visual search task having requirements similar to those of vigilance tasks. Groups of two, three, or four letters were displayed on a computer screen following a visual cue. Children were instructed to respond as quickly as possible if a target letter were present. ADHD children were consistently slower and less accurate than NCs. Their pattern of poor accuracy and variable reaction times resembled that of 6 year old children on Becker et al.'s (1988) GNG tasks.

ADHD children also make inappropriate responses on delayed reaction time (DRT) tasks in which a preliminary signal warns the child to prepare to respond to the reaction stimulus. Errors made by ADHD subjects include responding to the warning signal, making anticipatory responses prior to presentation of the reaction signal, and responding more than once to the reaction stimulus (Cohen & Douglas, 1972; Douglas & Peters, 1979; Firestone & Douglas, 1975). In this type of task, as in GNG tests, the child is "primed" to respond as quickly as possible.

Thus, like FL patients and normal 6 year old children, ADHD children make a significant number of errors in GNG-type tasks. Their performance is

highly variable and they show similar difficulty withholding responses following task-related response "priming". The prediction that ADHD children will have difficulty withholding primed responses on a GNG task will be tested in Study 1.

Inhibition of Echopraxic Responses

FLS. In simple motor inhibition tasks such as GNG, the subject is required to respond or inhibit responding to a simple stimulus. In more complex situations, the subject may be required to respond differently, or to inhibit responding, while observing the response being made by an examiner. Thus, the tendency to imitate is heightened and inhibition is more difficult.

When asked to imitate an examiner's gestures, FL patients are able to comply; thus, echopraxic (imitative) actions are intact. Yet if the instructions require a response which conflicts with the observed gesture, FL patients have considerable difficulty. For example, given the instruction: "When I raise my fist, you raise your finger" and vice versa, FL patients do not comply with the verbal instruction, but respond echopraxically, imitating the examiner's action. A similar type of error is seen if FL patients are instructed to tap twice in response to one signal and vice versa (Luria, 1973). These errors are not related to memory, as patients are able to remember and repeat the original instruction.

In her 1975 study, Drewe also investigated the performance of FL patients on a task requiring the inhibition of echopraxic responses. In the Incompatible Conditional Discrimination (ICD) task, patients had two keys in front of them, each associated with either a small red or blue light. A

larger central light was visible above the response keys and could be illuminated as either red or blue. Subjects were instructed to press the key below the small light incompatible with the color of the central light. Thus, if the central light was red, they were to press the key under the small blue light; if blue, the key beneath the red light. In keeping with Luria's observations, subjects in the FL group made significantly more motor errors than did the non-FL group. That is, they had more difficulty making a response which conflicted with the observed stimulus.

The Compatible Conditional Discrimination (CCD) task was designed as a control for the ICD task. It was identical to the ICD, but subjects were told to press the key under the small light compatible with the central light. Because the CCD does not involve a response which conflicts with the stimulus cue, according to Luria's (1973) findings FL patients should not be impaired. Yet, FL patients made significantly more errors than non-FL patients. The reason for their difficulty with the CCD task was not discussed by Drewe, but one could speculate that poor CCD performance reflects difficulties complying with task instructions (cf., Verbal-Motor Dissociation), motor perseverative tendencies (cf., Response Alternation), or difficulties with speeded decision making.

Finally, although FL patients performed worse than non-FL subjects on the CCD, errors for subjects with left FL damage were even higher on the ICD. This result would imply greater difficulty on the ICD which also requires inhibition of echopraxic responses.

In summary, FL patients have difficulty inhibiting imitative motor

responses when task demands require responses which conflict with the perceptual meaning of the stimulus observed. Failure to inhibit echopraxic responses may also be accentuated by deficits in simple motor inhibition.

Normal Development. There have been several studies of developmental changes in the ability to inhibit echopraxic responses. Strommen (1972) noted that some 5 year old children have achieved sufficient motor control to successfully respond or inhibit responding to a single stimulus on simple GNG tasks. In order to impose more complex demands, she used a "Simon Says" game, in which children had to make a conflicting response or inhibit responding while observing the response being made. She found that children younger than 7 years made significantly more errors than older subjects.

Passler et al. (1985) used two "perceptual conflict" tasks in their study of the development of behaviors associated with FL functions. In a "nonverbal conflict" task, children were asked to tap with a wooden dowel two times if they heard the examiner tap once, and once if the examiner tapped twice. Thus, the requirements of the task are identical to those of the tapping task used by Luria (1973) with FL patients. Passler et al. found that 6 year olds performed significantly worse than 8, 10 and 12 year olds, who did not differ from each other. These results resemble those found by Becker et al. (1988) with GNG tasks.

Passler et al. (1985) also used a "verbal conflict" test in which subjects were asked to point to a gray card when the examiner said "day" and to a white card when the examiner said "night". No significant differences were found between the four age groups. Passler et al. concluded that children at all four age levels were able to adequately shift response sets

and to inhibit impulsive tendencies to "mimic" an initial stimulus. These results are in apparent conflict with those of the nonverbal conflict task and with results for FL patients. Certain properties of the task, however, may be responsible for these differences.

First, perceptual disparity of signal and response was not as clear in Passler et al.'s (1985) verbal conflict task as it was in their nonverbal conflict task or in Drewe's (1975) ICD task. The ICD task requires direct inhibition of echopraxic responding, as both stimulus and response modes are visual. In the verbal conflict task, however, the stimulus was given verbally ("night") and the child responded visually (white card). Thus, the "perceptual conflict" aspect is greater in the ICD task. Second, experimenters may have failed to produce verbal "conflict"; the children may not have developed the assumed associations between gray/night and white/day. In fact, the association may be closer to the arbitrary right/red-left/blue type of association. Although Kendler (1972) identified difficulties learning a right-left task in 5-1/2 year old children, Drewe (1975) did not find significant impairments for FL patients on this type of task.

Two other non-verbal conflict tasks were administered by Becker et al. (1988) to 6, 8, 10, and 12 year old children. One task replicated the findings of Passler et al. (1985) on the auditory nonverbal conflict test (i.e., tapping). The other was a visual conflict task in which children were instructed to press a response bar twice if they saw one star and to press once if they saw two stars. A significant effect of age was found on both tests, with some 6 year old children showing considerable difficulty

inhibiting echopraxic responses. No differences were found between 8, 10 and 12 year old groups.

Thus, where there is direct perceptual conflict between stimulus and response (Becker et al., 1988; Passler et al., 1985; Strommen, 1972), inhibition of imitative responses is not mastered until around the age of 7 to 8 years.

ADHD. Inhibition of echopraxic responding has not been assessed in ADHD children. Findings on simple motor inhibition and inhibition of echopraxic responding tasks are very similar for both FL patients and young normal children. FL patients show deficits on both types of task and ND children seem to master both tasks around the age of 7 to 8 years. These results and the impairment of ADHD children on tasks requiring simple motor inhibition suggest that echopraxic response inhibition would likewise be impaired in ADHD children. This prediction will be tested in the current study using the CCD, ICD and conflicting motor response tasks of Luria (1973) and Drewe (1975).

Response Alternation.

FLS. Difficulty shifting between different responses is a frequently mentioned feature of the behavior of patients with FL damage. Difficulties of this kind represent one aspect of what is commonly referred to as a lack of flexibility or "perseveration". Although definitions of perseveration vary, reflecting the multidimensionality of the concept (Walsh, 1978), the focus in this section will be on difficulty shifting to conform with task demands for alternation of responses.

Luria (1966) noted that although FL patients can complete individual

elements of a task correctly (e.g., draw a circle, draw a square), they have difficulties shifting between these elements to complete an alternating series (e.g., repeatedly draw a circle-square-triangle sequence). They may continue to reproduce an initial element or their execution of the sequence may start correctly, then deteriorate into repetition of one stimulus element. For example, Luria and Homskaya (1964) used a task in which patients were instructed to arrange one black counter (B) followed by two white counters (W,W), then one B counter, etc. They described the performance of one patient with a left frontal lobe tumor who started the sequence correctly, but then began to place only W counters (B,W,W,B,W,W,W,W,W,...). On a second attempt, he continued to alternate colors, but not in the instructed sequence (B,W,W,B,W,B,W,W,B,W). In spite of these errors, the patient was able to repeat the instructions correctly, showing that the problem was not related to memory.

Reitan's Trail Making Test (TM; Reitan, 1955) is a standardized task from the Halstead-Reitan Neuropsychological Battery. Although sensitive to cortical dysfunction in other areas, it is most sensitive to frontal lobe lesions (Reitan, 1955; Reitan, 1986). The TM test is a paper-pencil task requiring subjects to trace a path according to a pre-identified rule. It consists of two parts. In Part A, subjects are asked to connect a sequential number series as quickly as possible. In Part B, they must alternate between numbers and letters. In Reitan's scoring system, patients are stopped when they make an error and errors must be corrected before proceeding. Scoring is based on time to complete the task.

FL patients are able to successfully complete TM-A within normal time

limits. They have difficulty, however, following the directions on TM-B to shift between stimulus dimensions. Reitan (1964) reported that patients with FL damage take longer than normal control or non-FL brain damaged subjects to complete TM-B successfully.

In summary, these findings demonstrate that FL patients are impaired on motor tasks which require flexible alternation between stimulus elements. These deficits may involve the patients' impulsive, poorly controlled motor behaviors or their perseverative rigidity and difficulties in shifting set, or both.

Normal Development. Passler et al. (1985) tested their different age groups of normal children on two motor perseveration tasks comparable to those used by Luria. On the first, children were asked to sort white (W) and black (B) marbles into a cylinder following the pattern B,W,W,B,W,W, etc. (i.e., the same pattern used by Luria and Homskaya, 1964). The second task required repetitive drawing of the geometric sequence: circle, square, triangle. Their results revealed that 6 year olds performed significantly worse than 8, 10, and 12 year old children, who did not differ from each other.

Thus, normal children performed tasks requiring response alternation at a level consistent with their mastery of simple motor inhibition and inhibition of echopraxic responding. That is, only children younger than 8 years were not able to maintain control of alternating responses.

ADHD. Deficits on tasks which require shifting between stimulus dimensions also have been shown in ADHD children. Although they have not been assessed on the tasks developed by Luria, they have been tested on a number of tasks with requirements like those of TM-A and TM-B.

The Progressive Figures and Color Form tests were designed as downward extensions of the TM task for children aged 5 to 8 years. The Progressive Figures Test consists of a series of geometrical forms having smaller, differently shaped forms within them. Subjects must move to a large-sized outside figure with the same shape as the small inside figure they are leaving. Clarkson and Hayden (1971) found significant differences between ADHD and NC groups on time taken to complete the task, but not on errors. Chelune et al. (1986) failed to find ADHD -- NC differences on this task.

The Color-Form Test requires that subjects alternate between color and form. They must move first to a figure of the same color, then to one of the same shape, as the starting figure. Clarkson and Hayden (1971) reported significant ADHD -- NC differences on both time and error measures, while Chelune et al. (1986) found significant differences for errors only.

Homatidis and Konstantareous (1981) tested ADHD and NC children on the Jumbled Numbers Game. Numbers, printed on colored backgrounds, appear in a random array. Children must read each number in order, then name the color of the background on which the number is printed. Thus, they must alternate between numbers and colors. Homatidis and Konstantareous found significant differences between ADHD and NC groups on both time and error measures.

Finally, Clarkson and Hayden (1971) tested ADHD and NC children on the adult version of the TM tasks. They found differences between ADHD and NC

groups on time and error measures of the TM-B task, but no differences on TM-A. Gorenstein et al. (in press) also found ADHD-NC differences on TM-B time, but not on TM-A. They did not measure number of errors. Thus, results for ADHD and FL patients on these tasks are similar. Both groups show deficits when required to alternate between stimulus dimensions. In addition, ADHD deficits are clearest on tests which are more demanding. That is, differences are less reliable on tests designed for mastery by 5 to 8 year olds than on the more demanding Jumbled Numbers Game and adult level TM tests. Normal children below the age of 8 years also show response alternation difficulties, although these have not been studied yet with TM-type tasks. This study will attempt to replicate Clarkson and Hayden's (1971) and Gorenstein et al.'s (in press) findings of impaired TM-B performance.

Verbal- Motor Dissociation

FLS. A "dissociation between knowing and doing" has been identified as one of the earliest signs of anterior frontal lobe dysfunction (Luria, 1973) and as one of the most characteristic features of the frontal lobe syndrome (Lezak, 1983; Luria, 1973; Teuber, 1964). FL patients' "knowledge" about a particular task or situation does not necessarily translate into appropriate behavior or speech, and vice versa. They may exhibit incorrect actions accompanied by correct verbal comments; or they may perform appropriately, yet fail to verbalize correctly about what they have done.

Luria (1973) has described clinical examples of this dissociation. One patient was "involuntarily drawn" to press a hospital call button. When the nurse responded, he was unable to say why he had pressed it. Another

patient was sent to his ward to get his cigarettes. He began to do so, but when he met a group of patients walking in the opposite direction, he turned and followed them, although he could repeat the original instruction.

A common factor underlying these situations is a lack of "connectedness" -- a dissociation -- between language and action. Lezak (1983) described this as a decreased use of "verbal cues (usually subvocalization) to direct, guide, or organize...ongoing behavior with resultant perseveration, fragmentation, or premature termination of a response (p. 66)." Individuals with intact frontal lobes typically use their own speech to structure behavior. For example, individuals learning a complex motor skill may describe the required actions as they perform.

In contrast, the speech of FL patients fails to exert a controlling influence over their actions (Luria, 1973). Patients may repeat a command correctly, but respond incorrectly, or speech may imitate motor actions so that both verbal and motor responses are incorrect. Luria (1973) obtained both behavior patterns using a task requiring subjects to reproduce a tapping pattern (strong-weak-weak). To aid performance, subjects were asked to verbalize the pattern as they tapped. Some FL patients verbalized the pattern correctly, but tapped a continuous rhythm; others began changing commands to fit their motor responding ("strong-weak-weak-weak"). Non-FL patients were able to use their own explicit verbal responses to regulate and improve motor performance.

Homskaya (1960; reported in Luria and Homskaya, 1964) investigated whether deficits in motor control of the type described by Ivanova (1953) could be reduced by concurrent verbalization of the correct response. He

asked brain damaged patients to push strongly on a lever to a red light and weakly to a green light. They also were instructed to verbalize the correct response following each color presentation, prior to pushing the lever. Although verbalizations helped patients with lesions involving non-FL cortical areas to improve motor performance impaired by kinesthetic deficits, the performance of FL patients was not helped by the verbal self-commands. FL patients were able to state the appropriate response, but tended to give identical motor responses to both stimuli. They also showed no tendency to correct motor actions which did not match their verbalizations.

Drewe (1975) also studied the influence of concurrent verbalization on GNG, CCD and ICD motor performance. Each task was composed of 60 trials. In trials 21-40, patients were required to make a verbal response compatible with their motor action. Thus, Drewe was able to investigate the relationship between verbal and motor responses.

In the verbal trials (21-40) of the GNG test, patients were instructed to say "yes" as they pressed the key to a red light and "no" while inhibiting responding to a blue light. As noted previously, FL patients made significantly more motor errors than non-FL patients. There was no difference in the number of verbal errors made by each group; however, the motor performance of the non-FL group improved over the 60 trials, whereas that of the FL group did not. Hence, although speech was not disrupted by motor errors, FL patients were not able to use their own verbalizations to improve motor responding.

During verbal trials of the CCD and ICD, patients were instructed to

verbalize the color of the light above the key they pressed. Because the CCD requires only imitation of the stimulus cue, the performance of FL patients should not be impaired. Nevertheless, FL patients made significantly more errors, both motor and verbal, than did non-FL patients. The non-FL group made fewer motor errors on trials requiring both a motor and verbal response than on trials requiring only a motor response, while the FL group tended to make more motor errors on these trials.

On the ICD, subjects in the FL group made more verbal and motor errors than the non-FL group. Non-FL patients made fewer errors on trials requiring both a motor and verbal response than on trials requiring only a motor response; FL patients made a similar number of errors on the two types of trials. Thus, for the ICD task, motor performance of FL patients was not aided by the introduction of their own verbal cues.

In summary, patients with FL damage are less able to use their own verbal cues to improve or regulate their motor performance than are patients with damage to other cortical regions. Moreover, Drewe's (1975) findings suggest that simple motor performance (CCD) seems to be "energized" (i.e., made more impulsive) by concurrent verbalizations.

Normal Development. Verbal-motor dissociation is also typical of young children. In his investigation of developmental changes in motor control, Luria (1959) assessed verbal regulation of motor behavior. In the GNG task, children were told to say "press" concurrent with responding to a red light and "don't press" when refraining from responding to a blue light, thus providing a guide for their action. Three to 3-1/2 year old children responded correctly to the "go" light; however, when presented with the "no

go" light, they not only failed to inhibit the motor response, but pressed even harder. This behavior resembles the increase in motor errors made by FL patients when they were required to verbalize on Drewe's CCD task (1975). Children were not able to use a verbal self-command to assist them to inhibit responding to the no go signal until age 4 to 4-1/2. Luria concluded that very young children are unable to use their own speech to direct their behavior and that the action of producing speech seems to energize movement rather than aid inhibition.

Meichenbaum and Goodman (1969a) studied verbal regulation using a finger tapping task. Kindergarten and first grade children were required to finger tap while verbalizing either "faster" or "slower", aloud or covertly (i.e., using lip movements only). They reported that the motor performance of kindergarten children approximated that of the first graders when verbalizations were overt, but that covert self-instructions had little effect on tapping speed. In first grade children, in contrast, self-instructions appeared more effective when covert than overt. Meichenbaum and Goodman concluded that the semantic meaningfulness of self-verbalizations, whether overt or covert, is important in controlling motor behavior of first graders; in the case of kindergarten children, only overt self-vocalization had this effect. Thus, younger children (5-1/2 to 6 years) performed better when using overt self-instructions and were more affected than older children (6-1/2 to 7 years) by the absence of spoken self-instructions.

These studies are consistent with the hypothesis that verbalizations contribute directly to the control of motor behaviors. Meacham (1978) also

investigated verbal guidance of behavior. Unlike prior studies in which children were instructed to speak and then act, Meacham avoided suggesting specific timing of verbal and motor responses. Children from 3-1/2, 4-1/2, and 5-1/2 year old groups were assigned to either verbal self-instruction or non-verbal conditions. They were told to ride a tricycle by complying with the examiner's commands. Children in the verbal condition were told to repeat these commands. Reaction times of both motor and verbal responses were recorded along with number of motor errors.

Meacham reported that mean reaction times for verbal activity were consistently slower than reaction times for motor responses for 20 of the 24 children in the verbal condition. Corrections of motor responses were significantly more likely to occur if there were a verbal response following the initial, incorrect movement. Hence, children's verbal responses followed their initial motor responses, but preceded corrections of those responses. Meacham did not analyze differences between age groups, but it appears from his reported results that children aged 3-1/2 to 5-1/2 years did not show strong differences between verbal and nonverbal conditions, a finding that is consistent with previous studies. In addition, older children were more likely to correct an inappropriate motor response following their correct repetition of the examiner's command, thus reflecting their ability to use the semantic meaning of the verbalization.

In summary, compatibility of verbal and motor responses in children appears to show a developmental gradient. Preschool children appear unable to use their own verbalizations to guide or inhibit motor responses and concurrent verbal activity sometimes seems to "release" motor inhibition.

From 5 to 6 years, children begin to make use of overt verbal cues to improve motor performance. By the ages of 7 to 8, children are able to produce and use covert self-verbalization effectively.

Thus, children aged 5 to 6 years are able to apply overt self-instructions to maintain or correct their motor performance. In conditions in which overt verbalizations do not occur, however, 5 to 6 year olds and FL patients perform in a similar manner on motor control tasks.

ADHD. Many educators, parents, and researchers have noted discrepancies between the verbal knowledge of ADHD children and their motor actions (Barkley, 1981; Douglas, 1983; Kronick, 1986; Thiffault, 1982). Thiffault (1982) provided a clinical example which strongly resembles those given for FL patients (Luria, 1973). He described a nine year old ADHD child who was asked to ride his bicycle to the store to buy a few items. He returned much later without the items or his bicycle, having been distracted by other events along the way. Although he could repeat what he was supposed to do, he failed to carry through on this information. Douglas (1983) formulated this discrepancy as one of whether ADHD children "can't, don't, or won't" perform in accordance with their knowledge and skills.

The effect of verbal control over motor actions has not yet been assessed in ADHD children. Meichenbaum and Goodman (1969b) tested cognitively "impulsive" (defined by fast-inaccurate performance on the MFFT) and "reflective" (i.e., slow-accurate performance) 5-1/2 to 6 year old kindergarten children on the finger-tapping test used in their (1969a) study with normal kindergarten and first grade children. They also used a CNG task (squeeze-don't squeeze) derived from Luria's task. "Impulsive"

children share important characteristics with ADHD children (e.g., Juliano, 1974; Messer, 1976). Meichenbaum and Goodman (1969b) found that both impulsive and reflective subjects were able to use their own verbalizations ("faster" or "slower") to control their tapping speed, as were ND children of the same age. On the GNG task, however, only 40% of the impulsive children met a criterion of 90% correct responding, while 85% of the reflective children met this criterion. Meichenbaum and Goodman concluded that the impulsive children were less able than reflective children to use self-verbalization to control motor responses.

There is some indirect evidence that ADHD children experience difficulty using verbal information to organize motor responding. Stevens, Stover, and Backus (1970) studied the ability of ADHD children to modify finger tapping speed. ADHD and normal control children were tested under three conditions. First, a baseline level was established by asking children to tap as quickly as possible. Then, they were given ongoing verbal encouragement to "tap faster". In the final condition, they were told they would receive one cent for each tap over the number achieved at baseline level. Results showed that, whereas the baseline performance of ADHD children was slightly faster than that of the controls, in both the verbal and monetary reinforcement conditions the control children tapped significantly faster. The failure of the ADHD group to increase tapping speed in conjunction with verbal instructions and encouragement to do so, is consistent with an inability to modulate behavior in accord with verbal information.

Similarly, on the visual search task described previously (cf., Simple

Motor Inhibition), Sergeant and Scholten (1985a) included instructions emphasizing speed plus accuracy, speed only, or accuracy only. Although control children were able to use the directions to alter their performance appropriately, ADHD children were not. Thus, for example, in the speed only condition, control children showed the expected loss in accuracy balanced by a gain in speed. ADHD children made more errors, but did not increase their speed.

Given that ADHD children demonstrate difficulties using verbal information to organize their motor actions and that Meichenbaum and Goodman (1969b) have shown that cognitively impulsive children are less able to use their own verbalizations to control motor responses, ADHD children would be predicted to demonstrate discrepancies between verbal and motor responses similar to those of FL patients and children younger than 5 to 6 years. This prediction will be tested in Study 1.

Plan for Study 1. Patients with FL damage show impaired motor control in each of four areas including simple motor inhibition, inhibition of echopraxic responses, response alternation, and verbal-motor compatibility. Normal developmental studies have shown that children develop consistent motor control on these types of tasks around the ages of 6 to 7 years. Children with ADHD have not been tested directly on most of the tasks used in studies of FL and ND subjects. Nevertheless, their performance on tasks on which they have been tested and on tasks having similar response requirements supports the hypothesis that the performance of ADHD children on motor control tasks will resemble that of adult FL patients and children

younger than 8 years of age. This hypothesis will be tested in Study 1 by using tasks from each of the areas reviewed. In order to ensure that all subjects should be able to perform these tasks successfully, no children younger than 8 years will be selected.

Tasks used to Investigate Motor Control Functions in Study 1

Go-No Go test (GNG). The GNG test requires rapid discrimination of "go" (S+) and "no go" (S-) signals. The subject must not only respond to the S+, but must inhibit both anticipatory motor responses and responses to the S-. No perceptual disparity or opportunity for echopraxic responding is involved. Ivanova (1953) and Drewe (1975) have reported that FL patients are unable to suppress responding to the S-, but show no response deficits to the presentation of an S+. Luria (1959) and Becker et al. (1988) demonstrated that children younger than 8 years show difficulty inhibiting responses to a no-go stimulus. ADHD children show difficulties inhibiting responses on tasks with similar requirements and are predicted to be impaired on this GNG task.

Luria's Test of Conflicting Motor Responding (CM). The CM test requires that the subject perform motor responses opposite to those modeled. Subjects must inhibit echopraxic movements. Luria (1973) found that when FL patients are asked to perform conflicting motor movements, they tend to respond echopraxically, imitating the model in spite of their ability to retain and repeat task instructions correctly. Strommen (1972), Passler et al. (1986), and Becker et al. (1988) reported that children younger than 7 to 8 years were unable to consistently inhibit echopraxic responding. ADHD children have not been tested on tasks of this type. Given their difficulty

controlling simple motor inhibition, it is predicted that they will show impaired performance on the CM task.

Compatible and Incompatible Conditional Discrimination (CCD; ICD). The CCD and ICD tasks require consistency of verbal/motor response pairs. In the case of the ICD test, responses are in conflict with the "perceptual meaning" of the stimulus and thus require the inhibition of verbal or motor imitative responses. Using these two tests, Drewe (1975) experimentally verified some of Luria's (1973) clinical observations. Patients with FL damage failed to respond as accurately as nonFL patients on both the CCD and ICD tasks and, on the ICD, were unable to consistently avoid naming and pointing to the response option which was of the same color as the stimulus cue. Six to 12 year old normal children did not show deficits on a verbal conflict task (Passler et al., 1986). It was not clear, however, to what extent the task required inhibition of echopraxic responses. As predicted for the CM task, ADHD children should show difficulties inhibiting echopraxic errors on the ICD. They may demonstrate problems on the CCD as well, given the impaired performance of FL patients on this task (Drewe, 1975).

Trail-Making Test -- Forms A and B (TM-A; TM-B). Reitan's TM test (Reitan, 1955) requires sustained attention, visuospatial scanning ability and motor and sequencing skills (Boll, 1981). Part B also requires that the subject (a) direct behavior according to a plan and remember and follow that plan; (b) maintain and integrate two simultaneous series, while (c) switching flexibly between the two different stimulus sets (Boll, 1981). FL patients are impaired on tasks involving response alternation (Luria, 1966;

Luria and Homskaya, 1964). Reitan (1955; 1986) has shown that patients with FL damage take significantly more time than nonFL patients and normal controls to complete TM-B. Passler et al. (1985) found that 6 year old children were unable to maintain control of alternating responses at the same level of accuracy as 8 to 12 year olds. ADHD children perform like FL patients and children younger than 8 years on complex response alternation tasks (Clarkson & Hayden, 1971; Gorenstein et al., in press; Homatidis & Konstantarteous, 1981). In the present investigation, ADHD children are predicted to resemble FL patients by taking significantly more time to complete TM-B. Errors will also be recorded in order to allow comparison with the findings of Clarkson and Hayden (1971).

Method

Subjects

The samples included 24 ADHD children (21 males, 3 females) and 24 matched normal control children (21 males, 3 females). Children younger than 8 years were excluded. Informed consent was obtained from all children and their parents; children were free to end participation at any time. Means and standard deviations for the ADHD and NC groups on age, IQ, Conner's Teacher Rating Scale (TRS) and Parent Rating Scale (PRS) variables are shown in Table 1. T-tests showed no significant differences between the ADHD and NC groups in age or IQ. As expected, the ADHD children received significantly worse ratings than the NC children on the TRS, $t(46)=18.20$, $p<.0001$, and PRS, $t(46)=13.21$, $p<.0001$.

Insert Table 1 about here

Selection Criteria and Procedures

ADHD subjects. Each ADHD child had been referred to the Hyperactivity Clinic at the Montreal Children's Hospital for attentional and impulsivity problems. To be included in the study, a child had to meet the DSM III-R diagnostic criteria for ADHD and receive ratings of 1.5 or greater on the Hyperactivity Index of both the Revised Conner's Parent and Teacher Rating Scales (PRS; TRS; Goyette, Conners, and Ulrich, 1978). Interviews with the mothers established that the children's problems were chronic and pervasive. In addition, the symptoms could not be attributed to demonstrated brain damage, epilepsy, psychosis or anxiety. Subject's IQ's had to be above 80 as measured by the Peabody Picture Vocabulary Test. Nine of the children were receiving stimulant medication. Their parents agreed not to administer the morning dosage the day of testing. This "wash-out" period of 20 to 24 hours was considered adequate as the half-life of methylphenidate in children is only 2 to 7 hours (Gualtieri et al., 1982).

Normal controls (NC). Teachers of the ADHD subjects were asked to select the next child on the class list who matched the ADHD child in sex, age (within six months) and IQ, but did not show behavioral difficulties. Parents of each potential control child were contacted by telephone and a short interview was carried out to verify that the child did not show attention or impulse control problems and did not have a history of

Table 1

Demographic Characteristics of the ADHD and NC

Subject Groups

(Means and Standard Deviations)

<u>Group</u>	<u>Age</u>	<u>IQ</u>	<u>TRS</u>	<u>PRS</u>
(N)	(MONTHS)			
ADHD	123.54	96.42	2.27*	2.12*
(24)	(18.82)+	(10.93)	(.40)	(.43)
NC	123.71	96.88	.30	.56
(24)	(18.48)	(11.57)	(.35)	(.39)

+ Standard deviations are in brackets

* $p < .0001$

TRS: Teacher Rating Scale

PRS: Parent Rating Scale

emotional difficulties, brain damage, epilepsy or psychosis. None of the children were taking psychotropic medication. Scores on both the PRS and TRS had to be below 1.5 on the Hyperactivity Index of the scale for inclusion in the NC group.

General Procedure

Subjects were tested individually in their schools in a single session lasting approximately one hour. Tests were administered in one of three orders and included tests which will be discussed in Study 2. Orders were randomly determined with the restriction that tests involving similar materials did not immediately follow one another. In addition, order of administration of the ICD and CCD tasks was counterbalanced.

Test Materials and Administration

Go-No Go test (GNG). The GNG task requires rapid discrimination of "go" (S+) and "no go" (S-) signals. Stimuli included forty cards with pictures of an apple (S+; 20 cards) or ice cream cone (S-; 20 cards). Subjects were required to press a response key as quickly as possible when presented with the S+, but to refrain from pressing in response to the S-. Cards were presented in a predetermined random sequence at the rate of one card per second. Total testing time was approximately three minutes. Depression of the response key to the S- and failure to respond to the S+ were scored separately as errors. However, because S+ errors were rare and occurred equally in the two groups (6 errors in each group), they were not included in the analyses.

Luria's Test of Conflicting Motor Responding (CM). This test was adapted from a test in the Luria-Christensen battery used to investigate verbal regulation of the motor act (Christensen, 1975). Subjects were given a gestural signal and were required to respond with an alternate movement. Subjects were told: "If I show you my finger, you show me your fist. If I show you my fist, you show me your finger." Each of the two gestures was presented 40 times in a predetermined random sequence at a rate of one gesture per second. Total testing time was approximately 2 minutes. Echopraxic errors were recorded. Reliability testing of the scoring procedure was accomplished by having a second trained examiner simultaneously score 80% of the children's performances. Kappa correlations of the two scorer's protocols showed scorer reliability of .68.

Compatible and Incompatible Conditional Discrimination (CCD; ICD). These two tasks require verbal and motor responses to colored cards. Subjects were asked to name and point to a response card which was either the same color (CCD) or a different color (ICD) than the stimulus card. In all cases, subjects were required to name the color of the card to which they pointed. In both tasks subjects were presented with a predetermined random sequence of 20 cards presented at a rate of one card per second. Order of administration of the two tasks was counterbalanced. Testing time for the two tasks was about four minutes. Verbal and motor errors were scored. Inter-rater reliability for the scoring method was determined as described for CM scoring and showed reliabilities ranging from .66 to .68 for ICD errors and .66 to .81 for CCD errors. Reliabilities are underestimates due to the large number of performances with no errors.

Reitan's Trail-Making Test -- Forms A and B (TM-A; TM-B). Reitan's TM test (1955; 1986) is composed of two parts. The first, TM-A, requires the subject to connect randomly placed, consecutively numbered circles as quickly as possible. Part B involves connecting numbered and lettered circles by alternating between the ordered number and alphabetical letter sequences as quickly as possible. Form A was always administered first. Subjects completed a short sample sequence, errors were corrected and, once the examiner was satisfied that the instructions were thoroughly understood, the test proper was given. Subjects were urged to work as quickly as possible. Errors were pointed out immediately and the subject was asked to continue from the last correct response without erasing the error. Time taken to complete the sequence correctly and number of errors were recorded. Testing time was approximately five minutes.

Results

T-tests and analyses of variance were used to assess group differences. Results of evaluation of statistical assumptions led to transformation of some variables to reduce skewness in their distributions, reduce the number and effect of outliers and improve homogeneity of variance. A square root transformation was used on the number of errors on the Trail-Making A and B tests, all ICD and CCD variables, and the GNG task. Response times for Trail-making A and B were submitted to a log transformation. In cases where significant heterogeneity of variance still existed, as determined by Levene's test (1960), separate variance estimates were used.

Means and standard deviations of the raw scores of the two groups of

children on each of the measures are presented in Table 2.

Insert Table 2 about here

Go-No Go task. A t-test performed on the number of errors showed that ADHD children made a significantly greater number of errors than did the NC children, $t(46)=2.75$, $p<.01$.

Conflicting Motor Response Test. T-tests were performed on the number of errors for the two groups. ADHD children made significantly more errors than the NC group, $t(46)=4.34$, $p<.0001$.

Compatible Conditional Discrimination Test. 2 (subject group) x 2 (order of CCD/ICD administration) ANOVAs were computed for the number of verbal and motor errors. ADHD children made more verbal errors than did NC children, $F(1,44) = 4.19$, $p<.05$. No other effect of subject group was significant. Both groups of children made more motor errors when the CCD task was presented prior to the ICD task, $F(1,44) = 5.90$, $p<.02$. No significant interactions between these factors were found.

Incompatible Conditional Discrimination Test. 2 (subject group) x 2 (order of administration) ANOVAs were computed for the number of verbal and motor errors.

The main effect of order of administration was significant in all analyses. Significantly more verbal and motor errors were made by both groups when the CCD task preceded administration of the ICD (verbal errors: $F(1,44) = 15.48$, $p<.0003$; motor errors: $F(1,44) = 18.45$, $p<.0001$).

The number of verbal errors showed a significant effect for subject

Table 2

Means and Standard Deviations of ADHD and NC
Children on Measures of Motor Control

	ADHD	NC	t/F	p
<u>Go-No Go Test</u> Errors	3.46 *(3.08)	1.58 (1.28)	2.75	<.01
<u>Conflicting Motor Response Test</u> Errors	4.83 (2.60)	2.04 (1.78)	4.34	<.0001
<u>Compatible Conditional Discrimination Test</u> Verbal Errors	.54 (.59)	.25 (.44)	4.19	<.05
Motor Errors	.42 (.58)	.33 (.48)	.42	n.s.
<u>Incompatible Conditional Discrimination Test</u> Verbal Errors	2.04 (1.60)	1.04 (.95)	8.54	<.006
Motor Errors	1.71 (1.37)	.92 (.93)	8.86	<.005
<u>Trail-Making Tests</u> A: Time (seconds)	50.58 (13.81)	51.96 (18.97)	.002	n.s.
: Errors	.63 (.88)	.21 (.41)	2.11	<.05
B: Time (seconds)	153.42 (70.30)	111.25 (43.55)	2.47	<.02
:Errors	2.42 (3.99)	.50 (.72)	2.41	<.03

* standard deviations are in brackets

group, $F(1,44) = 8.54, p < .006$. ADHD children made more verbal errors than did NC children, regardless of test order.

In comparison to NC children, ADHD children made significantly more motor errors, $F(1,44) = 8.86, p < .005$. No significant interactions of Subject Group x Test Order were found.

Trail-Making A; Trail-Making B. T-tests were computed for time taken for completion and number of errors made on each task for the two subject groups.

ADHD children made significantly more errors on the TM-A task than did the NCs, $t(46) = 2.11, p < .05$. No differences were found for time taken, $t(46) = .002, p > .05$.

The ADHD group made more errors on TM-B, $t(46) = 2.41, p < .03$, and took longer to complete the task, $t(46) = 2.47, p < .02$.

Discussion

This study was designed to investigate motor control abilities in ADHD and NC children. It was predicted that the performance of ADHD children would be significantly impaired compared to NCs and would resemble findings for FL patients and ND children younger than 8 years, in spite of their age range from 8 to 12 years.

As predicted, ADHD children were impaired relative to NCs in all four areas of motor control assessed. They were significantly less able to inhibit simple motor actions and echopraxic responses, to alternate responses quickly and correctly, or to use overt verbal self-cues to guide motor responses consistently. These results are consistent with those of studies testing ADHD children on similar tasks (e.g., Hoy et al., 1978;

Homatidis & Konstantareous, 1981; Stevens et al., 1970) and provide direct evidence of parallels between the performance of ADHD children and FL patients.

The performance of the ADHD group resembled that of FL patients and children younger than 8 years in several respects. First, like both reference groups, ADHD children showed difficulty inhibiting motor responses, including the withholding of echopraxic responses, as required on the CM and ICD tests. Like FL patients and normal 6 to 7 year olds, ADHD children responded impulsively when primed to react quickly and imitated the stimulus observed even when instructed not to do so.

Second, ADHD--NC differences on TM-B resemble findings of Reitan (1986) for FL patients and of Gorenstein et al. (in press) and Clarkson and Hayden (1971) for hyperactives, i.e., they showed significantly more problems than NCs in shifting between response dimensions. However, contrary to the findings of Gorenstein et al. and Clarkson and Hayden, ADHD children in the current study made significantly more errors on TM-A as well, although they were able to complete the task as quickly as NCs. Since the directions for both TM tasks emphasized speed, their difficulty withholding primed motor actions may have been heightened. Thus, rather than representing problems in sequencing or scanning per se, their performance probably resulted from impulsive actions. Investigators working with FL patients have not reported error scores. However, the pattern of significant differences on time scores on TM-B, and nonsignificant differences on TM-A, resembles findings from studies with FL patients.

Like FL patients in Drewe's (1975) study, ADHD children made more

verbal errors than their control group on the CCD test. Their verbal errors may be attributable to difficulty withholding primed responses under the fast-paced requirements of the task. Becker et al. (1988) reported that 6 and 8 year old children were less able than 10 and 12 year olds to make speeded decisions on GNG tasks as reflected by slower reaction times. Because the CCD was experimenter-paced, children experiencing difficulty could not slow down. A speed-accuracy trade-off would be expected for children unable to process stimuli and decide on required responses efficiently. Consequently, ADHD children seemed less efficient in making speeded decisions and in withholding task-primed responses until a decision could be made. Thus, the performance of 8 to 12 year old ADHD children resembled the level of attainment of 6 to 8 year olds in these skills and their verbal impairment on the CCD seems related to response inhibition difficulties.

It is interesting that, although ADHD children made significantly more verbal errors on the CCD, they did not make significantly more motor errors than NC children. This discrepancy implies that, at least on some trials, ADHD children were making mismatched motor and verbal responses. It is likely that the children may have been able to give a correct motor response by visually matching stimulus to response alternative. When required to generate the verbal response, however, they were more likely to make an impulsive vocalization, as noted above. This interpretation would point to a lack of "semantic meaningfulness" (Meichenbaum & Goodman, 1969a) of their verbal responses. Although it has been reported that 5-1/2 to 6 year old children are able to use overt self-instructions to control or correct

behavior (Meacham, 1978), FL patients have demonstrated difficulty using self-instructions effectively (Drewe, 1975; Homskaya, 1960). Verbal and motor errors were infrequent in both ADHD and NC groups and a more extensive study of verbal-motor dissociation in ADHD children would be necessary to confirm that the discrepancy represents a true dissociation. A detailed study, such as that of Meacham (1978), of the use of language by ADHD children, particularly as it relates to control of motor behavior, would be helpful in clarifying the relationship of verbal and motor behavior.

Study 2: Performance of ADHD children on tests measuring problem-solving skills

Patients with FL damage, normal young children and ADHD children also have been found to show deficiencies in a variety of skills required for efficient problem solving. The discussion of problem solving skills and performance will be subdivided into five areas. The first three sections will describe typical difficulties shown by FL and ADHD groups on trial-and-error learning, organization of task stimuli, and organization and planning of responses. Although normal developmental differences in these three areas have been studied, these studies have not included tasks used with FL patients. Parallels between all three groups will be described in the discussion of concept discovery strategies in the fourth section. The Wisconsin Card Sorting Test, which has been consistently associated with FL deficits and which requires the use of all the mentioned skills, will be discussed separately.

Trial-and-Error Learning

FLS. In order to perform trial-and-error learning tasks adequately, subjects must be able to appreciate errors and utilize error information to achieve a correct response, while observing task rules. FL patients show impairments in the use of error feedback as well as in complying with task rules.

Petrides (1987) constructed two conditional associative learning tasks to investigate the ability of FL patients to regulate their behavior by external signals and instructions. His tasks included both a spatial and a non-spatial version. Subjects were required to learn a series of

associations between six stimulus-cues and their six corresponding responses by a trial-and-error procedure. Petrides found that patients with FL lesions had significantly higher error scores than non-FL patients on both conditional associative tasks.

The failure of FL patients to use errors to modify or control their performance does not seem to reflect failure to recognize errors. Konow and Pribram (1970) described a woman with left FL damage who was able to reliably identify errors made by herself and others on tasks involving complex serial commands. Despite intact error recognition, she failed to use this knowledge. This description is consistent with Pribram's earlier (1960) demonstration in primates that error recognition is dependent on posterior cortex, whereas error "utility" is disturbed following frontolimbic lesions.

Milner (1964) described a distinctive lack of compliance with test instructions by FL patients on a stylus maze test. This task requires learning the correct path across an array of nailheads which act as visible "stepping-stones". Every time a response departs from the correct path, an error counter clicks loudly. These clicks provide feedback by which subjects should be able to learn the correct path. Rules for the task include: when the counter clicks, subjects must go back to the preceding nailhead; they must not go back and retrace the correct path; and they must not make diagonal movements across the maze. Non-FL patients were able to avoid rule-breaking, but FL patients were significantly more likely to break rules. Patients with FL lesions appeared to simplify the problem by trying to complete the task as quickly as possible without attending to the one

approved route. Thus, although FL patients understood and could repeat the rules, they failed to comply with them.

The same response style is evident in the performance of FL patients on the Porteus Maze test (Walsh, 1978). Patients with FL damage frequently entered the same incorrect alley repeatedly, often concurrently stating that the choice was incorrect. Hence, although they seemed aware of their errors, they were unable to use this knowledge to modify their actions.

In summary, patients with FL damage show impaired performance on trial-and-error tasks. The deficit is related both to difficulties in complying with task instructions and inability to use information from recognized errors to modify behavior. This pattern may stem from previously described problems with response flexibility and verbal-motor compatibility.

ADHD. ADHD subjects also show deficits in using response feedback during trial-and-error learning. Pigott and Douglas (1987) tested ADHD and nonADHD groups on Petrides' (1987) spatial conditional associative learning task. Consistent with the performance of FL patients, Pigott and Douglas reported that ADHD children were significantly poorer than nonADHD children at trial-and-error learning of associations between six stimulus cues (lights) and six corresponding responses (key presses). Thus, both FL and ADHD groups appear to have difficulty using this type of environmental information.

Like FL patients, ADHD children also make qualitative, "rule breaking", errors on the Porteus Maze test (Conners & Eisenberg, 1963; Conners & Rothschild, 1968; Parry, 1973). They cut corners, cross over lines, and lift the pencil in spite of directions not to do so.

Thus, both FL and ADHD subjects fail to demonstrate efficient learning using trial-and-error. Both groups fail to comply consistently with task instructions and seem impaired in the use of response feedback to correct or modify performance.

Stimulus Organization

FLS. Patients with FL damage have shown deficits on a number of tasks which require categorization and organization of stimuli. Stuss et al. (1983) tested leucotomized patients (i.e., patients with orbitofrontal lesions) on a "Visual-Verbal Test of Conceptual Thinking". The test involved grouping three out of four objects and identifying the grouping principles. Although no differences in number of correct groupings were found between leucotomized and normal control subjects, there was a significant difference in ability to identify grouping strategies. FL patients often grouped items appropriately but failed to give the correct reason. It is not clear whether these patients were unable to verbalize the basis for their decision, or whether they failed to formulate a deliberate strategy and simply grouped three items "automatically" on the relatively easy task.

Incisa della Rochetta (1986) did find impairment in FL patients on a picture categorization task when sorting demands were increased. Patients were required to sort thirty-six pictures into discrete categories of their own choice. Patients with FL damage showed a tendency to produce incomplete categorizations, i.e., they were more likely than non-FL patients to fail to include all the pictures in the categories formed. Incisa hypothesized that this tendency resulted from a failure to consider the entire set of items

prior to forming categories and during sorting. Hence, by the end of the sorting time allowed, FL subjects were left with items which did not fit easily into any of the categories they had chosen.

The inefficient visual search behavior of FL patients also reveals failure to consider all of the available information prior to acting. Luria (1973) tested patients' ability to deduce the thematic content of pictures. In order to perform well, subjects had to scan the pictorial information, compare informational fragments, form an hypothesis regarding the theme, and then test the hypothesis by comparison with picture content. Luria reported that, although the task was adequately performed by nonFL brain-damaged subjects, patients with FL damage tended to note one particular detail and then extrapolate directly from this detail to the meaning of the picture as a whole without verifying the hypothesis.

Luria (1973) also reported results of eye movement recordings during examination of thematic pictures. The eye movements of normal subjects showed scanning of the entire picture during a free observation period, whereas those of FL patients tended to return repeatedly to a few details. Similarly, normal subjects changed the direction and style of their visual scanning in response to specific questions about a picture; FL patients failed to adapt their scanning to answer different questions. They scanned randomly or returned to spontaneously noted details.

Miller (1983) also reported an inability of FL patients to use available information efficiently. She assessed FL and temporal lobe (TL) damaged patients and normal control subjects on visual and verbal tasks in which target items had to be guessed on the basis of partial information.

Up to three clues were given for each visual or verbal item. Clues were constructed so that the target items could be deduced by successively integrating the information from all three clues. Miller reported that FL patients consistently tended to neglect available information. One of the verbal tasks required subjects to identify a word meeting three definitions. Left TL and all FL patients were more likely to guess words without verifying that they satisfied all the clues. On the visual task, as well, FL patients failed to use all the information inherent in the clues more often than normal control or left TL patients.

Thus, patients with FL damage demonstrate difficulty categorizing and organizing stimulus materials. They fail to effectively scan all available information and to apply all information presented prior to responding. This behavior is consistent with previously described deficits in response inhibition and would support the notion that problems of control seen in motor responses also appear in cognitive performance.

ADHD. Children with ADHD also fail to process and organize stimulus materials efficiently. Further, as in FL patients, the performance difficulties of ADHD children become more severe when the number of elements to be processed increases.

For example, Hoy, Weiss, Munde, and Cohen (1978) administered a multiple-choice test of word knowledge to ADHD and normal control children. They reported that ADHD children performed as well as controls when two alternatives were given, but performed less accurately when given five alternatives. They suggested that this pattern was the result of the failure of ADHD children to consider all the alternatives prior to making

their decision.

Similar results were reported by Rovet (1980) using a version of the Matching Familiar Figures Test (MFFT) with impulsive and reflective children. The MFFT is a matching test in which subjects must identify which stimulus from a set of six is identical to the target. Many researchers have reported impaired performance by ADHD children on the MFFT (Campbell, Douglas & Morgenstern, 1971; Cohen, Weiss & Minde, 1972; Juliano, 1974). Rovet altered the test so that a varying number of response alternatives were available. He reported that, although both groups made more errors as the number of alternatives increased, the increase was more marked for impulsive children. In addition, impulsives did not increase their latencies to the first response as the number of alternatives increased, suggesting that they did not scan all the alternatives or at least did not process the available information effectively.

Studies of scanning behavior of impulsive children also show less efficient visual search strategies. Impulsives look less often at the target stimulus and each alternative and make fewer comparisons between the target and alternatives (Drake, 1970; Siegelman, 1969). They also use fewer strategies such as comparing the target with one alternative at a time and searching distinctive features systematically.

ADHD children also are impaired relative to normal control children on the Embedded Figures Test, in which subjects must conduct an organized search for the correct figure embedded in a visual array. ADHD children tend to respond to superficially similar stimulus attributes rather than making an exhaustive search and verifying their choice against the model

provided (Campbell et al., 1971; Cohen et al., 1972). These results resemble the inefficient visual search of FL patients on thematic pictures reported by Luria (1973).

Thus, ADHD children, like FL patients, tend to respond prior to organizing and exhaustively searching available stimuli. As noted for FL patients, these cognitive difficulties are likely to be related to response inhibition deficits. The failure to use available stimulus information effectively also is probably one aspect of poor organization and planning of responses, discussed in the next section.

Response Organization

FLS. FL patients typically fail to plan and organize response strategies. One example of this impairment that already has been described is their poor performance on maze tasks (Milner, 1964; Walsh, 1978). Lhermitte, Derosne, and Signoret (1972) demonstrated similar deficits on the Rey-Osterreith Complex Figure and block design tests. On both tasks, patients were asked to copy a model, either drawing a duplicate or using blocks to copy a geometric design. Although researchers have excluded the frontal lobes as the cause of constructional deficits per se (Hecaen, 1981), patients with FL damage showed performance disturbances in Lhermitte et al.'s study. On both tasks, they tended to skip preliminary examination of the design and focused on salient details to the exclusion of other design aspects. If, however, an external organization was imposed on the stimulus design (e.g., outlining each block on the model or presenting the components of the Complex Figure sequentially), the performance of FL patients improved, suggesting that their difficulties were related to failure to plan

response strategies.

Petrides and Milner (1982) investigated the ability of FL patients to organize and monitor their own responses. They presented subjects with stacks of cards, each picturing a set of 6, 8, 10, or 12 stimuli in a regular array. For each stack, the array, number of stimuli, and specific items remained the same, but the relative positions of the items varied randomly. Subjects were required to go through the stack, touching only one item on each card, without repeating any item. Hence, the subject initiated and determined the response sequence. Four stimulus sets were used: concrete and abstract words and abstract and representational drawings. Compared to non-FL patients and normal control subjects, FL patients were significantly impaired, particularly on the non-verbal stimulus sets. Whereas only left FL patients were impaired on the two verbal tasks, both left and right FL groups were impaired on the two non-verbal sets. Normal subjects attempted to impose an organization for the longer sequences (e.g., always touching the suitcase after the train). This strategic and meaningful grouping of items was less apparent in the FL groups. Thus, FL patients appeared less able to organize and monitor their own responses.

ADHD. Hamlett, Pellegrini, and Conners (1987) tested ADHD and normal control children on a task which required the sorting and recall of twenty stimulus cards. Children were encouraged to sort the cards "in a way that would help them remember". Following free recall, children were asked to explain to a younger child how to play the game in a way that would make it easy to remember all the cards. Hamlett et al. reported no significant difference in the time required for ADHD and control children to sort the

cards and only a slightly greater number of items recalled by control children. Analysis of the instructions they gave for younger children, however, revealed that ADHD children received significantly lower scores on task organization, strategy production and communicative effectiveness. That is, they were significantly less likely than controls to verbalize the spontaneous generation and use of strategies on a task requiring self-imposed structure.

ADHD children have not been tested on tasks which directly measure their ability to plan and monitor responses, such as Petrides and Milner's (1982) self-ordered pointing task. As previously discussed, however, on other tasks ADHD children demonstrate the rule-breaking, impulsive performance typical of FL patients and fail to organize and plan responses prior to acting. Like FL patients, they also show improvement when tasks are organized for them and when their performance is organized by sequential steps (Douglas, 1980). The Petrides and Milner (1982) task will be used in the present study to assess impaired organizational and self-monitoring abilities directly.

Concept Discovery

FLS. Patients with FL damage also have difficulties with concept discovery and matrix search tasks. Cicerone, Lazar, and Shapiro (1983) used a concept discovery task to study the use of hypotheses and cognitive strategies in FL patients. Subjects were given a series of two-choice visual discrimination problems consisting of stimuli varying on four dimensions. They were instructed to point to one stimulus on each trial and to use the examiner's feedback ("right"- "wrong") to discover which stimulus

dimension was "correct". FL patients produced fewer "appropriate" hypotheses (i.e., hypotheses consistent with all prior feedback) than did non-FL patients. They also produced fewer appropriate hypotheses after negative than positive outcome trials.

Poppen, Pribram, and Robinson (1965) reported impairments of FL (lobotomy) patients on a matrix search task. Subjects viewed a display consisting of sixteen windows in a 4x4 arrangement. Initially, windows displayed six different symbols, which varied position randomly among the sixteen windows. Subjects were required to identify the "correct" symbol by pressing the window displaying it. After five consecutive correct responses, a different symbol became "correct". After five of the six symbols had served as the correct stimulus, a seventh symbol was added and immediately became the correct stimulus. After six out of the seven symbols had been used, an eighth was added. The cycle repeated until patients had identified all possible correct symbols or until they exceeded the time limit. "Search" errors were defined as repetition of a response to an incorrect symbol prior to locating the correct symbol. A "post-search" error was a response to an incorrect symbol after the patient had identified the correct symbol for that program.

The most striking finding was that only half of the FL group as compared with over 77 percent of non-lobotomized schizophrenic controls completed all twenty trials. During task performance, when a new symbol became available, FL patients chose it correctly, but failed to stay with it to criterion. Unless a new symbol was presented, patients with FL damage had more difficulty both locating and persevering with a correct symbol.

Thus, the impairments of FL patients on matrix search and cognitive discovery tasks reflect difficulties in organizing stimuli, planning response strategies, and using response feedback to modify or maintain behavior.

Normal Development. Research on developmental changes in the concept discovery behavior of normal children has been concerned with how children attempt to solve matrix problems and whether they can learn to improve the efficiency of their performance. Investigators have found consistent developmental changes in the style and efficiency of strategies used by children.

Mosher and Hornsby (1966) studied strategies used by children playing the game of "Twenty Questions". They described two types of questions children used when required to find a "correct" picture from a larger matrix of pictures. Hypothesis-scanning (HS) questions test a specific hypothesis which is unrelated to previous questions (e.g., Is it the car?; Is it the dog?). Constraint-seeking (CS) questions eliminate more than one alternative (e.g., Is it a tool?; Is it red?). Because CS questions "focus in" on the solution, they result in more efficient problem-solving than the random guesses of HS questions. Mosher and Hornsby reported that children shift from HS to CS questions between the ages of six to eleven years.

Eimas (1970) further investigated the development of CS strategies using a "Twenty Questions" procedure. He tested four groups of children, aged 7-1/2, 9-1/2, 11-1/2, and 13-1/2. Children tried to discover the single cell designated "correct" by the experimenter, using as few questions as possible. Eimas reported that the two oldest groups of children performed

significantly better than the younger children. The youngest children (age 7-1/2) did little better than predicted by a HS guessing strategy.

Eimas (1970) also found a progressive increase in the number of "categorical" questions used. These questions included a class of objects (e.g., Is it a red one?) or involved at least two cells of the matrix (e.g., Is it a number between 2 and 6?). Use of categorical questions, however, did not begin to increase significantly until after 9-1/2 years of age. Children did not use "focusing" questions (i.e., eliminating half the possibilities) until 9-1/2 to 11-1/2 years and still used them only minimally by 13-1/2 years.

Eimas (1970) hypothesized three stages in the development of questioning strategies. The first (7-1/2 years) is characterized primarily by a guessing strategy, i.e., the HS questions of Mosher and Hornsby (1966). The second level (9-1/2 to 11-1/2 years) is one in which categorical questions occur with increasing frequency. The third level (11-1/2 to 13-1/2 years) is marked by a high incidence of categorical questions and, under simple to moderate levels of task complexity, the appearance of focusing strategies.

Kagan et al. (1979) reported that even when six year old children know information relevant for problem solutions, they may fail to use that information when needed. In one experiment, children were required to remember whether each in a series of dolls was right side up or upside down. When the arrangement was random, six year olds performed almost as well as eight year olds. If the dolls were organized in an alternating pattern, eight year old children were able to recognize and use the pattern to

remember a longer series. Although most of the six year olds understood the rule "alternate", they failed to apply that rule and performed at the same level as previously. Kagan et al. concluded that children reach maximal performance on tasks requiring efficient control processes around nine to ten years of age, with the greatest improvement between seven to nine years.

In summary, Kagan et al. (1979) placed developmental improvement in problem-solving skills to the period of seven to ten years of age. Mosher and Hornsby (1966) trace the development from HS to CS question styles to roughly the same age range. Eimas (1970) divided the development of CS questions into three periods. Seven year olds use predominantly a guessing strategy, with the shift to categorical questions not occurring until nine to eleven years. Optimal efficiency through the use of focusing questions does not appear until 11 to 13 years.

ADHD. Dykman, Ackerman, and Oglesby (1979) tested ADHD children on a test resembling the one used by Poppen et al. (1965) with FL patients. The test required that children find the symbol which would result in reinforcement. Initially, children were required to choose one of two possible symbols, to a criterion of five correct choices. The stimulus field was gradually increased to twelve symbols. Therefore, as in Poppen et al.'s task, a "search" strategy was needed to discover the "correct" symbol, while an "after-search" strategy determined behavior after the correct symbol was identified. Although performance measures were recorded somewhat differently from Poppen et al., certain comparisons are of interest.

Forty percent (8/20) of the ADHD children indicated that they were so tired of the "game" that they wanted to quit early, compared to one normal

control and one learning-disabled child. In addition, as the complexity and length of the task increased, the ADHD children had longer latencies on criterion than search trials. ADHD children also made a greater number of extraneous responses than the other two groups. Dykman et al. (1979) relate this pattern to Pribram's (1971) description of FL patients' "lack of tolerance for a problem". It is comparable to the findings of Poppen et al. in which fifty percent of the FL patients failed to complete the task. Dykman et al. report that ADHD children seemed as able as normal controls to locate the correct symbols, but they did not make consistent use of this information. Thus, like lobotomized FL patients, ADHD children showed considerable difficulty maintaining correct responses and their search and post-search errors were augmented by increasing task length and complexity.

Tant (1978) tested ADHD and normal control children using a Rule Learning task resembling the concept identification test used by Cicerone et al. (1983). The children were presented with pictures varying on four dimensions and were required to discover the rules determining which stimulus dimension was "correct". ADHD children used significantly less efficient strategies and failed to use prior feedback consistently.

Freibergs and Douglas (1969) and Douglas and Parry (1982) failed to find significant ADHD--normal control differences on an easier concept identification task. As in the tasks of Cicerone et al. (1983) and Tant (1978), children were given a series of two-choice visual discrimination problems. On this version, however, stimuli varied on only two dimensions. When continuous reinforcement was used, ADHD children did not differ from normal controls. Consistent with the results of Dykman et al. (1979) and

Cicerone et al. (1983), Freibergs and Douglas (1969) reported that ADHD children used a larger number of irrelevant hypotheses. The authors associated this finding with the failure of hyperactives to use task-related feedback consistently and efficiently.

Tant and Douglas (1982) found that ADHD children also used less efficient questioning strategies on a Matrix Search task of the type used by Mosher and Hornsby (1966) and Eimas (1970). Following administration of the child-generated "Twenty Questions" portion of the task, a recognition task was given in which children indicated which of two experimenter-generated questions was "better" to solve the matrix. Dependent variables included a measure of average number of pictures eliminated per question and the frequency of four different question types. Question types were defined in a fashion resembling that of Eimas (1970). "Ideal" CS questions were the same as Eimas' focusing strategy, i.e., questions eliminating half the available alternatives. "Good" CS questions were equivalent to categorical questions which grouped at least two items. "One-item" questions were equivalent to Eimas' (1970) guessing strategy and Mosher and Hornsby's (1966) hypothesis seeking questions. "Non-informative" questions were irrelevant to the task or repeated previously acquired information.

Tant and Douglas (1982) reported that ADHD children were less efficient questioners than the normal control children, i.e., they eliminated significantly fewer items per question. In addition, the hyperactive group asked significantly fewer ideal CS questions and more one-item questions. Thus, ADHD children tended to guess about individual items as did the 7-1/2 year old children in Eimas' (1970) study.

In a post-test interview, Tant and Douglas (1982) found that hyperactives were less likely than control subjects to verbalize all relevant dimensions by which matrix items could be classified. Nevertheless, 19 out of 21 hyperactives identified stimulus dimensions which they had not used in formulating their questions. Hyperactives also recognized significantly fewer good questions than did normal controls. Thus, ADHD children seemed to approach this type of task in a more immature fashion than normal controls. Like the 6 year olds in Kagan et al.'s (1979) study, they were capable of recognizing dimensions, but did not seem to consider stimuli "categorically" and therefore did not take advantage of that information. Like FL subjects, they typically failed to conduct an exhaustive perceptual analysis of the stimulus matrix. Finally, they failed to use all the information available to them. Even when they knew the concept and recognized it in the display, they did not consistently apply this knowledge to achieve successful performance. This behavior also resembles the performance of ADHD children on the matrix search test of Dykman et al. (1979).

In summary, both ADHD and FL groups show difficulties performing efficiently on concept discovery tasks. Both groups have problems categorizing stimuli and using prior knowledge to guide questioning strategies. Impairments are greater when stimulus and task complexity are increased. As on motor tasks, ADHD children tend to perform like younger normal children. This tendency is apparent especially in the results of Tant and Douglas (1982) where normal control children with a mean age of 9-1/2 used age-appropriate categorical and focusing strategies (Eimas,

1970). ADHD children, in contrast, were more likely to use the HS, guessing strategy typical of children about 7 years of age, in spite of their mean age of over 9-1/2 years. The failure of ADHD children to recognize and apply categorical information also suggests that they were functioning at a level typical of six to seven year old children (Kagan et al., 1979).

Wisconsin Card Sorting Test

The Wisconsin Card Sorting Test (WCST) has consistently been associated with deficits following FL damage. For successful performance, it requires integration of a wide variety of cognitive skills on which FL patients have been shown to be impaired, including inspection of stimulus attributes, planning of response strategies, rule compliance, utilization of performance feedback, inhibition of impulsive responding, alternation between response categories, concept discovery, and coordination of verbal and motor information. Interestingly, adult FL patients, children with FL damage, ADHD children, and normally developing children have all been tested on this task.

FLS. The WCST test requires subjects to sort cards categorically by color, form, or number. The examiner provides feedback for each card placement, indicating whether the sort is correct or not, but gives no information regarding possible categories or category shifts. No correction of errors is allowed and the correct sorting category shifts without warning. Thus, the subject must use verbal feedback from the examiner in order to discover the correct sorting category and to know when to shift from this category.

Patients having lesions of dorsolateral frontal cortex typically

complete fewer categories and make significantly more perseverative errors than other subjects, i.e., they persist in making responses which would have been correct for the previous category (Drewe, 1974; Milner, 1963, 1964; Robinson, Heaton, Lahman & Stilson, 1980). In addition, some FL patients will spontaneously verbalize that "it has to be the color, the form, or the number," but do not change their response pattern to conform to that knowledge.

Stuss, Benson, Kaplan, Weir, Naeser, Lieberman, and Ferrill (1983) have described a different type of deficit on the WCST by leucotomized patients (i.e., patients with lesions involving the orbitofrontal cortex). Stuss et al. presented the first set of 64 cards following Milner's (1963) description. They then explained the idea of sorting to the three criteria and gave examples. Their purpose was to ensure that any deficits would not be attributable to lack of knowledge of the three criteria or the concept of sorting. The second set of 64 cards then was administered. No differences between the FL patients and normal controls were found for the first 64 cards. For the second 64 cards, normal controls completed significantly more categories and made significantly more correct responses. The FL patients produced approximately the same number of correct responses in both halves, but decreased the number of categories attained in the second half. That is, FL patients did not persevere in a category long enough to achieve the criterion level, shifting after three to five consecutive responses.

Cavazutti, Fischer, Welch, Belli, and Winston (1983) reported WCST results for seventeen children with FL damage following surgery for tumor removal. They were tested an average of ten years following surgery and at

a mean age of 15.4 years. This age is well above that shown to be critical for WCST performance (Chelune & Baer, 1986). Seventy percent of these subjects failed to complete more than four categories. In contrast, only 6% of children with the same type of tumor treated without surgery failed to complete four categories. Perseveration scores of the FL group also were significantly higher than those of the control children and approximated norms for 6 to 8 year olds established by Chelune and Baer (1986). Thus, both adults and children with FL damage show deficits on the WCST. In addition, scores of the FL children were similar to those of FL adults on categories achieved and number of perseverative errors.

Normal Development. Chelune and Baer (1986) constructed developmental norms for the WCST. They reported that children younger than 7 years performed at a level comparable to FL adults, both in number of categories achieved and number of perseverative errors. Performance improved dramatically from age 6 to 7, but children did not achieve normal adult levels until age 10. These results are consistent with those reported for normal children tested on the concept discovery tasks discussed previously.

Chelune and Baer (1986) also measured failures to maintain set, i.e., shifting away from a correct category prior to reaching criterion. Although children approached normal adult levels by 10 years, they did not match them until age 12. Thus, there seem to be three developmental stages comparable to those described for mastery of concept discovery tasks. During the first, 6 to 7 year old children perform like adults with FL dysfunction, showing perseveration and difficulties generating problem solving strategies. The authors interpret this finding as an indication that the

frontal lobes are not functionally mature at age 6. During the second stage (7 to 10 years), children perform better than FL patients, but not at the level of normal adults, suggesting that the frontal lobes are beginning to become operational, but are not yet functionally mature. During the third stage (10 to 12 years), children are able to perform the WCST as efficiently as adults. They are able to formulate strategies, shift sets, and test hypotheses.

ADHD. ADHD children also show performance deficits on the WCST. Both Parry (1973) and Chelune et al. (1986) reported that ADHD children achieved significantly fewer categories and made significantly more perseverative errors than normal control children. Corenstein et al. (in press) also found that ADHD children made significantly more perseverative errors, but not nonperseverative errors, than NCs. In contrast to the other studies cited, however, Corenstein et al. did not find ADHD-NC differences on number of categories.

ADHD children appear to have difficulties on the WCST similar to those of FL patients with dorsolateral lesions (Milner, 1963, 1964). The pattern of performance and the error levels reported for ADHD children resemble those of FL patients (e.g., Drewe, 1974), children with FL damage (Cavazzuti et al., 1983), and children younger than age 10 (Chelune and Baer, 1986). Thus, the WCST reveals performance similarities between adults who have lost frontal lobe functions, children who have not yet developed these functions, children having damage to the neurological substrate underlying the development of frontal lobe functions, and ADHD children.

Plan for Study 2. FL patients have difficulty using error feedback to modify performance, show rule-breaking errors, fail to search for and use available information prior to responding or to plan response strategies. They do not perform well on concept discovery tasks or on the WCST.

Young children (7 to 9 years) perform inefficiently on concept formation and WCST tasks. Efficient CS questions are not used reliably until approximately 10 years and adult levels of performance on the WCST are not reached until the same age. Like FL adults, young children may not utilize information they "know". In contrast to motor control skills, where children show consistent performance by approximately 6 to 7 years, cognitive problem-solving skills seem to show major development between the ages of 10 to 12.

ADHD children generally show deficits on these tasks similar to those of FL patients. In addition, consistent with their tendency to perform at the 6 to 7 year level on motor control tasks, ADHD children seem to resemble 6 to 8 year olds on WCST and concept discovery tests in spite of sample mean ages of 9 to 10 years. These deficits are probably attributable to inhibitory difficulties and their impaired performance on trial-and-error learning and stimulus organization skills. Response organization deficits were hypothesized to parallel those of FL patients, but ADHD samples have not been directly tested on this type of task. The present investigation will attempt to provide evidence of response organization deficits as measured by Petrides and Milner (1982) and to replicate previous findings of impaired performance on the WCST.

Tasks Used to Investigate Problem-Solving Skills in Study 2

Wisconsin Card Sorting Test (WCST). The WCST is a sorting task which is thought to be sensitive to: difficulties in formulating and testing hypotheses (Bond & Buchtel, 1984; Drewe, 1974; Milner, 1963); cognitive flexibility and the use of feedback to modify behavior (Milner, 1963); and the ability to maintain cognitive set (Parsons, 1975). Weinberger, Berman, and Zec (1986), using regional cerebral flow measures, have demonstrated localized activation of the frontal cortex, especially in the dorsolateral region, during WCST performance.

Self-Ordered Pointing Task (SOP). The SOP task (Petrides & Milner, 1982) requires response organization and planning, including the ability to (a) initiate a sequence of responses; (b) monitor previous responses within a trial; (c) discriminate responses made in prior trials, and (d) plan future responses. Attention and short-term memory skills must also be intact. Because all FL subjects were impaired on the nonverbal tasks, subjects in the current study were administered either the representational or abstract design sequences.

Method

Subjects

The samples studied included all the children tested in Study 1 (24 ADHD children and 24 matched normal control children). Statistical comparisons of descriptive data were presented in Table 1.

General Procedure

Subjects were tested individually in the same session and under the same conditions as in Study 1.

Test Materials and Administration

Wisconsin Card Sorting Test (WCST). The standard method of administration was used (Heaton, 1981). Four stimulus cards, differing in color, form and number were placed in front of the subject: one red triangle, two green stars, three yellow crosses and four blue circles. A pack of 128 response cards, varying along the same dimensions of color, form and number as the stimulus cards, were presented to the subject one at a time. Subjects were asked to place each response card below the stimulus card with which they thought it belonged and were told that the examiner would indicate whether the choice was "right" or "wrong". Subjects were required to discover and sort to a single category. After ten consecutive correct color responses, the sorting principle would shift without warning. Categories shifted from color to form to number, then again to color, form and finally to number. Subjects continued sorting until the six possible categories were achieved or until all 128 cards were placed. Total testing time was approximately 15 to 20 minutes.

Five measures of performance were recorded: (1) number of categories achieved (0-6); (2) "extra correct" responses: number of cards correctly sorted, but not a part of the ten consecutive correct responses; (3) perseverative errors: responses which would have been correct for the previous category; (4) nonperseverative errors: any incorrect placement not of a perseverative nature; and (5) unique errors: those not matching the

card with which they were paired in either color, form or number. These errors were also included as nonperseverative errors.

Self-Ordered Pointing Task (SOP). Subjects were presented with stacks of 21.5 x 28 cm pages displaying matrices of 6, 8, 10, or 12 representational pictures or abstract designs. The same pictures were used in each matrix set, but their relative positions varied randomly and no picture appeared in more than one set. Three trials were given for each set of stimuli beginning with the 6 item set and progressing to the 12 item set.

Subjects were instructed to touch each picture in a set by touching one picture on each page. Pictures could be touched in any order, but each picture could be touched only once. Thus, subjects were free to initiate and organize their own response sequences as they moved through the pages in a set. The only restriction involved repeated pointing to the same spatial location. Although this may be an efficient strategy, it does not require the monitoring and organization of responses which the task was designed to measure. Subjects were told in the initial directions that this strategy was not acceptable and any subsequent attempt to use it resulted in a repetition of the rule and a request that the child choose another picture. These responses were recorded and scored as "rule breaks".

The child was told that accuracy was the primary task requirement. If a subject hurried or seemed not to be focusing on the test items, the examiner redirected attention to the test stimuli and repeated the instruction to "choose a different picture every time". The examiner turned the pages at a rate of approximately three to five seconds per page to slow the speed of impulsive, nonattending subjects. Subjects were not pressed to

perform at a rate faster than appeared comfortable. Testing time was approximately 15 minutes over all four sequence lengths. Errors and rule breaks were recorded.

Results

T-tests and analyses of variance were used to assess group differences. Results of evaluation of statistical assumptions led to transformation of some variables to reduce skewness in their distributions, reduce the number and effect of outliers and improve homogeneity of variance. A square root transformation was used on all WCST variables. In cases where significant heterogeneity of variance still existed, as determined by Levene's test (1960), separate variance estimates were used.

Means and standard deviations of the raw scores of the two groups of children on each measure are presented in Table 3.

Insert Table 3 about here

Wisconsin Card Sorting Task. T-tests comparing the two subject groups were computed for: number of categories achieved, extra correct sorts, perseverative errors, nonperseverative errors and unique errors. Compared to the NC group, ADHD children sorted to significantly fewer categories, $t(46) = 3.40$, $p < .002$, and made significantly more perseverative errors, $t(46) = 3.04$, $p < .004$, and nonperseverative errors, $t(46) = 2.80$, $p < .007$. Significant differences were not found for number of unique errors, $t(46) = 1.28$, $p > .05$, or for extra correct responses, $t(46) = 1.72$, $p > .05$.

Table 3

Means and Standard Deviations of ADHD and NC
Children on Tests Measuring Problem-solving Skills

	ADHD	NC	t/F	p
<u>Wisconsin Card Sorting Test</u>				
Categories Achieved	3.79 (1.73)	5.14 (1.06)	3.40	<.002
Extra Correct Responses	27.42 (13.71)	20.42 (14.88)	1.72	n.s.
Perseverative Errors	27.21 (11.57)	17.17 (11.23)	3.04	<.004
Nonperseverative Errors	23.71 (15.02)	13.29 (10.16)	2.80	<.007
Unique Errors	9.42 (11.36)	5.79 (7.88)	1.28	n.s.
<u>Self Ordered Pointing Test</u>				
Representational:				
Errors (summed across trials)	14.73 (7.80)	9.31 (4.55)	5.08	<.05
Rule Breaks	1.18 (1.33)	.15 (.38)	2.68	<.03
Abstract:				
Errors	26.25 (7.17)	24.15 (10.0)	.33	n.s.
Rule Breaks	1.67 (2.57)	.46 (.66)	1.68	n.s.

* standard deviations are in brackets

Self-Ordered Pointing test: Representational Designs. A 2 (subject group) x 4 (sequence length) ANOVA with repeated measures on the second factor was performed for the number of errors in each sequence.

The number of errors committed differed significantly across the four sequence lengths, $F(3, 66) = 19.96, p < .0001$, i.e., number of errors increased with increasing sequence length.

There was a significant main effect of group on error scores, $F(1, 22) = 5.08, p < .05$, with ADHD children making more errors than the NC group. There were no significant interactions between diagnosis and sequence length.

A t-test computed for the number of rule breaks committed during the entire task showed that ADHD children made significantly more rule breaks than did the NC group, $t(22) = 2.68, p < .03$.

Self-Ordered Pointing test: Abstract Designs. A 2 (diagnostic group) x 4 (sequence length) ANOVA with repeated measures on the second factor was computed for the number of errors in each sequence length. A significant effect of sequence length was found, $F(3, 69) = 26.93, p < .0001$, reflecting the effect of the increasing number of designs on the difficulty level of the task. There was no significant effect of group, $F(1, 23) = .33, p > .05$, or interaction of group and sequence length, $F(3, 69) = 2.61, p > .05$. A t-test for the number of rule breaks did not show any significant differences between the two diagnostic groups, $t(23) = 1.68, p > .05$.

Discussion

This study investigated problem-solving skills in ADHD and NC children by testing response organization skills and performance on the Wisconsin Card Sorting Test. It was predicted that ADHD children would show significantly more item repetitions on the SOP and would be more likely to break task rules. It was expected that performances on the WCST would replicate previous findings of impaired performance of ADHD children compared to NCs. In addition, performance of the ADHD children with a mean age of 10.3 years was predicted to resemble that of normal children younger than 10 years, as reflected by the norms established by Chelune and Baer (1986).

Results on the WCST replicated, in part, previous findings by Parry (1973), Chelune et al. (1986), and Gorenstein et al. (in press). ADHD children in all four studies made significantly more perseverative errors. The present study also replicated the ADHD-NC differences found by Parry and Chelune et al. on number of categories completed, although Gorenstein et al. did not find significant differences on this variable. Interestingly, the levels of performance on these variables closely resembled one another in all of the studies, with the exception of number of categories achieved in the study of Gorenstein et al.

In contrast to the findings of Gorenstein et al. (in press) and Parry (1973), however, ADHD children in this study also made significantly more nonperseverative errors. (Chelune et al. did not report nonperseverative errors.) Although this type of error was not reported by Milner (1963) or Robinson et al. (1980), Drewe (1974) found that FL patients made

significantly more of both nonperseverative and perseverative errors. Thus, the pattern found in the present study is consistent with Drewe's findings with a FL sample.

Performance of ADHD children in the present study was comparable to the performance levels of FL children and adults (Cavazzuti et al., 1983; Drewe, 1974; Milner, 1963). Also, as predicted, the performance of ADHD children whose mean age was approximately 10 years was at the level of norms for 6 to 7 year old children reported by Chelune and Baer (1986). The performance of the 10 year old NC children in the present study closely matched that of the 10 year old group in Chelune and Baer's study.

The failure of ADHD children to complete as many categories as the NC children and their significantly higher number of perseverative and nonperseverative errors supports the hypothesis that ADHD children, like FL patients and 6 to 7 year old children, are impaired in the formulation and testing of hypotheses and in using feedback to modify their behavior. This is consistent with their difficulties on other problem-solving tasks, as described previously (e.g., Dykman et al., 1979; Tant, 1978).

Chelune et al. (1986) reported that ADHD children did not show significant group differences from NC children in failure to maintain set. The comparable measure used here, Extra Correct Responses, also failed to show significant group differences. These results support the conclusion that ADHD children did not leave a successful sorting strategy prematurely once they had made several consecutive correct responses.

Finally, the lack of significant differences between ADHD and NC groups on Unique errors suggests that most ADHD children understood the nature of

the task and were sufficiently aware of the relevant dimensions to use them as sorting strategies. This resembles the pattern described by Kagan et al. (1979) for 6 year olds and by Tant and Douglas (1982) for ADHD children: children may be aware of stimulus dimensions without using that information to solve problem situations.

Results from the two SOP tests were less clear. ADHD--NC differences were found for the Representational Designs (RD) task and supported the prediction that ADHD children would show significantly more difficulty than NCs organizing and monitoring their responses. On the Abstract Designs (AD) test, however, the ADHD group did not appear to have more difficulty than NCs.

Representational stimuli are usually less difficult than abstract designs, as they can be processed verbally in addition to nonverbally. That ADHD children did not show poorer performance on the AD test is in apparent contradiction to findings that FL impairments are greater in situations that are more cognitively demanding. A comparison of the performance of ADHD and NC groups on both SOP tests with the mean error scores of FL and NC groups reported by Petrides and Milner (1982) may help explain this discrepancy. On the easier RD task, normal adults made approximately 2.5 errors across all four list lengths, while FL patients made between 7 and 10 errors. While NC children in the present study made 9.3 errors, resembling the scores of FL patients, ADHD children had a mean score of 14.7 errors. Thus, they had more difficulty than either NC children or FL patients. On the more difficult AD task, although normal adults had a mean error score of approximately 9, the FL groups scored from 15 to 19 errors. Both groups of

children in this study exceeded the FL error scores, making approximately 24 to 26 errors.

This pattern suggests that 8 to 12 year old children have not yet developed the skills necessary for adult-level mastery of the SOP task. NC children evidently had acquired sufficient self-organization skills to perform the RD test significantly better than ADHD children, but neither group was able to perform well on the more difficult, nonverbal AD test. A developmental study of children's performance on the SOP task would help clarify the significance of the apparent impairment of ADHD children on the RD test.

Finally, a significant difference in number of rule breaks was found on the RD task. The tendency of ADHD children to attempt to point to only one matrix position, thereby simplifying task demands, is consistent with performance of ADHD children on the Porteus Maze test (e.g., Parry, 1973) and the performance of FL patients on stylus maze and Porteus Maze tests (e.g., Milner, 1964; Walsh, 1978). Hence, on tasks which NC children were able to perform, they did not break task rules as frequently as ADHD children. Although the ADHD group also broke task rules more often than NC children on the AD test, the difference failed to reach significance. Thus, rule breaks may occur as a consequence of failure to master task demands, rather than representing a noncompliant "performance style" per se. This suggestion is consistent with a clinical description by Craine (1982) of a FL patient who demonstrated increased impulsivity with more complex treatment tasks.

In summary, ADHD children demonstrated significant impairments compared

to NC children in the areas of problem-solving skills assessed: formulation and testing of hypotheses; use of feedback to modify and guide responding; self-organization of responding and adherence to task demands. Although the prediction of response organization deficits and the occurrence of rule-breaking was not supported by the AD task, it was suggested that the difficulty level of the test may have precluded ADHD--NC differences. The performance of the ADHD group, especially on the WCST, replicated their previously reported difficulties on similar tests and resembled the performance of FL children and adults. In addition, as found in Study 1, although the mean age of the ADHD children was 10.3 years, their level of task mastery matched that of ND children younger than 8 years.

Study 3: Performance of ADHD children on tests measuring memory skills

Research into the memory capabilities of FL patients and ADHD children has produced mixed findings. Basic memory processes seem to be largely intact in both ADHD and FL subjects. In both groups, however, deficits do appear which seem to be related to a failure to process and retrieve information in an active, efficient manner. Indeed, in so far as memory is a complex, self-ordered activity, disturbances of motor inhibition and problem-solving skills such as planning and organization are likely to produce some degree of mnestic impairment (Luria, 1973).

Three aspects of memory performance of ADHD and FL groups will be discussed: impact of increasing processing demands; depth of information processing; and sensitivity to stimulus characteristics. Where the same tasks have been used with normal children, results will be included in the discussion.

Increased processing demands

FLS. Although FL patients demonstrate impairments in encoding and retrieval on memory tasks, these deficits do not appear to involve impaired primary memory processes. Ghent, Mishkin, and Leuber (1962) obtained consistently negative results when FL and nonFL brain-damaged patients and normal controls were compared on digit recall, immediate and delayed recall of geometric forms and memory for position.

A number of findings demonstrate that FL patients show impairments on memory tasks with increased processing demands. Barbizet (1970) reported that FL subjects performed at normal levels on tasks requiring simple

registration and recall of visual and verbal material. Yet performance was impaired when subjects were required to remember and use several facts simultaneously.

Luria (1960) demonstrated that recognition of previously viewed pictures was intact in FL patients. Yet when task complexity was increased by increasing the number of recognition alternatives, deficits appeared in the form of perseverations or intrusions of irrelevant, previously formed associations (i.e., proactive interference). When patients were required to repeat a single series of four or five words or digits, initial repetitions were correct. If a different series or a different order of the same series was presented, however, FL subjects showed proactive intrusion errors.

FL patients also show retroactive interference effects. Stuss et al. (1982) found that leucotomy patients performed as well as normal subjects on logical memory and paired associates tests from the Wechsler Memory Scale. Yet presentation of an interference task prior to recall of consonant trigrams resulted in significant impairment of FL subjects.

Thus, FL subjects show difficulties maintaining information in the face of interference or increased task-related information. The impaired use of memory skills by FL patients is elicited by the presence of extra material, whether task-related or irrelevant, which produces an increase in processing demands.

Normal Development. Passler et al. (1985) tested the memory performance of children using verbal and nonverbal proactive and retroactive inhibition tasks. In the proactive inhibition tasks, children were asked to imitate either two 3-word lists or two series of taps and then to repeat the second stimulus series. The authors reported that 6 and 8 year old children were significantly less able than 10 and 12 year olds to inhibit proactive interference. Eight year olds performed significantly better than 6 year olds only on the nonverbal task.

In the verbal and nonverbal retroactive inhibition tasks, children again were required to imitate two 3-word lists and two tapping sequences. This time they were required to complete both series and then repeat the first series. Therefore, in order to do well, they had to ignore the second, more recent, series. Six year old children were significantly worse than the older groups at inhibiting verbal and nonverbal retroactive interference. The performance of 8 and 10 year olds did not differ significantly on either task. Although 10 year olds performed as well as 12 year old children on the verbal task, the 12 year olds performed significantly better than all other groups on the nonverbal task.

Overall, ND children show a developmental increase in their ability to inhibit proactive and retroactive interference. Six year old children show consistent difficulties on both verbal and nonverbal forms of proactive and retroactive inhibition recall tasks. With the exception of the verbal proactive inhibition task, 8 and 10 year olds perform at an equivalent level. Twelve year old children consistently outperform all other groups. The critical ages seen in this developmental sequence are the same as those

reported for the concept discovery and WCST developmental stages discussed previously.

ADHD. Like FL adults, ADHD children generally are not impaired on tasks requiring primary memory processes. In a comprehensive examination of memory skills in ADHD and normal control children, Benezra (1980; Benezra & Douglas, 1988) failed to discover differences in recall of digits forward or backward, letters forward or ordered alphabetically, consonant trigrams, a 12 word list, paired associates for meaningfully related word pairs, block series forward or backward, recurring figures, or dot position recall. Douglas and Peters (1979) reported no deficit in picture recall of ADHD children, with or without distracting stimuli. O'Neill (in preparation; O'Neill & Douglas, in preparation) tested story recall (based on Brown & Smiley, 1977) in ADHD and control children and found no significant difference in number of story units recalled or their level of importance.

Children with ADHD do show evidence of memory impairment when task requirements are more stringent. Although performance of ADHD children did not differ significantly from normal controls on a 12 word list (Benezra & Douglas, 1988), Douglas and Peters (1979) reported significant impairment of recall of a 34 word list and O'Neill and Douglas (in preparation) found significant normal-ADHD differences on a 24 word list. Similarly, Spring, Yellin, and Greenberg (1976) reported impaired recall of Digit Span by ADHD children when an extended form of the task was used.

Ceci and Tishman (1984) found that ADHD children recalled central and task irrelevant information as well as or better than normal controls on simple tasks. Yet when task demands were increased by decreasing the

meaningfulness of the stimuli or by using a faster presentation speed, the ADHD group recognized significantly fewer central target stimuli than normal control children.

Douglas and Benezra (in preparation) reported that ADHD children showed deficits in recall of arbitrary paired associates, but performed at the level of a normal control group when the word associations were meaningful. The authors used these findings and interviews about the childrens' memory strategies to argue that the ADHD group made less use of elaborative mnemonic strategies. By analyzing the types of errors made by subjects, they found that the youngest ADHD children (ages 7 to 8) made more intrusion errors (i.e., words from other pairs in the lists) than control subjects of the same age. The finding of interference from earlier lists resembles the verbal proactive inhibition deficits described for FL patients.

Gorenstein et al. (in press) used a memory task with ADHD and normal control children which involves both proactive and retroactive interference. In the Sequential Memory Task for Children, subjects viewed two cartoons for 2 seconds each, separated by a 5 second delay. After another 5 second delay period, children were asked to identify the cartoons from a selection of four choices in the same order as presented. In a control version, both cartoons were viewed simultaneously for 4 seconds, then identified from a selection of four following a 5 second delay. This version was constructed to minimize interference effects, but otherwise maintain task difficulty. Gorenstein et al. reported that ADHD children were significantly impaired on the interference version. This is consistent with findings of susceptibility to interference of FL patients and children younger than 8

years. In addition, although not explained by Gorenstein et al., is the finding that ADHD children were also impaired on the control condition. This finding may be associated with decreased efficiency of stimulus processing, as will be discussed in the next section.

Depth of processing

FLS. FL patients fail to actively use complex mnemonic strategies to assist stimulus encoding and retrieval. They do not use aids which are presented or actively produce their own, hence the potential interference of irrelevant information is heightened. For example, in list-learning experiments providing mnemonic strategies (e.g., 1=bun, 2=shoe...), nonFL brain-damaged patients perform normally. FL patients not only fail to use the associative techniques provided, but the strategic associates themselves may appear as irrelevant responses (Stuss & Benson, 1984).

Luria (1973) suggested that FL patients rely on "passive imprinting" of external information. Luria (1966) studied the memory performance of FL patients using a superspan learning task requiring recall of a long series of words. Non-brain damaged subjects gradually increased the number of words they learned by directing their attention to previously missed words. FL patients recalled a few words easily, but failed to increase the total number of words learned and recalled different words on consecutive trials. Hence, the learning curve of the FL patients tended to be flatter than that of the controls. Luria suggested that, although passive registration of material was intact, FL patients show a deficit in the active control of learning and retrieval.

Lezak (1983) described the use of the Sequential Matching Memory Task

(SMMT) by Collier and Levy to measure allocation of attention over time. The task consists of decks of cards bearing one of two distinctive symbols (e.g., a plus vs a minus sign) and presented sequentially. Subjects are given a 20-card practice trial in which they must recall the symbol on the card before the previous card (i.e., the card once removed). In the standard administration, there are three 35-card trials requiring the subject to remember the card twice removed. Thus, subjects must generate and use a strategy which allows them to track the three cards shown prior to the one currently observed. Because the reference point is continually shifting, the strategy requires perceptual and response flexibility. In an unpublished study, Collier and Levy reported differences between epileptic and lobotomized patients and a control group of unoperated schizophrenics. Whereas the schizophrenic control group averaged 9+ errors per 35-card trial, the FL (lobotomized) group averaged 16+ errors. Thus, FL patients were either unable to generate a strategy for recalling sequential stimuli, or to apply a strategy in a flexible manner, or both.

ADHD. The use of strategies to improve performance on memory tasks also seems to be impaired in ADHD children. Kinsbourne (1977) reported the use of a pictorial paired associate task in which children were required to memorize pairings of animals and "zoos". ADHD children demonstrated a flatter learning curve than a normal control group. Although the significance of this finding was not discussed by Kinsbourne (1977), it resembles the performance of FL patients on Luria's (1966) superspan learning task.

The failure of ADHD children to effectively utilize sophisticated

mnemonic strategies also is illustrated in studies comparing depth of processing of ADHD and normal children. Douglas and Benezra (in preparation) used a recognition task for recall of paired associates. Children were offered four choices which included the correct association, a semantic synonym, an acoustically related word and an unrelated word. They found that, compared to control children, ADHD children made significantly more errors which involved acoustically related words.

Weingartner et al. (1980) reported a similar finding in an investigation of depth of processing in ADHD children. They found that, in a free recall condition, ADHD children were less likely than normal controls to recall semantically related words. There were no differences in recall of acoustically related words. In addition, the ADHD group used less clustering of related words and, when a clustering strategy was used, they were more likely to cluster words that were acoustically related than ones that were semantically related. Based on these results, Weingartner et al. proposed that ADHD children process material more superficially producing "less well-organized, meaningful (and perhaps strong) trace events in memory" which are "less likely to be stored in...permanent memory...and may be more susceptible to post-processing [retroactive] interference" (p.36).

The preference of ADHD children (mean age of 10 years; Weingartner et al., 1980) for acoustic processing of material resembles the preference of young children (6-7 years) for non-semantic, especially acoustic, encoding in memory tasks. Older children (10-11 years) consistently encode and retrieve material semantically, as do adults (Craik & Lockhart, 1972; Geis & Hall, 1976, 1978; Weiss, Robinson & Hastie, 1977).

In a study providing further support for the hypothesis of superficial processing by ADHD children, Lufi and Cohen (1985) administered a variation of the Wechsler Coding subtest to ADHD and educationally disabled (ED) children. After the standard administration, the examiner covered the number-symbol key and asked the child to draw the symbols. The performance of the ADHD children was significantly inferior to that of the ED group. Also, scores of the ED children correlated significantly with Verbal WISC-R subtests, whereas scores of the ADHD group correlated with Performance subtests. Lufi and Cohen suggested that the control children had assigned verbal meaning to the symbols, while the ADHD children failed to "translate" them from geometric shapes. It may be concluded that the ADHD children processed the symbols more superficially.

Ain (1980) used evidence from memory tasks to argue that ADHD children process stimuli less efficiently. She administered subject-paced viewing tasks followed by an unannounced recognition task. ADHD children were less accurate than normal controls in recognizing previously viewed stimuli even though both groups viewed the pictures for the same period of time. In a second study, ADHD children required more study time in order to equal the accuracy of normal controls in matching pictures during an announced recognition test. Thus, like FL patients, ADHD children seem to fail to process information in a strategic, effortful fashion.

Gorenstein et al. (in press) found ADHD--normal control differences on the SMMT (Lezak, 1983). They did not report how many 35 card trials were given and a simpler version was used in which cards twice removed from the current card were to be recalled. Hence, it is difficult to compare their

results directly with those for FL patients. Nevertheless, ADHD children made an average of 13.8 errors compared to 10.0 for normal control children. These results are similar to those of Collier and Levy. Thus, both ADHD and FL groups have shown impaired recall on tasks requiring the use of memory strategies.

Sensitivity to Stimulus Characteristics

FLS. FL patients are impaired on a number of memory tasks that involve sensitivity to various aspects of stimulus material, even when the tasks do not appear to require the strategic, effortful processing discussed above. For example, Milner (1982; Milner & Petrides, 1984) has described work by Corsi demonstrating impaired temporal ordering of recent events by FL patients. In these recency-discrimination ("recency") tasks, subjects viewed a long, rapidly presented series of cards, each of which showed two stimulus items. On approximately every other card, a question mark appeared between two random items as a cue to the subject to indicate which item had been seen more recently. Thus, unlike the SMMT, the subject was unable to rehearse items. Generally, both items had been viewed before, but occasionally one of the stimuli was new; in the latter case, the card assessed stimulus recognition rather than recency. Patients with FL damage were able to discriminate normally between stimuli presented earlier and new stimuli. In judging the relative recency of items, however, the FL patients showed significant impairments compared to temporal lobe damaged (TL) patients and non-brain damaged controls. Patients with TL damage were somewhat impaired on tests of recognition, but showed no difficulties with recency.

Smith and Milner (1988) reported deficits of FL patients on a frequency sensitivity task. Subjects viewed a series of abstract designs in which individual designs appeared a varying number of times. After viewing the entire series, subjects estimated the number of times each design had appeared. Thus, as in Corsi's recency tasks, patients had to monitor stimuli over time. New designs were included in the post-viewing test list as a measure of recognition accuracy. As in Corsi's tasks, patients with FL damage were impaired on accuracy of frequency estimation, but showed no difficulty on recognition of new items. In comparison, patients with right TL damage made a significant number of recognition errors, but were as accurate as normal control subjects on frequency estimation.

In contrast, FL patients were not impaired on a task assessing memory for spatial location. Sensitivity to frequency and recency requires monitoring of stimuli over time. In contrast, spatial location recall requires reference to a "spatial map" derived from a single experience. Smith and Milner (1981, 1984) tested FL, TL, and normal control subjects on incidental recall of objects and their spatial location. Toys were presented in a random array and subjects were asked to estimate the price of the real object. Following price estimates, subjects were given an unannounced object-recall test and were then asked to replace the toys in exactly the same position they had occupied during the pricing task. None of the subject groups showed difficulty in immediate object recall. Although patients with right TL damage showed impaired recall of object location, FL patients did not differ significantly from normal controls.

However, patients with right FL lesions did make significantly more

extreme price estimates than normal control or TL groups. This finding is consistent with the results on a cognitive estimation task reported by Shallice and Evans (1978). They found that FL patients gave more bizarre estimates than TL patients to questions requiring reasoning based on general knowledge but for which no obvious strategy is available (e.g., "How fast do race horses gallop?"). Both Shallice and Evans and Smith and Milner (1984) interpreted estimation deficits as a specific instance of difficulties in forming and using problem-solving strategies.

Thus, FL patients seem to process or recall less information regarding stimulus attributes when information must be monitored across time. Accordingly, they are impaired on temporal and frequency sensitivity, but do not show difficulty recalling spatial location. Estimation of stimulus attributes (e.g., speed, size) is also impaired and has been linked to the typical impairments of FL patients in problem-solving.

Normal Development. Normally developing children have been tested on temporal and frequency tasks similar to those used with FL patients. Becker et al. (1988) investigated the normal development of temporal sensitivity using a test resembling that of Corsi (Milner, 1982). Ninety visual abstract designs were presented consecutively. When "test" pictures were presented showing two previously viewed designs and one novel design, children were required to select the design seen most recently. Thus, as in the recency task of Corsi, recency and recognition errors could be recorded. The task used by Becker et al., however, differed from Corsi's version in that recognition errors could be made on every trial.

Becker et al. (1988) reported that 6 year old children made

significantly fewer correct choices and chose novel designs significantly more often than 8 year olds, who were significantly less accurate and chose more novel designs than 10 and 12 year olds. Ten and 12 year old children did not differ from each other. The authors concluded that children's performance did not level out until 10 to 12 years. They noted the difficulty in determining whether the younger children had greater difficulty remembering temporal sequences per se, or were attracted to the novelty of new designs more often than older children. Both patterns are typical of patients with FL damage (Milner, 1982; Poppen et al., 1965). Thus, as in the use of problem-solving strategies, patients with FL damage perform at the level of 6 to 8 year old children.

ADHD. Little work has been done on the performance of ADHD children on tasks measuring sensitivity to stimulus characteristics. Ackerman, Anhalt, Holcomb, and Dykman (1986) tested ADHD, reading-disabled and normal control groups of children on frequency sensitivity and temporal sensitivity tasks. The frequency of occurrence task was a simpler version of the test used by Smith and Milner (1988). In Smith and Milner's test, designs were repeated up to nine times; in the version used by Ackerman et al. the maximum number of repetitions was four. The temporal sensitivity task was substantially different from the one designed by Corsi (Milner, 1982) and used by Becker et al. (1988). Children were asked to name drawings shown in two decks of cards presented sequentially. After naming, the decks were shuffled together and the children were required to re-sort the cards into Decks 1 and 2. Following other tasks, the children were given a deck of cards containing cards from Decks 1 and 2 in addition to new cards and were asked

to create two new decks: one consisting of previously seen cards and the other of new cards.

Ackerman et al. (1986) did not find significant differences between ADHD children and other groups on either of these tasks. However, in an analysis of outlying scorers, eight of the worst nine performers were ADHD children. Based on this finding, they suggested that although temporal and frequency sensitivity judgements per se may be intact, the precision of these judgments is less accurate in some ADHD children. The finding of greater variability within the ADHD sample is consistent with the greater variability of FL patients in making cognitive estimates (Shallice & Evans, 1978; Smith & Milner, 1984). It is possible that more demanding versions of these tasks, or versions closer to those used with FL patients, would have elicited significant differences between NC and ADHD children.

ADHD children have not been assessed on spatial location or cognitive estimation tasks such as those used by Smith and Milner (1984). The present study will attempt to establish whether the dissociation between location recall and estimation performances appears in ADHD children as it does in FL patients.

Plan for Study 3. FL patients show impaired performance on memory tasks when task complexity and processing demands are increased. These deficits probably are related to their failure to generate and use mnemonic problem-solving strategies and their difficulty monitoring information over time. FL patients perform much like children aged 6 to 8 years when tested on comparable tests. ADHD children show a pattern resembling that of FL

patients and 6 to 8 year old children. They have more difficulty when task demands are increased and appear to process material more superficially. The present investigation will attempt to confirm that ADHD children can perform as well as NC children on relatively simple memory tests. It is predicted that they will show the dissociation between adequate recall of spatial location and impaired price estimation shown by FL patients on the Spatial Location task (Smith and Milner, 1984). In addition, it is expected that they will perform poorly on the SMMT, thus replicating the findings of Gorenstein et al. (in press).

Tasks used to Investigate Memory Performance in Study 3

Wechsler Memory Scale: Logical Memory (LM). The LM subtest of the Wechsler Memory Scale (WMS) tests recall of verbal ideas from two meaningful prose paragraphs. Reed, Jagust, and Budinger (1987), using regional cerebral blood flow measures, showed that performance of the LM test is related to activation of temporo-parietal cortex.

In clinical testing of patients with localized brain damage, those with dysfunction of the temporal lobe are most likely to show impairment on verbal memory tasks, including the WMS:LM subtest (e.g., Glowinski, 1973; Milner, 1972), especially following delays. FL patients typically have not shown significant impairments in the WMS:LM test (Delaney, Rosen, Mattson & Novelly, 1980). Thus, ADHD children are not expected to have significant difficulties on this task.

WMS: Paired Associate Learning (PA). The PA subtest of the WMS requires that the subject learn ten word pairs: six are meaningful, "easy" associations (e.g., baby - cries); four are nonmeaningful, "hard"

associations (e.g., cabbage - pen). The list is read three times with a memory trial following each reading. Recall of the pairs after a delay period is measured by a single memory trial.

The PA subtest measures a subject's ability to learn and retain new information (Brandt & Butters, 1986). The use of hard and easy pairs tests retention of previously well-learned associations and of new, unfamiliar associations.

The PA, like the LM subtest, reveals memory deficits in patients with TL dysfunction (Walsh, 1978). Vargha-Khadem (1987) demonstrated that children with left TL lobectomy were significantly impaired compared to NC children. Stuss et al. (1982) reported that leucotomized patients performed as well as normal controls on WMS subtests. Based on this distinction between the performance of FL and TL patients, ADHD children are not expected to show significant difficulties.

WMS: Digit Span (DS). The DS subtest of the WMS includes two tasks: Digits Forward (DS-F) and Digits Backward (DS-B). Both consist of five pairs of from 3 to 9 random number sequences read aloud by the examiner at a rate of one digit per second.

DS-F has been described as measuring efficiency of attention rather than "memory" per se (Spitz, 1972). Stromgren (1977) described it as requiring "simple, readily accessible material which can be reproduced almost automatically...". DS-B requires that subjects hold digits in memory while simultaneously reversing their order (Weinberg, Diller, Gerstman & Schulman, 1972). TL and parietal lobe brain-damaged subjects may show digit span impairments. FL patients typically are not impaired on simple digit

recall tasks like the WMS:DS. ADHD children are expected to perform as well as NCs on this task.

Sequential Matching Memory Test (SMMT). The SMMT requires generation of a response strategy, memory of a (temporal) sequential stimulus ordering, sustained attention and the ability to ignore the interfering effects of salient stimuli, and perceptual and response flexibility (Lezak, 1983). Collier and Levy (from Lezak, 1983) have shown frontal lobotomy patients to be impaired on this test. Gorenstein et al. (in press) found significant ADHD--NC differences on a version of the SMMT. It is predicted that these ADHD--NC differences will be replicated.

Recall of Spatial Location Task (Location). On a test assessing the incidental recall of objects and their spatial location, Smith and Milner (1981, 1984) reported that patients with right TL damage show impaired recall of object location. Both left and right TL groups were impaired in delayed recall of objects, although immediate object recall was not impaired. FL subjects were accurate in both recall of objects and their spatial location compared to NC and TL groups, but gave significantly more extreme price estimations. It is predicted that ADHD children will show a similar dissociation by performing adequately on immediate object and location recall, but will give significantly more extreme price estimates.

Method

Subjects

This study was carried out subsequent to the first two studies. Forty families agreed to continued participation. There were twenty-two (19 male, 3 female) children in the ADHD group and eighteen (16 male, 2 female) in the normal control (NC) group. Demographic data and behavioral ratings are presented in Table 4. Statistical analyses showed no significant differences between the two groups on age, IQ or sex. As expected, Parent Rating Scale and Teacher Rating Scale scores were significantly higher for the ADHD children (TRS: $t(38) = 314.77$, $p < .0001$; PRS: $t(38) = 116.42$, $p < .0001$).

Insert Table 4 about here

Procedure

Subjects were tested individually in a single session lasting approximately 45 minutes. The children were tested in their school during an ordinary school day. Tests were administered in one standard order.

Test Materials and Administration

Wechsler Memory Scale. The Paired Associate Learning (PA), Digit Span (DS) and Logical Memory (LM) subtests were administered according to the standardized instructions. In addition, thirty minute delayed recall was obtained for the LM and PA subtests following administration of the SMMT and Location tasks.

Sequential Matching Memory Test (SMMT). The task was simplified from

Table 4

Demographic Characteristics of the ADHD and NC Subject Groups
(Means and Standard Deviations)

<u>Group</u>	<u>Age</u> (Months)	<u>IQ</u>	<u>TRS</u>	<u>PRS</u>
ADHD (N=22)	119.10 (20.59)	94.10 (10.76)	2.32* (.37)	2.16* (.38)
NC (N=18)	119.53 (19.18)	95.13 (9.29)	.28 (.33)	.71 (.45)

Standard deviations are in parentheses

IQ: Peabody Picture Vocabulary Test

TRS: Teacher Rating Scale Hyperactivity Index score

PRS: Parent Rating Scale Hyperactivity Index score

* $p < .0001$

the version described by Lezak (1983) in order to make it more appropriate for use with children. Children were given two trials of 35 cards showing pictures of either an ice cream cone or an apple. These were administered in a predetermined random sequence at a rate of approximately one card every four seconds. Subjects were required to recall the card seen two cards previous to the one currently viewed. Children were first given a practice session in which they were asked to recall the card seen just before the current one to a criterion of six consecutive correct answers; then they were asked to name the card seen two previously, continuing to the same criterion. Total testing time was approximately 10-15 minutes. Number of errors in each of the two 35 card trials was recorded.

Recall of Spatial Location Task (Location). Sixteen small, easily recognizable toys were placed on a sixty cm square sheet of heavy brown paper. For each subject the toys were placed in different random positions.

The children were told that this was a game in which they were to tell the examiner the average price of the real life objects the toys represented. The "average" price was explained as being "not a very expensive one and not one that's very cheap, but somewhere in the middle." They were warned not to touch the toys, but to point to each using a small paintbrush. They were to point to each toy in any order, name it and then estimate its price. Ten seconds were allowed between naming and pricing. Three practice items were given during which the children were free to ask questions. When it was clear that they understood the instructions, they were shown the array of sixteen items and asked to name and tell the price of each. They were then asked to turn their back to the array and it was

covered.

A test of object recall was given immediately following pricing. Children were asked to name as many of the toys as they could remember within one minute. After a short delay of five minutes (administration of DS task), a sheet of blank paper of the same dimensions as the original was placed in front of the children along with the sixteen items. They were asked to place all the toys in the same location and orientation in which they had seen them when giving their prices. Exactness of placement was emphasized and a maximum of two minutes was allowed.

Scores on object recall, location recall and price estimation were computed. The object recall score reflected the number of objects correctly named within one minute. Location recall was assessed by measuring the mean displacement of the objects in centimeters from their original positions in the array. Price estimation errors were defined as extreme estimates greater than \pm two standard deviations from the mean of the normal control group (Smith & Milner, 1981, 1984).

Results

Means and standard deviations of the performance of the two groups on each measure are presented in Table 5.

Insert Table 5 about here

WMS: Logical Memory (LM). T-tests were computed for Immediate recall of the two stories (A and B). No significant differences were found between the diagnostic groups, LM:A $t(38)=.24$, $p>.05$; LM:B $t(38)=.52$, $p>.05$.

Table 5

Means and Standard Deviations of ADHD and NC Children
on Measures of Memory Performance

	ADHD	NC	t/F	p
WMS ¹ : Logical Memory Story A				
Immediate Recall:	7.43 (3.35) ²	7.17 (3.31)	.24	n.s.
Delayed Recall:	6.11 (2.76)	5.67 (2.49)	.36	n.s.
WMS: Logical Memory Story B				
Immediate Recall:	7.30 (3.19)	6.78 (3.10)	.52	n.s.
Delayed Recall:	6.48 (3.50)	6.33 (3.35)	.17	n.s.
WMS: Paired Associates				
Immediate Recall:	15.09 (2.81)	15.92 (2.88)	.91	n.s.
Delayed Recall:	8.95 (1.29)	9.67 (.97)	3.74	<.06
WMS: Composite Delayed Recall:	15.23 (2.89)	15.67 (2.70)	.36	n.s.
WMS: Digit Span: Forward	5.41 (1.10)	5.33 (1.33)	.20	n.s.
: Backward	4.18 (.80)	3.83 (.92)	1.28	n.s.
Sequential Matching Memory Task:				
Errors	11.91 (4.18)	10.24 (3.48)	2.82	n.s.
Location Recall Task				
No. of Objects Recalled:	8.77 (1.50)	9.67 (2.25)	1.51	n.s.
Mean Object Displacement: (in cm)	5.92 (.58)	5.38 (.70)	1.00	n.s.
Mean Estimation Errors:	3.42	.83	4.15	<.001

¹ WMS: Wechsler Memory Scale

² Standard Deviations appear in brackets

n.s.: not significant

WMS: Paired Associate Learning. A t-test for Immediate recall of the paired-associate word lists was performed for the two diagnostic groups. No significant difference was found, $t(38)=.91, p>.05$.

WMS: Digit Span (DS). T-tests were computed for the mean number of digits recalled forward and backward. No differences on either measure were found between the ADHD and NC groups (DS-F: $t(38)=.20, p>.05$; DS-B: $t(38)=1.28, p>.05$).

WMS: Delayed Recall of LM and PA. T-tests were computed for recall of the LM stories and associate-learning lists following the 30 minute delay. There were no significant differences between the groups for either dependent variable. However, there was a trend on the delayed recall of PA, $F(1,38)= 3.74, p <.06$. This trend reflects the somewhat higher recall of the NC group (NC mean = 9.67; ADHD mean = 8.95). Separate analysis of "easy" and "hard" word pairs revealed no significant differences between ADHD and NC children.

Overall delayed verbal recall was assessed using a combined measure based on the delayed-recall scores of the LM and PA subtests (Milner, 1975). This composite score is the sum of the mean number of items correctly recalled from the two LM stories plus the number of correct word associations. Again, no significant difference between ADHD and NC children was found, $t(38) = .36, p>.05$.

Sequential Matching Memory Task. A 2 (subject groups) x 2 (trials) ANOVA with repeated measures on the second factor did not indicate a significant difference in number of errors between the two subject groups, $F(1,34)=2.82, p>.05$. Number of errors did not change significantly between

the two 35-card trials, $F(1,34)=2.10$, $p>.05$, nor was there a significant interaction between diagnostic group and trial, $F(1,34)=.01$, $p>.05$.

Location Recall Task. T-tests were computed for the mean displacement in cm and the number of objects recalled by each diagnostic group.

The number of objects recalled immediately after viewing the array did not differ significantly between the two subject groups, $t(38)=1.51$, $p>.05$. There was also no significant difference in the average distance of objects replaced as closely as possible to their positions in the original array, $t(38)=1.00$, $p>.05$.

The method of Smith and Milner (1981, 1984) was used to assess differences in price estimation. A cut-off point was set at \pm two standard deviations from the mean of the price estimates given by the normal control children for each object. Any estimate that fell outside this range was considered an error. Twenty children in the ADHL group made a total of 74 errors. A total of fifteen errors were made by seven NC children. Chi square analyses indicated significant differences both in the number of subjects making errors ($X^2 = 4.68$, $p<.05$) and in the number of errors made by each group ($X^2 = 45.43$, $p<.001$). A t-test also yielded significant differences between the groups in the mean number of errors made, $t=4.15$, $p<.001$.

Discussion

This study investigated memory performance in ADHD and NC children. It was predicted that ADHD children would not demonstrate significant difficulties on the relatively simple tests of the WMS (LM, AL, DS). In contrast, on the SMMT, a test thought to require the generation and use of an effective mnemonic strategy, they were expected to be significantly less accurate than NCs. On the Location Recall task, a measure of sensitivity to stimulus characteristics and cognitive estimation, it was predicted that ADHD children would show a dissociation between recall performance and accuracy of price estimation. That is, it was expected that, like FL patients, they would not have difficulty recalling objects or their locations, but would produce extreme estimations of their prices.

As predicted, the performance of ADHD children did not differ significantly from NCs on any of the WMS recall measures. NC children tended to do better on delayed recall of PA word pairs, although the difference did not reach significance. No differences were found on performance of hard vs easy pairs. Both groups of children performed well on this task: NC children missed an average of less than one pair out of the ten possible; ADHD children missed just over one pair. Thus, it appears unlikely that ADHD children were demonstrating meaningful difficulties in recall on this simple test. These results are consistent with those in studies previously described in which ADHD subjects were able to perform at NC levels on tests which did not require the use of complex mnemonic strategies (Benezra & Douglas, 1988; Douglas & Peters, 1979).

The SMMT was included to represent tests requiring the use of a

deliberate strategy. Contrary to predictions and the findings of Gorenstein et al. (in press), ADHD children were not impaired relative to NCs. The SMMT used in this study, however, was a simplified version of the one described by Lezak (1983). This was done in order to ensure that the difficulty level would be suitable for children. Instead of naming the card three prior to the observed card, children were required to recall the card two prior. This test condition was identical to the practice condition used by Collier and Levy and described by Lezak (1983). FL subjects did not show performance difficulties in the 10-card practice trial. In addition, only two 35-card trials were used, rather than three as used by Collier and Levy. Thus, the lack of significant ADHD--NC differences may indicate that the task was not sufficiently demanding to require complex strategies.

As noted previously, Gorenstein et al. (in press) did not specify how many trials were given in their version. Although they used the same recall criteria as in the present study, their statistics (i.e., use of t test) imply that only a single trial was administered. The mean errors per trial, sample sizes, and standard deviations are similar in both ADHD studies. ADHD children in this study made an average of 11.9 errors compared to 13.8 errors in the results of Gorenstein et al. NC children made an average of 10.2 vs 10.0 errors, respectively. Thus, the levels of performance were similar in both investigations. The statistical evaluation of the repeated trials in the current study may account, in part, for the apparent "difference" in findings. Use of a more demanding version of the SMMT, such as that used by Collier and Levy, may clarify whether these ADHD--NC differences are meaningful.

Finally, as predicted, ADHD children showed the dissociation between recall performance and price estimation seen in FL patients (Smith & Milner, 1981, 1984). Accuracy of their recall of objects and object location did not differ from that of NCs. Their pricing of objects, in contrast, was significantly more extreme. It is interesting to compare the mean number of extreme estimates made by ADHD and NC children to those of right FL (RF) and NC adults (Smith & Milner, 1984). RF patients made an average of 3.7 extreme price estimates compared to 3.4 for the ADHD children in the current study. NC adults made .6 extreme estimates compared to .8 for the NC children in the present study. Thus, the performance of ADHD children resembled that of FL subjects on the Location Recall task both in their pattern of performance and the number of extreme estimates they made.

In summary, the pattern of results obtained supports the hypothesis that, like FL patients, ADHD children do not have primary memory difficulties. In so far as estimation tasks represent special instances of conceptualizing and planning response strategies, these results are consistent with the findings of Studies 1 and 2 and with previously reported performance deficits of ADHD children.

General Discussion and Conclusions

The purpose of the three studies reported in this dissertation was to explore, within a developmental context, the relationship between impairments associated with FL dysfunction and those associated with ADHD. The studies provided evidence of similar patterns of impairment and intact functioning in ADHD children and FL patients in three major areas of cognitive functioning: motor control, problem-solving skills, and memory performance. Wherever norms were available for normal children on similar tests of FL functions, ADHD subjects performed like 6 to 7 year olds, in spite of their mean age of approximately 10 years and minimum age of 8 years.

In Study 1, ADHD children were significantly less likely than controls to inhibit motor actions, including echopraxic responses on the GNG, CM, and ICD tasks. They also had difficulty alternating responses quickly and accurately on TM-B. This was interpreted as a vulnerability to response priming, which produced failures to inhibit motor responses when primed to react quickly. In addition, they showed a tendency to exhibit dissociation of verbal and motor responses on the CCD task. It was suggested in the discussion of this finding that the verbal responses of ADHD children may lack "semantic meaningfulness" (Meichenbaum & Goodman, 1969a) and thus would be more vulnerable to disruption by priming.

In Study 2, ADHD children made significantly more perseverative and nonperseverative errors and completed fewer categories than NCs on the WCST. This pattern was interpreted as evidence of a broad-based impairment in

formulating and testing hypotheses and using feedback provided by the examiner to modify and guide responding. Although ADHD children discovered all of the stimulus dimensions on the WCST, they did not use this categorical information during problem-solving as efficiently as NCs.

ADHD children also had greater difficulty organizing and directing their responses and adhering to task constraints on the SOP task. They performed significantly worse than the NC group on the SOP-Representational Designs task and were significantly more likely to break task rules. This difference was not seen on the Abstract Designs version, which was more difficult and was associated with increases in rule breaks for both groups. This association raises the possibility that the "noncompliant" rule-breaking of ADHD children is related to problems in mastering environmental demands.

The findings on memory tasks in Study 3 confirmed previously reported findings (Benezra & Douglas, 1988; Douglas & Benezra, in preparation; Douglas & Peters, 1979) that ADHD children are able to perform as well as NCs on simple, direct memory tasks. Normal memory performance was demonstrated in both verbal and visuospatial dimensions. On the more complex price estimation component of the Location Recall test, however, ADHD children made significantly more extreme estimates. Thus, where the task required recall, organization and judgement regarding information derived from daily experience, ADHD children were less able to construct a problem-solving strategy, to retrieve relevant information, to verify estimates against prior experience, or some combination of the three. Smith and Milner (1984) reported similar difficulties on this task for FL

patients. Shallice and Evans (1978) also described extreme cognitive estimations by FL patients. This result is consistent with the difficulty of ADHD children on other tasks requiring the construction and implementation of complex, deliberate strategies (e.g., Tant & Douglas, 1982).

Results for the SMMT were inconclusive. ADHD children did not demonstrate significantly impaired performance on this version of the SMMT. This result may be related to level of task difficulty, as the version used was easier than that used by Collier and Levy (Lezak, 1983). Slight changes in task demands have been shown to affect the performance of ADHD children (Douglas, 1988). Gorenstein et al. (in press), however, did report significant differences on a version similar to the one used in the present study. Although means and standard deviations were similar in both studies, differences in statistical analyses led to differing conclusions. Further investigation of ADHD performance on the SMMT is necessary to clarify these findings.

Conclusions

The first conclusion drawn from these three studies is that frontal lobe dysfunction provides a useful functional analogy to describe the performance characteristics of ADHD children. This conclusion is based on the finding that ADHD children were consistently impaired on tests assessing frontal lobe functions.

Secondly, the performance of ADHD children on these tests was developmentally anomalous. This is based on their differences from matched NCs as well as the finding that, in spite of their mean age of about 10

years, ADHD children tended to perform like 6 to 8 year old normal children. Studies of normal children show that performance of these tests demonstrates a developmental gradient. Normal children younger than 8 years make many more errors than older children and use simpler strategies. Their performances resemble those of adult FL patients on the same tasks.

The third conclusion is that this anomaly appears to be relatively specific to frontal lobe processes. ADHD children showed the same pattern of difficulties and intact functions reported by other investigators for FL patients on tests sensitive to frontal lobe and temporal lobe functioning. They were impaired on tests measuring frontal lobe functions, but did not differ from normal control children on tests sensitive to temporal lobe function. The Location test provides a particularly good example of this dissociation. ADHD children, like Smith and Milner's (1984) FL patients, made extreme estimates of the prices of stimulus objects. Neither ADHD children in the current study nor FL patients in the Smith and Milner study showed impaired immediate recall of objects or their spatial locations. In contrast, Smith and Milner (1984) reported that TL patients showed impaired recall on both measures, but did not have difficulty making realistic estimations.

Thus, comparison of the performance of ADHD children and FL patients on the neuropsychological measures used in the present study establishes the descriptive accuracy of frontal lobe dysfunction as an analogy for ADHD. Having established the appropriateness and specificity of the analogy, it may be possible to apply knowledge about the frontal lobes to contribute to an understanding of ADHD.

Earlier ADHD--FL Studies

Previous investigators who have attempted to apply information about frontal lobe dysfunction to ADHD children have tended to focus on specific impairments described in the literature on the performance of FL patients. Some authors have stressed the ADHD child's lack of behavioral inhibition or "lack of tolerance for a problem" as the key deficit associated with FL dysfunction (Chelune et al., 1986; Dykman et al., 1979; Mattes, 1980). Although these researchers have not clearly defined "inhibition" and "problem tolerance", they believe that a lack of inhibition can explain the children's impulsiveness, decreased focused attention, and distractibility. Consequently, they conclude that an inhibitory deficit is a sufficient explanation of their impairments.

Although lack of inhibition appears to be a major component of the impairments shown by ADHD children on several tasks in the present study, including the GNG, CM, ICD, and CCD tasks, it does not seem sufficient to explain the children's deficits completely. Inhibitory deficits do not appear to explain fully the extreme price estimations made by the children, their pattern of errors on the WCST, or their inconsistent mastery of response alternation tasks.

For example, in the present study, ADHD children made significantly more errors and took significantly longer to complete TM-B than NCs. Yet, as demonstrated in prior studies, they did not show consistent difficulties on response alternation tasks designed for mastery by 5 to 8 year olds such as the Progressive Figures and Color Form tests (Clarkson & Hayden, 1971; Chelune et al., 1986). That is, impulsive difficulties of ADHD children are

more clearly elicited by more complex and demanding tasks. Thus, the differential occurrence of inhibitory failures on various alternation tasks seems related to increasing levels of task complexity.

In addition, the quality of responses made by ADHD children is not always consistent with simple inhibitory difficulties. Informal observations during the price estimation component of the Location task revealed that ADHD children often seemed to be carefully considering prices before giving an estimate. This style does not seem to reflect an impulsive blurting of the first price that comes to mind. Instead, it points to a failure to be able to integrate relevant information, as discussed previously.

Similarly, on the WCST, ADHD children in this study did not seem to be making purely impulsive responses. They were able to sort cards to relevant stimulus dimensions, as implied by the failure to find significant ADHD--NC differences on Unique errors. In the study of Crelune et al. (1986), once ADHD children had identified the sorting principle, they maintained categories as well as normal controls, as measured by number of failures to maintain set. In fact, NCs tended to shift prematurely more often than ADHD children, although the difference was not significant and frequency of occurrence was low in both groups (NC: 1.83; ADHD: 1.17). Thus, although ADHD children have more difficulty with this task as reflected in their significantly greater numbers of perseverative and nonperseverative errors and fewer categories achieved, they did not respond in ways that suggest purely inhibitory difficulties. Instead, the occurrence of inhibitory failures seems, in part, to be related to problem solving difficulties and

task complexity and is not independent of task context.

The results of Dykman et al. (1979) also point to problems beyond response inhibition difficulties. As described earlier, Dykman et al. used a matrix search task. ADHD children made an increasingly greater number of errors than NCs as task complexity increased. These results support the suggestion that inhibitory difficulties increase as cognitive demands increase. Thus, lack of inhibition appears to interact with problem solving difficulties.

Gorenstein et al. (in press; Gorenstein & Newman, 1980) have attributed attention and impulse control deficits in ADHD children to "susceptibility to disruption by a competing response." They define "competing responses" as those which are "artificially compelled or naturally prepotent" when presented with stimuli which have high salience for the child. Gorenstein et al. conclude that the deficits they found in their ADHD sample on tasks sensitive to frontal lobe abilities support this interpretation. They point especially to greater perseverative errors on the WCST, more errors on the SMMT, and longer time scores on the TM-B and Stroop Color-Word distraction conditions.

However, this theory does not account for the significant ADHD--NC differences Gorenstein et al. obtained on the baseline conditions of both the Stroop task and the Sequential Memory Test for Children. The baseline Stroop condition required only that the child name the color presented. Thus, the salient response was the correct one and slow response times represent difficulty quickly identifying the colors presented. This type of difficulty is not clearly explained by an hypothesis of "competing" or

"prepotent" responses as no competing response was present and the naturally prepotent response was correct. Also, although Gorenstein et al. did not obtain ADHD--NC differences on nonperseverative errors on the WSCT, ADHD children in the present Study 2 did make significantly more of these errors. FL patients also make more perseverative and nonperseverative errors than NCs (e.g., Drewe, 1975). High error rates on these measures point to difficulties in the problem-solving aspect of the WCST rather than simple responding to one prepotent stimulus dimension.

The hypothesis of competing responses also does not account for some of the other ADHD--NC differences found in the three studies of the present report. Prepotent competing responses were not involved in the CCD, TM-A, and price estimation tasks. Yet, ADHD children made more errors on each of these. ADHD children made more verbal errors on the CCD although the correct response was the most salient and they often were making simultaneous correct motor responses. This type of error is consistent with a lack of "semantic meaningfulness" as discussed in Study 1 in regard to CCD verbal errors and points to "higher order" cognitive impairment. In TM-A, there is no clear "prepotent response". TM-A presented only a single, typically overlearned, number sequence, yet ADHD children made more errors. The price estimation measure is a complex problem-solving task which does not present clearly defined prepotent or competing response alternatives. Thus, although failure to inhibit responses to salient stimuli is almost certainly one aspect of ADHD impairment, it is not sufficient to explain their performance characteristics.

The hypotheses of inhibitory deficits and heightened responsiveness to

salient stimuli are certainly important components of the performance of ADHD children. Neither provides a sufficient explanation by itself, however. ADHD children demonstrate difficulties in the areas of problem-solving, effective use of feedback, generation and use of strategies, etc. When presented with a complex task, inhibitory deficits seem to be heightened and ADHD children make more responses to stimuli of greater salience such as novel cues (e.g., Dykman et al, 1979), or to perceptually identical stimuli such as in the ICD in the present investigation. Thus, these hypotheses may represent partial explanations or aspects of a wider mechanism.

Perspectives from the FL literature

Stuss and Benson (1986) note that early in the study of the frontal lobes, there was considerable controversy as to whether they had any unique function. In order to demonstrate that the frontal lobes did play an important role in brain functioning, researchers focused on specific impairments shown by patients with FL damage, such as lack of motor inhibition and impulsivity (e.g., Bianchi, 1895), perseveration and cognitive rigidity (e.g., Rylander, 1939), and attentional deficits (e.g., Ferrier, 1886). In spite of this emphasis on specific deficits, investigators hypothesized that these performance characteristics represented part of a larger, more pervasive problem.

The neuroanatomical significance of the frontal lobes played a part in the development of these theories. Frontal cortex is a final end-point for visual, auditory and somesthetic sensory systems. Direct sensation from primary sensory areas is projected to secondary association areas where

higher-order perceptual analysis occurs. These secondary areas project to the frontal region. By this means, the frontal lobes receive information from the external environment after it has been analyzed and processed by modality-specific and inter-modal association regions (Nauta, 1971).

Neural connections also project to the frontal lobes from thalamic and limbic areas, including the amygdala and hippocampus. By these connections, the frontal lobes receive information regarding relevant memories and internal states such as affect and motivation and their somatic concomitants (Nauta, 1971, 1973).

(Nauta, 1973) In addition to receiving internal and external information from cortical and subcortical regions, the frontal lobes have efferent connections to various sensory, motor and subcortical areas. These efferent pathways are believed to play an important role in the monitoring and modulation of cortical sensory and motor areas and limbic functions (e.g., Nauta, 1971). Nauta (1971) described the FL syndrome as a "consequence of loss of a sensory-effector organization involved in mechanisms of both perceptual processing and behavioral programming (p. 181)."

It is important to note that it is not just the monitoring of current environmental information which is critical to task performance. Via connections with the amygdala, hippocampus, and other limbic nuclei, the frontal lobes also are able to integrate relevant prior learning and motivational/affective states with current conditions. This is an important element of problem solving, responsiveness to reinforcement, response consistency, and other functions typically impaired in FL patients.

Many terms have been used to label this integrative failure in FL patients, including: control, integration, and regulation; planning; organization; goal setting; self-regulation; self-monitoring; problem solving; and anticipation (e.g., Fuster, 1985; Luria, 1973; Nauta, 1971; Stuss & Benson, 1986). These terms refer to higher-level cognitive or "executive" skills. Theories of FL functions attempt to explain the impact of the breakdown of these skills.

Nauta (1971) focused directly on the anatomical connections and discussed their implications for behavioral anticipation and foresight. Fuster (1985) also emphasized aspects of the temporal integration of behavior which enhances the achievement of goals. He specified three aspects, including anticipation, or the use of past experience to prepare for anticipated goal-oriented events; provisional memory, or the holding of information until the goal is reached; and the inhibitory control of interference.

Shallice (1982) referred to the frontal lobe system as a "Supervisory Attentional System" (SAS) which organizes nonroutine goal achievement. When it is damaged, skills such as planning, handling novel situations, and flexible accommodation to new situations are impaired. Routine, overlearned tasks, on the other hand, still can be performed efficiently. Shallice points to perseveration and distractibility or impulsivity as consequences of the SAS failure. Pribram (1973) also described difficulties associated with FL dysfunction as due to inappropriate or absent behavioral schedules or routines. The FL dysfunction is hypothesized to interfere with structuring of context-dependent behaviors. Thus, organization and planning

of behavior within a situational context is impaired.

Luria (1966; 1973) emphasized the importance of the frontal lobes in the integration of information from other areas of the brain. Like Nauta, he viewed the frontal area as a final common pathway which collected information necessary for self-regulation of behavioral and affective states.

Stuss and Benson (1986) believe that deficits in executive skills reflect a breakdown of the hierarchically higher component of "self-awareness". Thus, although each theorist has emphasized somewhat different aspects and used different labels, each posits some form of impairment of a "higher-order" complex cognitive function. This type of broader, more comprehensive explanation unifies the various performance deficits of FL patients. It is useful in giving an overview of the types of deficits to be expected and in conceptualizing treatment approaches.

In addition to postulating a unified basis to the performance characteristics of FL patients, researchers have begun to identify specific anatomical loci in the FLs and to relate them to particular deficits. For example, animal studies have provided evidence that the planning and monitoring of response sequences, such as in the SOP task, is disrupted by lesions in the mid-lateral frontal cortex (Petrides, 1988). Performance of the conditional associative tasks described earlier, which involve trial-and-error learning, is disrupted by lesions in the posterior lateral frontal cortex (Petrides, 1982). Bachevalier and Mishkin (1986) demonstrated that bilateral lesions of posterior ventromedial frontal cortex disrupted recognition memory performance, while lesions in the dorsolateral

areas did not. Hence, when discrete lesions can be made, these "frontal lobe" skills can be dissociated anatomically.

Petrides (1989) suggested that specialized processing areas in the lateral frontal lobes play a part in the general frontal lobe role of organizing complex behavior. For example, monitoring a series of actions and recalling the order of occurrence of specific events are aspects of developing and executing plans. Orbital FL function seems more related to the limbic system memory system.

Thus, even though the frontal lobes have been identified as playing an important role in the organizational aspects of complex behavior, animal studies provide evidence of separate frontal lobe subsystems which act as "specialized functional modules" (Petrides, 1989). Although FL dysfunction in humans is rarely discrete enough to reproduce these findings, it is important to maintain an awareness of the separateness of the functions and of which functions are being measured by specific tasks.

Implications for ADHD

As an initial application of the FL analogy, it may be theoretically and clinically useful to consider ADHD as an impairment of higher-order cognitive processing. From this perspective, deficits such as attention, impulse control problems and failure to inhibit responses to salient stimuli would be consequences of difficulty integrating information in order to plan, set goals, monitor progress, anticipate outcomes, etc.

Along this line, Douglas (1983, 1985) has brought together a number of the performance deficits of ADHD children by proposing a generalized defect

performance, while lesions in the dorsolateral areas did not. Hence, when discrete lesions can be made, these "frontal lobe" skills can be dissociated anatomically.

Petrides (1989) suggested that specialized processing areas in the lateral frontal lobes play a part in the general frontal lobe role of organizing complex behavior. For example, monitoring a series of actions and recalling the order of occurrence of specific events are aspects of developing and executing plans. Orbital FL function seems more related to the limbic-thalamic memory system.

Thus, even though the frontal lobes have been identified as playing an important role in the organizational aspects of complex behavior, animal studies provide evidence of separate frontal lobe subsystems which act as "specialized functional modules" (Petrides, 1989). Although FL dysfunction in humans is rarely discrete enough to reproduce these findings, it is important to maintain an awareness of the separateness of the functions and of which functions are being measured by specific tasks.

Implications for ADHD

As an initial application of the FL analogy, it may be theoretically and clinically useful to consider ADHD as an impairment of higher-order cognitive processing. From this perspective, deficits such as attention, impulse control problems and failure to inhibit responses to salient stimuli would be consequences of difficulty integrating information in order to plan, set goals, monitor progress, anticipate outcomes, etc.

Along this line, Douglas (1983, 1985) has brought together a number of the performance deficits of ADHD children by proposing a generalized defect

in "self-regulatory control". This self-regulatory deficit is exhibited in attentional, inhibitory, arousal, and reinforcement abnormalities. Thus, Douglas explicitly emphasizes the interdependence of the dysfunctions and suggests an underlying, broader deficit in higher-order cognitive processes. Reference to the FL analogy demonstrated in the three studies presented here would support this conceptualization.

It may also be important to consider the functional differences in frontal lobe "subsystems". Gorenstein et al. (in press) have suggested that the impairments of ADHD children may not follow FL functional divisions because their "FL dysfunction" is likely to be diffuse. Nevertheless, deficits which are anatomically associated presumably have some common underlying cognitive factor which differentiates them from other, dissociable, deficits. Identifying which tasks ADHD children have trouble with and relating the resulting pattern to the functional FL divisions may clarify the underlying cognitive impairment(s). For example, ADHD children typically do not show difficulties on recognition memory tasks associated with ventromedial frontal cortex (e.g., Benezra & Douglas, 1988). In contrast, they do show impairments on tasks such as the WCST, conditional association learning, and SOP which are associated with lateral frontal regions. This dissociation, if replicated and extended by further research, would support the general conceptualization of ADHD as a problem in integrating, planning, and organizing.

In addition, just as "FL dysfunction" increasingly appears to represent a collection of functional subsets of patients with specific types of higher-order organizational deficits, "ADHD" may include distinct subsets of

children. These subsets may include those for whom the FL analogy represents a "good fit" versus those for whom it is not. Alternatively, a number of subsets of children impaired in different aspects of FL function may emerge.

The developmental aspects of FL maturation also are relevant. Although little is known about the relationship between structural and functional brain development, neurophysiological findings and theories are largely consistent with the developmental neuropsychological findings of Becker et al. (1988) and Passler et al. (1985). Both neuroanatomical and behavioral developmental positions posit that maximal development of the frontal lobes occurs from 8 years up to 12 years.

Hence, development of the frontal lobes is associated with increasing efficiency of information gathering from many brain areas and the modulation of their activities. Although the efficiency of this integrative capacity develops across a wide age range, large gains are seen in children between ages 8 and 12. Based on the findings of the present studies, ADHD children with a mean age of 10 years appear to have failed to develop this capacity to the same degree as their age-matched NCs, or as would be predicted from the normal developmental studies reviewed earlier.

Thus, longitudinal and cross-sectional studies of ADHD children should be undertaken to investigate the rate and extent of development of FL skills. It would be important clinically to know whether these children eventually develop normal levels of abilities associated with FL functioning, whether they consistently lag behind by up to 3 to 4 years as did the group in the present study, or whether the level of functioning

displayed in these studies is the highest point achieved. Chelune et al. (1986) reported that their ADHD children made appropriate maturational gains on the WCST, but at a level approximately two years behind their age-matched cohorts. They suggested that this pattern supports the view of ADHD as a maturational lag, but stress the need for developmental studies across a wide age range and to determine whether ADHD children ever achieve normal adult levels of performance on the WCST.

Finally, investigation of the accuracy of the analogy with FL dysfunction leads naturally to questions regarding whether deficits of ADHD children on FL tasks are a consequence of actual FL dysfunction. To establish this, it will be necessary to undertake further studies to investigate actual differences in FL functioning of well-defined groups of ADHD children using physiological measures such as positron emission tomography (e.g., (Buchsbaum et al., 1982; Roland, 1984), regional cerebral blood flow (e.g., Weinberger, Berman & Zec, 1986), or brain electrical activity mapping (e.g., Duffy, Denckla, Bartels & Sandini, 1980; Duffy, Denckla, Bartels, Sandini & Kiessling, 1980).

Statement of Original Contribution

ADHD children were tested on an array of measures in the areas of motor control and problem solving shown by prior investigators to be sensitive to frontal lobe dysfunction. The impairment of ADHD children on these tasks was used to support the hypothesis that their deficits resemble those shown by adults with FL dysfunction. Further, by comparing their performance levels with those reported in developmental studies and with the performance of matched normal control children, it was shown that their mastery of the tasks lagged behind their age-mates by up to 3 to 4 years.

In contrast to earlier studies, ADHD children also were tested on measures associated with impaired performance by patients with temporal lobe, but not frontal lobe, dysfunction. Using these tasks, their deficits were demonstrated to be limited to tasks associated with frontal lobe functioning, and not the result of a global inability to perform well on any task administered.

By demonstrating a relatively specific pattern of strengths and weaknesses which resembles that shown by FL patients, the specificity as well as the accuracy of the analogy received initial confirmation. Demonstration that the analogy of frontal lobe dysfunction is a "good fit" to the cognitive and behavioral performance of ADHD children allows the heuristic application of information about frontal lobe functioning to the understanding and treatment of ADHD.

References

- Ackerman, P. T., Anhalt, J. M., Holcomb, P. J., & Dykman, R. A. (1986). Presumably innate and acquired automatic processes in children with attention and/or reading disorders. Journal of Child Psychology and Psychiatry, 27(4), 513-529.
- Ain, M. (1980). The effects of stimulus novelty on viewing time and processing efficiency in hyperactive children (Doctoral dissertation, McGill University). Montreal.
- American Psychiatric Association. (1987). Diagnostic and Statistical Manual of Mental Disorders. Third edition, Revised. Washington, D.C.: American Psychiatric Association.
- Bachevalier, J., & Mishkin, M. (1986). Visual recognition impairment follows ventromedial but not dorsolateral prefrontal lesions in monkeys. Behavioral Brain Research, 20, 249-261.
- Barbizet, J. (1970). Human memory and its pathology. San Francisco: Freeman.
- Barkley, R. A. (1977). A review of stimulant drug research with hyperactive children. Journal of Child Psychology and Psychiatry, 18, 137-165.
- Barkley, R. A. (1981). Hyperactivity. In E. J. Mash, & L. G. Terdal (Eds.), Behavioral assessment of childhood disorders. New York: Guilford Press.
- Becker, M. G., Isaac, W., & Hynd, G. W. (1988). Neuropsychological development of non-verbal behaviors attributed to "frontal lobe" functioning. Developmental Neuropsychology, 3, 275-298.
- Benezra, E. (1980). Verbal and nonverbal memory in hyperactive, reading disabled and normal children (Doctoral dissertation, McGill University). Montreal.

- Benezra, E., & Douglas, V. I. (1988). Verbal and nonverbal memory in ADD-H children. Journal of Abnormal Child Psychology, 16(5), 511-525.
- Bianchi, L. (1895). The function of the frontal lobes. Brain, 18, 497-522.
- Blumer, D., & Benson, D. F. (1975). Personality changes with frontal and temporal lesions. In D. F. Benson, & D. Blumer (Eds.), Psychiatric aspects of neurologic disease. New York: Grune & Stratton.
- Boll, T. J. (1981). The Halstead-Reitan neuropsychological battery. In S. Filskov, & T. J. Boll (Eds.), Handbook of clinical neuropsychology (Vol. 1). New York: Wiley (Interscience).
- Boll, T. J. (1983). Minor head injury in children--Out of sight but not out of mind. Journal of Clinical Child Psychology, 12, 74-80.
- Boll, T. J., & Barth, J. T. (1981). Neuropsychology of brain damage in children. In S. B. Filskov, & T. J. Boll (Eds.), Handbook of clinical neuropsychology. New York: Wiley.
- Bond, J. A., & Buchtel, H. A. (1984). Comparison of the Wisconsin card sorting test and the Halstead category test. Journal of Clinical Psychology, 40(5), 1251-1255.
- Brandt, J., & Butters, N. (1986). The alcoholic Wernicke-Korsakoff syndrome and its relationship to long-term alcohol abuse. In I. Grant, & K. M. Adams (Eds.), Neuropsychological assessment of neuropsychiatric disorders (pp. 441-477). New York: Oxford University Press.
- Brown, A. L., & Smiley, S. S. (1977). Rating the importance of structural units of prose passages: A problem of metacognitive development. Child Development, 48, 1-8.
- Buchsbaum, M. S., Ingvar, D. H., Kessler, R., Waters, R. N., Cappelletti,

- J., van Kammen, D. P., King, A. C., Johnson, J. L., & and others. (1982). Cerebral glucography with positron tomography. Archives of General Psychiatry, 39, 251-259.
- Campbell, S. B., Douglas, V. I., & Morgenstern, G. (1971). Cognitive styles in hyperactive children and the effect of methylphenidate. Journal of Child Psychology and Psychiatry, 12, 55-67.
- Cantwell, D. P. (1975). Familial-genetic research with hyperactive children. In D. P. Cantwell (Ed.), The hyperactive child: Diagnosis, management, current research (pp. 93-108). New York: Spectrum.
- Cavazutti, V., Fischer, E. G., Welch, K., Belli, J. A., & Winston, K. R. (1983). Neurological and psychological sequelae following different treatments of craniopharyngioma in children. Journal of Neurosurgery, 59, 409-417.
- Ceci, S. J., & Tishman, J. (1984). Hyperactivity and incidental memory: Evidence for attentional diffusion. Child Development, 55, 2192-2203.
- Chelune, G. J., & Baer, R. A. (1986). Developmental norms for the Wisconsin card sorting test. Journal of Clinical and Experimental Neuropsychology, 8(3), 219-228.
- Chelune, G. J., Ferguson, W., Koon, R., & Dickey, T. O. (1986). Frontal lobe disinhibition in attention deficit disorder. Child Psychiatry and Human Development, 16(4), 221-234.
- Christensen, A. L. (1975). Luria's neuropsychological investigation. New York: Spectrum.
- Cicerone, K. D., Lazar, R. M., & Shapiro, W. R. (1983). Effects of frontal lobe lesions on hypothesis sampling during concept formation.

Neuropsychologia, 21, 513-524.

- Clarkson, F. E., & Hayden, B. S. (1971). Developmental study of perceptual, conceptual, motivational and self-concept differences between and within hyperactive and normal groups of preadolescent boys. Project 5-0414, Dept. of HEW, U.S. Office of Education, Bureau of Education for the Handicapped, Dec.
- Cohen, N. J., & Douglas, V. I. (1972). Characteristics of the orienting response in hyperactive and normal children. Psychophysiology, 9, 238-245.
- Cohen, N. J., Weiss, G., & Minde, K. (1972). Cognitive styles in adolescents previously diagnosed as hyperactive. Journal of Child Psychology and Psychiatry, 13, 203-209.
- Coleman, M. (1971). Serotonin concentrations in whole blood of hyperactive children. Journal of Pediatrics, 78, 985-990.
- Conners, C. K. (1969). A teacher rating scale for use in drug studies with children. American Journal of Psychiatry, 126, 884-888.
- Conners, C. K., & Eisenberg, L. (1963). The effects of methylphenidate on symptomatology and learning in disturbed children. American Journal of Psychiatry, 120, 458-464.
- Conners, C. K., & Rothschild, G. (1968). Drugs and learning in children. In J. Hellmuth (Ed.), Learning disorders (Vol. 3, pp. 191-223). Seattle: Special Child.
- Craik, F. I., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. Journal of Verbal Learning and Verbal Behavior, 11, 671-684.

- Craine, J. F. (1982). The retraining of frontal lobe dysfunction. In L. E. Trexler (Ed.), Cognitive rehabilitation: Conceptualization and intervention. New York: Plenum Press.
- Delaney, R. C., Rosen, A. J., Mattson, R. H., & Novelly, R. A. (1980). Memory function in focal epilepsy: A comparison of non-surgical, unilateral temporal lobe and frontal lobe samples. Cortex, 16, 103-117.
- Douglas, V. I. (1980). Treatment and training approaches to hyperactivity: Establishing internal or external control. In C. K. Whalen, & B. Henker (Eds.), Hyperactive children: The social ecology of identification and treatment. New York: Academic Press.
- Douglas, V. I. (1983). Attentional and cognitive problems. In M. Rutter (Ed.), Developmental Neuropsychiatry (pp. 280-329). New York: Guilford Press.
- Douglas, V. I. (1984). The psychological processes implicated in ADD. In L. M. Bloomingdale (Ed.), Attention deficit disorder: Diagnostic, cognitive and therapeutic understanding (pp. 147-162). Jamaica, NY: Spectrum.
- Douglas, V. I. (1985). The response of ADD children to reinforcement: Theoretical and clinical implications. In L. M. Bloomingdale (Ed.), Attention Deficit Disorder: Identification, course and rationale (pp. 49-66). Jamaica, NY: Spectrum Publications.
- Douglas, V. I. (1988). Cognitive deficits in children with attention deficit disorder with hyperactivity. In L. M. Bloomingdale, & J. Sergeant (Eds.), Attention deficit disorder: Criteria, cognition, intervention (Book supplement to the Journal of Child Psychology and Psychiatry, (5). New York: Pergamon Press.

- Douglas, V. I., & Parry, P. (1982). Effects of reinforcement on concept identification in hyperactive children. Journal of Abnormal Child Psychology, 11(2), 327-340.
- Douglas, V. I., & Peters, K. G. (1979). Toward a clearer definition of the attentional deficit of hyperactive children. In G. A. Hale, & M. Lewis (Eds.), Attention and the development of cognitive skills. New York: Plenum Press.
- Drake, D. M. (1970). Perceptual correlates of impulsive and reflective behavior. Developmental Psychology, 2, 202-214.
- Drewe, E. A. (1974). The effect of type and area of brain lesion on Wisconsin Card Sorting Test performance. Cortex, 10, 159-170.
- Drewe, E. A. (1975). An experimental investigation of Luria's theory on the effects of frontal lobe lesions in man. Neuropsychologia, 13, 421-429.
- Dubey, D. R. (1976). Organic factors in hyperkinesis: A critical evaluation. American Journal of Orthopsychiatry, 46(2), 353-366.
- Duffy, F. H., Denckla, M. B., Bartels, P. H., & Sandini, G. (1980). Dyslexia: Regional differences in brain electrical activity by topographic mapping. Annals of Neurology, 7(5), 412-420.
- Duffy, F. H., Denckla, M. B., Bartels, P. H., Sandini, G., & Kiessling, L. S. (1980). Dyslexia: Automated diagnosis by computerized classification of brain electrical activity. Annals of Neurology, 7(5), 421-428.
- Dykman, R. A., Ackerman, P. T., & Oglesby, D. M. (1979). Selective and sustained attention in hyperactive, learning-disabled, and normal boys. Journal of Nervous and Mental Disease, 167(5), 288-297.
- Dykman, R. A., Ackerman, P. T., & Oglesby, M. (1980). Correlates of problem

- solving in hyperactive, learning disabled, and control boys. Journal of Learning Disabilities, 13(6), 23-32.
- Ebaugh, F. G. (1923). Neuropsychiatric sequelae of acute epidemic encephalitis in children. American Journal of Diseases of Children, 25, 89-97.
- Eimas, P. D. (1970). Information processing in problem solving as a function of developmental level and stimulus saliency. Developmental Psychology, 2, 224-229.
- Ferguson, H. B., & Pappas, B. A. (1979). Evaluation of psychophysiological, neurochemical, and animal models of hyperactivity. In R. L. Trites (Ed.), Hyperactivity in children (pp. 61-92). Baltimore: University Park Press.
- Ferrier, D. (1886). The functions of the brain. London: Smith, Elder.
- Feuerstein, M., Ward, M. M., & LeBaron, S. W. (1978). Neuropsychological and neurophysiological assessment of children with learning and behavior problems: A critical appraisal. In B. B. Lahey, & A. E. Kazdin (Eds.), Advances in clinical psychology, 2. New York: Plenum.
- Firestone, P., & Douglas, V. I. (1975). The effects of reward and punishment on reaction times and autonomic activity in hyperactive and normal children. Journal of Abnormal Child Psychology, 3, 201-216.
- Fletcher, J. M., & Taylor, H. G. (1984). Neuropsychological approaches to children: Towards a developmental neuropsychology. Journal of Clinical Neuropsychology, 6(1), 39-56.
- Freibergs, V., & Douglas, V. I. (1969). Concept learning in hyperactive and normal children. Journal of Abnormal Psychology, 74, 388-395.
- Fuster, J. M. (1985). The prefrontal cortex, mediator of cross-temporal

- contingencies. Human Neurobiology, 4, 169-179.
- Geis, M. F., & Hall, D. M. (1976). Encoding and incidental memory in children. Journal of Experimental Child Psychology, 22, 58-66.
- Geis, M. F., & Hall, D. M. (1978). Encoding and congruity in children's incidental memory. Child Development, 49, 857-861.
- Ghent, L., Mishkin, M., & Teuber, H. L. (1962). Short-term memory after frontal lobe injury in man. Journal of Comparative and Physiological Psychology, 55, 705-709.
- Glowinski, H. (1973). Cognitive deficits in temporal lobe epilepsy. Journal of Nervous and Mental Disease, 157, 129-137.
- Gorenstein, E. E., Mammato, C. A., & Sandy, J. M. (in press). Performance of inattentive-overactive children on selected measures of prefrontal-type function. Journal of Clinical Psychology.
- Gorenstein, E. E., & Newman, J. P. (1980). Disinhibitory psychopathology: A new perspective and a model for research. Psychological Review, 87, 301-315.
- Goyette, C. H., Conners, C. K., & Ulrich, R. F. (1978). Normative data on revised Conners parent and teacher ratings scales. Journal of Abnormal Child Psychology, 6(2), 221-236.
- Greenblatt, M., & Soloman, H. C. (1966). Studies of lobotomy. In Proceedings of the association for research in nervous and mental disease: Volume 36: The brain and human behavior (pp. 19-34). New York: Hafner.
- Gualtieri, C. T., & Hicks, R. E. (1985). Neuropharmacology of methylphenidate and a neural substrate for childhood hyperactivity. Psychiatric Clinics of North America, 8(4), 875-892.

- Gualtieri, C. T., Wargin, W., Kanoy, R., Patrick, K., Shen, C. D., Youngblood, W., Mueller, R. A., & Breese, G. R. (1982). Clinical studies of methylphenidate serum levels in children and adults. Journal of the American Academy of Child Psychiatry, 21, 19-26.
- Guitton, D., Buchtel, H. A., & Douglas, R. M. (1982). Disturbances of voluntary saccadic eye-movement mechanisms following discrete unilateral frontal-lobe removals. In G. Lennerstrand, D. S. Zee, & E. L. Keller (Eds.), Functional basis of ocular motility disorders (pp. 497-499). Oxford: Pergamon.
- Hamlett, K. W., Pellegrini, D. S., & Conners, C. K. (1987). An investigation of executive processes in the problem-solving of attention deficit disorder-hyperactive children. Journal of Pediatric Psychology, 12(2), 227-240.
- Hastings, J. E., & Barkley, R. A. (1978). A review of psychophysiological research with hyperkinetic children. Journal of Abnormal Child Psychology, 6(4), 413-447.
- Heaton, R. K. (1981). A manual for the Wisconsin card sorting test. Odessa, FL: Psychological Assessment Resources.
- Hecaen, H. (1981). Apraxias. In S. B. Filskov, & T. J. Boll (Eds.), Handbook of clinical neuropsychology (Vol. 1, pp. 257-286). New York: Wiley.
- Hirsch, J. F., Renier, D., Czernichow, P., Benveniste, L., & Pierre-Kahn, A. (1979). Medulloblastoma in childhood: Survival and functional results. Acta Neurochirurgie, 48, 1-15.
- Hohman, L. B. (1922). Post-encephalitic behavior disorders in children. Johns Hopkins Hospital Bulletin, 33, 372-375.

- Homatidis, S., & Konstantareous, M. M. (1981). Assessment of hyperactivity: Isolating measures of high discriminant ability. Journal of Consulting and Clinical Psychology, 49(4), 533-541.
- Hoy, E., Weiss, G., Minde, K., & Cohen, N. (1978). The hyperactive child at adolescence: Cognitive, emotional, and social functioning. Journal of Abnormal Child Psychology, 6(3), 311-324.
- Incisa della Rochetta, A. (1986). Classification and recall of pictures after unilateral frontal or temporal lobectomy. Cortex, 22, 189-211.
- Johnston, C. W. (1986). The neuropsychological evaluation of attention deficit disorder. Psychiatric Annals, 16(1), 47-51.
- Juliano, D. B. (1974). Conceptual tempo, activity, and concept learning in hyperactive and normal children. Journal of Abnormal Psychology, 83(6), 629-634.
- Kagan, J., & et al. (1979). A cross-cultural study of cognitive development. Monographs of the Society for Research in Child Development, 44(5).
- Kendall, & Braswell. (1985). Cognitive-behavioral therapy for impulsive children. New York: Guilford Press.
- Kendler, T. S. (1972). An ontogeny of mediational deficiency. Child Development, 43(1), 1-17.
- Kenny, T. J. (1980). Hyperactivity. In H. Rie, & E. Rie (Eds.), Handbook of minimal brain dysfunctions (pp. 437-455). New York: Wiley.
- Kinsbourne, M. (1977). The mechanism of hyperactivity. In M. E. Bow, Q. Rapin, & M. Kinsbourne (Eds.), Topics in child neurology (pp. 289-306). New York: Spectrum.
- Knights, R. M., & Hinton, G. G. (1973). Neuropsychological test results in

- children with posterior fossa tumors. (Research bulletin no. 7, Dept. of Psychology, Carleton University, Ottawa)
- Konow, A., & Pribram, K. H. (1970). Error recognition and utilization produced by injury to the frontal cortex in man. Neuropsychologia, 8, 489-491.
- Kronick, D. (Speaker). (1986). Critical issues of investigation--metacognition (Presented at annual meeting of OACLD, Toronto).
- Kun, L. E., Mulhern, R. K., & Crisco, J. J. (1983). Quality of life in children treated for brain tumors: Intellectual, emotional, and academic function. Journal of Neurosurgery, 58, 1-6.
- Lahey, B. B. (1979). Behavior therapy with hyperactive and learning disabled children. New York: Oxford University Press.
- Levene, H. (1960). Robust tests for equality of variance. In I. Olkin (Ed.), Contributions to Probability and Statistics (pp. 278-292). Palo Alto, CA: Stanford University Press.
- Lezak, M. D. (1983). Neuropsychological assessment (2nd ed.). New York: Oxford University Press.
- Lhermitte, F., Derosne, J., & Signoret, J. L. (1972). Analyse neuropsychologique du syndrome frontal. Revue Neurologique, 127, 415-440.
- Lou, H. C., Henriksen, L., & Bruhn, P. (1984). Focal cerebral hypoperfusion in children with dysphasia and/or attention deficit disorder. Archives of Neurology, 41, 825-829.
- Lufi, D., & Cohen, A. (1985). Attention deficit disorder and short-term visual memory. Journal of Clinical Psychology, 41(2), 265-267.

- Luria, A. R. (1966). Higher cortical functions in man. New York: Basic Books.
- Luria, A. R. (1969). Speech development and the formation of mental processes. In M. Cole, & I. Maltzman (Eds.), A handbook of contemporary Soviet psychology (2nd ed.). New York: Basic Books. (Original work published in 1959)
- Luria, A. R. (1973). The working brain: An introduction to neuropsychology. New York: Basic Books.
- Luria, A. R., & Homs kaya, E. D. (1964). Disturbance in the regulative role of speech with frontal lobe lesions. In J. M. Warren, & K. Akert (Eds.), The frontal granular cortex and behavior. New York: McGraw-Hill.
- Mattes, J. A. (1980). Role of frontal lobe dysfunction in childhood hyperkinesis. Comprehensive Psychiatry, 21, 358-369.
- McMahon, R. C. (1981). Biological factors in childhood hyperkinesis: A review of genetic and biochemical hypotheses. Journal of Clinical Psychology, 37, 12-21.
- Meacham, J. A. (1978). Verbal guidance through remembering the goals of actions. Child Development, 49, 188-193.
- Meichenbaum, D., & Goodman, J. (1969a). The developmental control of operant motor responding by verbal operants. Journal of Experimental Child Psychology, 7, 553-565.
- Meichenbaum, D., & Goodman, J. (1969b). Reflection-impulsivity and verbal control of motor behavior. Child Development, 40, 785-797.
- Messer, S. B. (1976). Reflection-impulsivity: A review. Psychological Bulletin, 83, 1026-1052.

- Miller, L. A. (1983). Effects of frontal or temporal lobectomy on cognitive risk-taking and on the ability to synthesize fragmented information (Doctoral dissertation, McGill University). Montreal.
- Millichap, J. G. (1977). Learning disabilities and related disorders. New York: Year Book Medical.
- Milner, B. (1963). Effects of different brain lesions on card sorting. Archives of Neurology, 9, 90-100.
- Milner, B. (1964). Some effects of frontal lobectomy in man. In J. M. Warren, & K. Akert (Eds.), The frontal granular cortex and behavior (pp. 313-334). New York: McGraw Hill.
- Milner, B. (1972). Disorders of learning and memory after temporal lobe lesions in man. Clinical Neurosurgery, 19, 421-446.
- Milner, B. (1982). Some cognitive effects of frontal lobe lesions in man. Philosophical Transactions of the Royal Society of London, B298, pp. 211-226.
- Milner, B., & Petrides, M. (1984). Behavioral effects of frontal lobe lesions in man. Trends in Neurosciences, 7, 403-407.
- Morrison, J. R., & Stewart, M. A. (1971). A family study of the hyperactive child syndrome. Biological Psychiatry, 3, 189-195.
- Morrison, J. R., & Stewart, M. A. (1973). Evidence for polygenetic inheritance in the hyperactive child syndrome. American Journal of Psychiatry, 130(7), 791-792.
- Mosher, F. A., & Hornsby, J. R. (1966). On asking questions. In J. S. Bruner, R. R. Olver, & P. M. Greenfield (Eds.), Studies in cognitive growth. New York: Wiley.

- Nauta, W. J. (1971). The problem of the frontal lobes--A reinterpretation. Journal of Psychiatric Research, 8, 167-187.
- Nauta, W. J. (1973). Connections of the frontal lobe with the limbic system. In L. V. Laitinen, & K. E. Livingston (Eds.), Surgical approaches in psychiatry (pp. 303-314). Baltimore: University Park Press.
- Nuechterlein, K. H. (1983). Signal detection in vigilance tasks and behavioral attributes among offspring of schizophrenic mothers and among hyperactive children. Journal of Abnormal Psychology, 92(1), 4-28.
- O'Dougherty, M., Nuechterlein, K. H., & Drew, B. (1984). Hyperactive and hypoxic children: Signal detection, sustained attention, and behavior. Journal of Abnormal Psychology, 93(2), 178-191.
- O'Neill, M. E. (in preparation). Study strategies: Knowledge and usage in ADD-H, reading disabled, and normal boys.
- O'Neill, M. E., & Douglas, V. I. (in preparation). Study strategies and prose recall in Attention Deficit Disorder (ADDH), reading disabled and normal boys.
- Ounsted, C. (1955). The hyperkinetic syndrome in epileptic children. Lancet, 6885, 303-311.
- Parry, P. (1973). The effect of reward on the performance of hyperactive children. Doctoral dissertation, McGill University.
- Parsons, O. A. (1975). Brain damage in alcoholics: Altered states of consciousness. In M. M. Gross (Ed.), Alcohol intoxication and withdrawal. New York: Plenum Press.
- Pasamanick, B., & Knobloch, H. (1966). Retrospective studies on the epidemiology of reproductive casualty: Old and new. Merrill Palmer

Quarterly of Behavioral Development, 12, 7-26.

- Passler, M. A., Isaac, W., & Hynd, G. W. (1985). Neuropsychological development of behavior attributed to frontal lobe functioning in children. Developmental Neuropsychology, 1(4), 349-370.
- Pelham, W. E., Milich, R., & Walker, J. L. (1986). Effects of continuous and partial reinforcement and methylphenidate on learning in children with attention deficit disorder. Journal of Abnormal Psychology, 95(4), 319-325.
- Perret, E. (1974). The left frontal lobe of man and the suppression of habitual responses in verbal categorical behavior. Neuropsychologia, 12, 323-330.
- Petrides, M. (1982). Motor conditional associative-learning after selective prefrontal lesions in the monkey. Behavioral Brain Research, 5, 407-413.
- Petrides, M. (1987). Conditional learning and the primate frontal cortex. In E. Perecman (Ed.), The frontal lobes revisited. New York: IRBN Press.
- Petrides, M. (1988). Performance on a nonspatial self-ordered task after selective lesions of the primate frontal cortex. Society for Neuroscience Abstracts.
- Petrides, M. (1989). Frontal lobes and memory. In F. Boller, & J. Grafman (Eds.), Handbook of neuropsychology (Vol. III). Amsterdam: Elsevier.
- Petrides, M., & Milner, B. (1982). Deficits on subject-ordered tasks after frontal and temporal lobe lesions in man. Neuropsychologia, 20, 249-262.
- Pigott, S., & Douglas, V. I. (1987). Complex task performance of ADD-H children (abstract). Canadian Psychology, 28(2a), 475.
- Pontius, A. A. (1973). Dysfunction patterns analogous to frontal lobe system

- and caudate nucleus syndromes in some groups of minimal brain dysfunction. Journal of the American Medical Women's Association, 28, 285-292.
- Poppen, R. L., Pribram, K. H., & Robinson, R. S. (1965). Effects of frontal lobotomy in man on the performance of a multiple choice test. Experimental Neurology, 11, 217-229.
- Pribram, K. H. (1960). Intrinsic systems of the forebrain. In J. Field, H. W. Magoun, & V. E. Hall (Eds.), Handbook of physiology, Neurophysiology II (pp. 1323-1344). Washington, DC: American Physiological Society.
- Pribram, K. H. (1971). Languages of the brain: Experimental paradoxes and principles in neuropsychology. Englewood Cliffs, NJ: Prentice-Hall.
- Pribram, K. H. (1973). The primate frontal cortex - executive of the brain. In K. H. Pribram, & A. R. Luria (Eds.), Psychophysiology of the frontal lobes (pp. 293-314). New York: Academic Press.
- Rapoport, J. L., & Ferguson, H. B. (1981). Biological validation of the hyperkinetic syndrome. Developmental Medicine and Child Neurology, 23, 667-682.
- Reed, B. R., Jagust, W. J., & Budinger, T. F. (1987). Memory dysfunction and regional cerebral blood flow in Alzheimer's disease. Abstract of paper presented at the 15th annual INS meeting. Washington, D.C.
- Reitan, R. M. (1955). The relation of the Trail Making test to organic brain damage. Journal of Consulting Psychology, 19, 393-394.
- Reitan, R. M. (1964). Psychological deficits resulting from cerebral lesions in man. In J. M. Warren, & K. A. Akert (Eds.), The frontal granular cortex and behavior. New York: McGraw-Hill.

- Reitan, R. M. (1986). Theoretical and methodological bases of the Halstead-Reitan neuropsychological test battery. In I. Grant, & K. M. Adams (Eds.), Neuropsychological assessment of neuropsychiatric disorders (pp. 3-30). New York: Oxford University Press.
- Reynolds, C. R., & Kamphaus, R. W. (1986). The Kaufman assessment battery for children: Development, structure, and application in neuropsychology. In D. Wedding, A. M. Horton, & J. Webster (Eds.), The neuropsychology handbook: Behavioral and clinical perspectives (pp. 194-216). New York: Springer.
- Robinson, A. L., Heaton, R. K., Lahman, R. A., & Stilson, D. W. (1980). The utility of the Wisconsin Card Sorting Test in detecting and localizing frontal lobe lesions. Journal of Consulting and Clinical Psychology, 48, 605-614.
- Roland, P. E. (1984). Metabolic measurements of the working frontal cortex in man. Trends in Neurosciences, 7, 430-435.
- Ross, D. M., & Ross, S. A. (1982). Hyperactivity: Current issues, research, and theory. New York: Wiley.
- Rovet, J. (1980). A parametric measure of reflection-impulsivity. Journal of Applied Developmental Psychology, 1, 221-225.
- Rutter, M. (1981). Psychological sequelae of brain damage in children. American Journal of Psychiatry, 138(12), 1533-1544.
- Rutter, M. (1982). Syndromes attributed to "minimal brain dysfunction" in childhood. American Journal of Psychiatry, 139, 21-33.
- Rylander, G. (Ed.). (1939). Personality changes after operations on the frontal lobes: A clinical study of 32 cases. Acta Psychiatrica Neurologia

(Supp.), 20.

- Schierberl, J. P. (1979). Physiological models of hyperactivity: An integrative review of the literature. Journal of Clinical Child Psychology, 9, 163-172.
- Sergeant, J. A., & Scholten, C. A. (1985a). On resource strategy limitations in hyperactivity: Cognitive impulsivity reconsidered. Journal of Child Psychology and Psychiatry, 26(1), 97-109.
- Sergeant, J. A., & Scholten, C. A. (1985b). On data limitations in hyperactivity. Journal of Child Psychology and Psychiatry, 26(1), 111-124.
- Shallice, T. (1982). Specific impairments of planning. In D. E. Broadbent, & L. Weiskrantz (Eds.), The neuropsychology of cognitive function (pp. 199-209). London: The Royal Society.
- Shallice, T., & Evans, M. E. (1978). The involvement of the frontal lobes in cognitive estimation. Cortex, 14, 294-303.
- Shaywitz, B. A., Shaywitz, S. E., Byrne, T., Cohen, D. J., & Rothman, S. (1983). Attention deficit disorder: Quantitative analysis of CT. Neurology, 33, 1500-1503.
- Shaywitz, S. E., Cohen, D. J., & Shaywitz, B. A. (1978). The biochemical basis of minimal brain dysfunction. Journal of Pediatrics, 29, 179-187.
- Siegelman, E. (1969). Reflective and impulsive behavior. Child Development, 40, 1213-1222.
- Smith, M. L., & Milner, B. (1981). The role of the hippocampus in the recall of spatial location. Neuropsychologia, 19, 781-793.
- Smith, M. L., & Milner, B. (1984). Differential effects of frontal-lobe

- lesions on cognitive estimation and spatial memory. Neuropsychologia, 22(6), 697-705.
- Smith, M. L., & Milner, B. (1988). Estimation of frequency of occurrence of abstract designs after frontal or temporal lobectomy. Neuropsychologia, 26, 297-306.
- Spitz, H. H. (1972). Note on immediate memory for digits: Invariance over the years. Psychological Bulletin, 78, 183-185.
- Spring, C., Yellin, A. M., & Greenberg, L. M. (1976). Effects of imipramine and methylphenidate on perceptual-motor performance of hyperactive children. Perceptual and Motor Skills, 43, 459-470.
- Stamm, J. S., & Kreder, S. V. (1979). Minimal brain dysfunction: Psychological and neurophysiological disorders in hyperkinetic children. In M. S. Gazzaniga (Ed.), Handbook of behavioral neurobiology (Vol. 2, Neuropsychology). New York: Plenum Press.
- Stevens, D. A., Stover, C. E., & Backus, J. T. (1970). The hyperkinetic child: Effect of incentives on the speed of rapid tapping. Journal of Consulting and Clinical Psychology, 34, 56-59.
- Still, G. F. (1902). Some abnormal psychical conditions in children. Lancet, 161(1), 1008-12, 1077-82, 1163-68.
- Strecker, E. A., & Ebaugh, F. (1924). Neuropsychiatric sequelae of cerebral trauma in children. Archives of Neurology and Psychiatry, 12, 443-453.
- Stromgren, L. S. (1977). The influence of depression on memory. Acta Psychiatrica Scandinavia, 56, 109-128.
- Strommen, E. A. (1972). Verbal self-regulation in a children's game: Impulsive errors on "Simon says". Child Development, 44, 849-853.

- Stuss, D. T., & Benson, D. F. (1984). Neuropsychological studies of the frontal lobes. Psychological Bulletin, 95, 3-28.
- Stuss, D. T., & Benson, D. F. (1986). The frontal lobes. New York: Raven Press.
- Stuss, D. T., Benson, D. F., Kaplan, E. F., Weir, W. S., & Della Malva, C. (1981). Leucotomized and nonleucotomized schizophrenics: Comparison on tests of attention. Biological Psychiatry, 16, 1085-1100.
- Stuss, D. T., Benson, D. F., Kaplan, E. F., Weir, W. S., Naesar, M. A., Lieberman, I., & Ferrill, D. (1983). The involvement of orbitofrontal cerebrum in cognitive tasks. Neuropsychologia, 21(3), 235-248.
- Stuss, D. T., Kaplan, E. F., Benson, D. F., Weir, W. S., Chiulli, S., & Sarazin, F. F. (1982). Evidence for the involvement of orbitofrontal cortex in memory functions: An interference effect. Journal of Comparative and Physiological Psychology, 6, 913-925.
- Tant, J. L. (1978). Problem solving in hyperactive and reading disabled boys (Doctoral dissertation, McGill University). Montreal.
- Tant, J. L., & Douglas, V. I. (1982). Problem-solving in hyperactive, normal, and reading disabled boys. Journal of Abnormal Child Psychology, 10(3), 285-306.
- Taylor, G. H. (1983). MBD: Meanings and misconceptions. Journal of Clinical Neuropsychology, 5(3), 271-287.
- Teuber, H. L. (1964). The riddle of frontal lobe function in man. In J. M. Warren, & K. A. Akert (Eds.), The frontal granular cortex and behavior. New York: McGraw Hill.
- Thiffault, J. (1982). Les enfants hyperactifs: Les deux visages de

l'hyperactivite. Montreal: Quebec/Amerique.

- Thompson, J. S., Ross, R. J., & Horowitz, S. J. (1980). The role of computed axial tomography in the study of the child with minimal brain dysfunction. Journal of Learning Disabilities, 13, 334-337.
- Vargha-Khadem, F. (1987). Effects of age and locus of injury on verbal and perceptual learning in children (abstract). Presented at the 15th annual INS meeting. Washington, D.C.
- Waldrop, M. F., Bell, R. Q., McLaughlin, B., & Halverson, C. F. (1978). Newborn minor physical anomalies predict short attention span, peer aggression and impulsivity at age 3. Science, 199, 563-565.
- Waldrop, M. F., & Goering, J. D. (1971). Hyperactivity and minor physical anomalies in elementary school children. American Journal of Orthopsychiatry, 41, 602-607.
- Walsh, K. W. (1978). Neuropsychology: A clinical approach. New York: Churchill Livingstone.
- Weinberg, J., Diller, L., Gerstman, L., & Schulman, P. (1972). Digit span in right and left hemiplegics. Journal of Clinical Psychology, 28, 361.
- Weinberger, D. R., Berman, K. F., & Zec, R. F. (Eds.). (1986). Physiologic dysfunction of dorsolateral prefrontal cortex in schizophrenia. I. Regional cerebral blood flow evidence. Archives of General Psychiatry, 43, 114-124.
- Weingartner, H., Rapoport, J. L., Buchsbaum, M. S., Bunney, W. E., Ebert, M. H., Mikkelsen, E. J., & Caine, E. D. (1980). Cognitive processes in normal and hyperactive children and their response to amphetamine treatment. Journal of Abnormal Psychology, 89(1), 25-37.

Weiss, S. L., Robinson, G., & Hastie, R. (1977). The relationship of depth of processing to free recall in second and fourth graders. Developmental Psychology, 13, 525-526.

Wender, P. H. (1971). Minimal brain dysfunction in children. New York: Wiley-Interscience.