THE NEUROPSYCHOLOGICAL INVESTIGATION OF DYSLEXIC READERS: AN EXPERIMENTAL APPROACH TO SUBTYPING

by

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(ABSTRACT)

Based on Luria's notion of functional neuronal systems, reading has been hypothesized to require the adequate functioning of both the anterior and posterior cerebrum. Failure to be able to read has been hypothesized to be the result of dysfunction occurring anywhere throughout those functional units. In adults, anterior and posterior language problems have been established by assessing verbal fluency. Nonfluent output has been associated most often with anterior dysfunction, while fluent output has occurred with posterior dysfunction. The primary purpose of the present exploratory study was to evaluate the utility of verbal fluency as a dimension on which to classify children with the language problem of dyslexia. Subjects first were identified as dyslexic readers (DR) or normal readers (NR) based on a statistical formula which determined whether IQ and reading achievement scores were significantly discrepant. A traditional measure of verbal fluency then was used to determine that the DR children were less fluent than NR children. DR children subsequently were classified into nonfluent (NF) and fluent (F) subgroups. Initial validation for the fluency construct then was established by examining children's performance on other language and motor tasks associated with anterior and posterior functioning. As predicted, the DR-NF children performed more poorly or displayed specific deficits on tasks purported to tap anterior functioning (e.g., verbal memory, motor perseveration, and vigilance) while DR-F and NR children did not. A dual processing model was proposed to explain the findings for the DR-NF children. Limitations, implications for the treatment of DR children, and directions for future research are outlined.

Acknowledgements

With the completion of a major milestone such as this dissertation, my relief is so great that I am tempted to thank anyone and everyone with whom I came into contact during its preparation. However, I only have limited space and impeccably good taste and therefore will keep my acknowledgements brief and to the point.

I first want to thank the students, teachers, and administration of the Pulaski County School District. Without their participation and cooperation, this project never would have gotten started. I extend special thanks to , Director of Special Education, for her willingness to recognize the importance of neuropsychological theory in understanding reading difficulties and to allow nontraditional neuropsychological assessment of her students.

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Finally, I want to thank my family and friends for their support and encouragement—especially: for helping me "survive" working with , and for reminding me that the process does end (with or without Cheese Whiz!), my step-family and

just for being interested, for reminding me not to take myself too seriously, and my grandfather, , for understanding that there is more to life than just "settling down." I extend special thanks to my sister, , and my mother, for their love, tough honesty, and humor, and because they always have believed in me.

Table of Contents

List of Illustrations

List of Tables

Introduction

Neuropsychology is the study of the relationship between brain and behavior (Heilman & Satz, 1983). The basic assumption underlying neuropsychology is that all behavior ultimately is mediated by physical processes. This implies that in order for an organism to display a certain behavior, the brain of that organism must have the necessary neuronal systems to mediate that behavior. If it does not, the behavior may never develop, may disappear from the organism's repertoire, or be manifested in some atypical manner. Importantly, variables such as attention, emotion, learning, and experience contribute to behavior. However, these are also considered to be neuropsychological variables, and therefore are a result of their own neuronal systems.

A complex human behavior to which this neuropsychological approach has been applied is reading and reading failure. Indeed, the correspondence between brain anatomy and function and reading behavior has been examined for nearly 100 years (Friedman & Albert, 1985). Traditionally, investigators have employed clinical techniques which begin with descriptions of verbal expressiveness (i.e., fluent versus nonfluent output) and incorporate evaluations of repetition, comprehension, naming, oral reading, and writing samples (Benson, 1985). Most clinical research has focused on patients who have lost their previously acquired skills in reading following cerebral damage, while a few investigations have described cases in which apparently healthy and intelligent children have failed to develop these skills.

Repeated findings suggest that reading can be viewed as a unique, independent functional system (e.g., Luria, 1973; Hynd & Hynd, 1984), or as one aspect of a larger language or communication system which for most individuals is lateralized to the left hemisphere of the brain (e.g., Dejerine, 1891, 1892; Wada, 1949; Reitan, 1955; Gazzaniga, 1970; Benson, 1985; Dean, 1986). Consequently, reading failure can be viewed as a result of dysfunction in either of these systems.

The general purpose of this investigation is to utilize the neuropsychological analysis of language and reading systems and the basic diagnostic factor of fluency to examine reading failure in school-aged children. In the subsequent sections, a more extensive historical review of traditional clinical and neurobiological investigations in reading will be presented. This will be followed by a detailed description of the functional systems approach. A rationale for the present study, hypotheses, and specific procedures will be outlined. Finally, the results will be presented and their significance will be discussed.

Historical Overview

It is commonly accepted that lesions in specific areas of the brain change behavior in specific ways (Heilman & Valenstein, 1985). Studies which correlate behavioral changes with lesion sites have yielded important clinical information. Thus, from a given behavioral disturbance, the site of a lesion can be predicted, and conversely, from the site of a lesion, the type of behavioral changes which might be expected can be identified.

As noted above, much of our knowledge of reading has been derived by repeatedly examining and finding consistent results in adults who have already acquired reading skills but who subsequently experience one or another form of central nervous system damage which results in loss or changes in these skills. The disorders that occur in these instances have been labelled the alexias or acquired dyslexias (Carlson, 1986).

Traditionally, the clinical syndromes of alexia have been classified according to whether there is a concomitant absence or presence of writing disorders: alexia without agraphia (i.e., pure alexia or pure word blindness) and alexia with agraphia (Dejerine, 1891, 1892). It is the general consensus that these types are clinically distinct and have different anatomical bases (Friedman & Albert, 1985). Each of these classic syndromes will be described briefly.

In pure alexia, comprehension of written language is greatly impaired while oral language is essentially normal. Typically, there are no impairments in writing or spelling, but these patients often have problems copying and performing written calculations. A right homonymous hemianopia (i.e., blindness in the right visual field of both eyes) almost always is present. Dejerine (1892) originally described this syndrome. Postmortem examination of his patient revealed that a lesion had destroyed the fibers connecting the left calcarine region (primary visual cortex) to the angular gyrus (located at an area where the left occipital, parietal, and temporal lobes meet). The central site of the damage was located in the white matter (fibers) of the lingual lobule (occipital region). Dejerine concluded that having a lesion in this area apparently prevented visual stimuli entering the left hemisphere from reaching the angular gyrus, a pathway essential for the integration of sensory information.

Further refinement of the anatomical correlates implicated a lesion in the splenium, i.e., the posterior portion of the corpus callosum (Brissaud, 1900; Redlich, 1895). This finding was significant because it suggested that visual impulses from the intact (right) hemisphere were prevented from reaching the opposite calcarine region. Quesel (1931) described this as the "disconnection" theory of pure alexia. At present, most clinicians emphasize that pure alexia is the result of a combination of lesions in the lingual and fusiform gyri of the dominant occipital lobe, and in the splenium of the corpus callosum (e.g., Geschwind, 1962; Sperry & Gazzaniga, 1967; Cumming, 1970; Yamadori, 1980).

The second classic alexic syndrome, alexia with agraphia, again was first described by Dejerine (1891). Clinically, this reading disorder manifests itself as an inability to read individual letters or words. The writing disorder is severe, and appears in all aspects of writing (e.g., spontaneously, to dictation, and copying). Often, elements of a well-established clinical entity known as the Gerstmann syndrome are present. These include acalculia (an acquired disturbance in computation), agraphia, impairment in the ability to identify fingers, and right-left spatial disorientation. Apraxia (the inability to perform skilled or purposive movements) also might occur, and the ability to spell is affected. However, disorders of spoken or oral language typically are absent.

The anatomy of alexia with agraphia is much less complicated than that of pure alexia. In 1891, the autopsy of Dejerine's original case revealed that the patient had a cortical-subcortical lesion affecting the left angular gyrus. Since then, consistent clinical findings have verified a lesion in the angular gyrus of the dominant hemisphere as the anatomical correlate of this syndrome (e.g., Benson & Geschwind, 1969; Friedman & Albert, 1985).

In addition to these classic alexic syndromes, Benson and his colleagues (Benson, 1977; Benson & Geschwind, 1969) have described instances of acquired alexias in which the reading problems are seen as part of a larger language disturbance. The term aphasic alexias has been utilized in these instances. The two most prominent examples of aphasic alexia are those associated with anterior (nonfluent) and posterior (fluent) aphasia. In each case, the reading disorders tend to parallel the disorders of language (Friedman & Albert, 1985).

Broca's (1861) aphasia is caused by lesions of the dominant (usually left) inferior premotor regions of the anterior cortex (i.e., "Broca's area"). This type of aphasia is well-documented and results in nonfluent verbal output, comparatively well-preserved comprehension of spoken language, and severe limitations in both repetition and naming (Benson, Brown, & Tomlinson, 1971; Gardner & Zurif, 1975; Benson, 1977; Benson, 1985). Words produced in speech are most likely to be concrete nouns, and utterances lack grammatical structure. Similarly, in Broca's aphasic alexia, reading comprehension is good;

however, oral reading is severely impaired. Concrete nouns are more likely to be read correctly than abstract nouns or grammatical words. Patients also typically display "pure letter blindness" in which words cannot be broken-down and read letter-by-letter. Instead, words are read as wholes.

In addition, depending upon how extensive the anterior lesion is, related motor activities necessary for reading might be affected (Benson, 1977). For example, eye movements (particularly the motor activity needed to produce scanning from left to right) have been associated with activity in the frontal eye fields. The motor movements necessary to produce speech (i.e., to read out loud) also require functioning of the pre-central gyrus and motor cortex.

Wernicke's (1874) aphasia differs dramatically from Broca's aphasia--anatomically and clinically. Lesions typically occur in the posterior-superior temporal lobe ("Wernicke's area"). The key language finding is a striking disturbance in comprehension. In contrast to Broca's aphasia, verbal output is fluent but hampered by semantic paraphasias (errors that are semantically related to the target word in some way). Consequently, reading comprehension is poor and contaminated by semantic paralexias. Fluent aphasic alexia typically is related to dysfunction of the posterior-superior temporal lobe (Benson & Geschwind, 1969; Hecaen & Albert, 1978; Friedman & Albert, 1985).

Probably the most extensive verification of the acquired reading disturbances just described has been provided by A. R. Luria (1973, 1975, 1980). He completed literally hundreds of clinical and research case examinations over nearly 50 years of work. He reported that acquired difficulties in reading may be a function of any one or a combination of the following lesions: (1) the occipital divisions of either hemisphere and/or splenium (i.e., alexia without agraphia); (2) occipital-temporal-parietal region or the angular gyrus of the left hemisphere (i.e., alexia with agraphia); (3) inferior regions of the left premotor region (Broca's aphasic alexia); and (4) temporal divisions of the cortex (i.e., fluent aphasic alexia).

Interestingly, Luria also described lesions elsewhere in the brain which had not been identified previously but which were purported to affect reading. For example, Luria (1973) noted that lesions of the anterior frontal lobes result in an inability to use prediction and confirmation skills in reading. Lesions of the medial regions of the frontal lobes which impinge on the reticular formation result in poor arousal modulation and inability to sustain attention to the reading task. It is only recently that these frontal lobe factors have received more extensive consideration (Heilman & Valenstein, 1985).

Luria's work is significant not only for substantiating the classic alexic syndromes but also for resulting in a cogent theoretical explanation for reading. As a brief introduction, he advanced the notion that reading ability is a complex behavior accomplished by means of a complicated functional system of cooperating zones of the cerebral cortex. Accordingly, a deficit in any one or several of these zones may impede the learning and/or performance of fluent reading behavior. Luria's theory is central to the present investigation and thus, will be described in more detail later.

To this point, the review has focused on adults who, because of some lesion or damage to the brain, have lost previously acquired reading skills. The overall findings indicated that there is not one unitary cause or structural defect responsible for reading failure in the adult. Rather, it can be attributed to multiple, interdependent lesions which result in specific behavioral sequelae.

There is evidence to suggest that some children have great difficulty learning to read and never become fluent readers, even though they are otherwise intelligent (Carlson, 1986). Clinical cases of children who failed miserably in reading and writing in school despite average to above-average estimates of their general abilities were described almost as early as the classic cases of adult alexia (Morgan, 1896; Bastian, 1898). Unfortunately, considerable controversy regarding reading and other learning problems in children exists in the literature at present. What began as a rather straightforward clinical description has become a sociopolitical entity subsumed by the field of learning disabilities (Morris, 1988).

At the heart of the controversy is the basic question of how the disturbances in these children should be defined and identified. Educators, psychologists, physicians, and parents have employed numerous terms including: dyslexia, reading disability, learning disability in reading, reading retardation, specific learning disability, specific developmental reading disability, and many other combinations of the above. At this time, these terms should be viewed as nothing more than descriptive labels. However, what has occurred is that the terms have become associated with different implicit etiologies which have not been tested but which often result in the utilization of criteria that somewhat arbitrarily includes or excludes children from educational services (Morris, 1988).

From the neuropsychological perspective, any factor that impacts upon the neuronal systems involved in reading is hypothesized to affect reading. These impacting factors might include developmental anomalies, the environment, learning, motivation, or emotion. Many of the formal definitions of learning and reading problems (e.g., the National Joint Committee for Learning Disabilities or the International Reading Association definitions) exclude these factors. From a theoretical standpoint, this hinders the understanding of reading problems in children. Even more unfortunate is the fact that the exclusions probably will be perpetuated. Practically, educational systems cannot provide special services to all children (Morris, 1988). However, as Torgesen (1986) points out, to achieve advancement in the scientific understanding of these problems, research must distance itself from sociopolitical influences.

For the purposes of this study, children who fail to learn to read or who display significant reading disturbances despite adequate intellectual capacities will be labelled dyslexics. These children fail to achieve in reading at a level which is commensurate with their abilities. In line with the neuropsychological approach described earlier, the assumption that will be associated with this label is that failure in reading is the result of some variant of central nervous system function. This assumption is based on theory and not sociopolitical regulations. Factors such as motivation, emotion, or the environment are themselves the result of and have an effect on neuronal systems, and therefore must at least be considered in the theoretical appraisal of reading.

Since dyslexia is not a life-threatening disorder, it never is presented to a pathologist as the manifest disorder in a death (Hynd & Cohen, 1983). Consequently, directly observable neuropathological correlates of dyslexia have been few. However, five postmortem case reports and a few studies using sophisticated recording techniques suggest that dysfunction in the language-and reading-related cortical areas described in adult alexia may be responsible for dyslexia. These examples will be described below.

A landmark case was published by Drake (1968) in which a 12-year-old boy with a well-documented reading disturbance died unexpectedly. Developmental history revealed that the patient was born at term after a normal gestation and delivery. Apparently there were no neonatal complications, and his early developmental milestones were judged to be normal. The boy had been referred to school personnel because of his marked difficulty in reading comprehension, poor writing and spelling skills, problems in arithmetic, and slowness in completing his schoolwork. While intellectual testing on two separate occasions revealed average abilities, his scores on word-meaning and paragraph-meaning tests only were in the 8th and 14th percentiles respectively. Interestingly, word-recognition skills assessed by the reading subscale of the Wide Range Achievement Test (WRAT) were in the above average range.

Behavioral observations of the boy during testing revealed that he read in a monotone voice, omitting certain words and substituting others. He moved his lips and whispered during silent reading. Oral reading speed was slow. He used his thumb as a guide to move along the lines of the page, but still had difficulties making accurate return sweep eye movements from line-to-line.

A physical examination revealed nothing unusual. However, the boy was right-hand and left-eye dominant, and had a positive family history for mixed cerebral dominance. (Tests such as handedness, footedness, and eye preference commonly are used to determine cerebral hemisphere dominance for language.)

The boy also displayed a number of behavioral problems. He experienced violent outbursts, was unusually active, had staring spells, enuresis, recurring unilateral headaches, and was considered to be manipulative by parents and teachers. It was suspected, although never verified, that the boy was experiencing minor epileptic seizures.

On the day the patient died, he experienced a temper outburst, and complained of a mild headache and lethargy. He died in his sleep of a massive hemorrhage in the inferior portion of the cerebellum which extended into the subarachnoid and ventricular regions. The cause of the hemorrhage was determined to be a cerebellar angioma.

Gross examination of the brain revealed anomalies in the convolutional pattern of the parietal region bilaterally. The cortical pattern was disrupted by penetrating deep gyri that appeared disconnected. In addition, related areas of the corpus callosum appeared thin. (Both of these areas have been implicated in alexia in adults.) Microscopic examination revealed nerve cells which were spindle shaped and numerous ectopic neurons in the white matter. Importantly, it was determined that these pathological findings were not the result of the angioma which had resulted in death.

A more recent case study was presented by Galaburda and Kemper (1979). They examined the brain of a 20-year-old man with a well-documented history of reading problems who died from internal bleeding resulting from a fall. A review of the patient's history revealed no prenatal or postnatal complications or developmental milestone delays. Only clumsiness seems to have been a general observation of any clinical significance. Speech development, however, was slow; and once he got to school, the patient had considerable difficulties in learning to read and spell. Despite average intellectual abilities and intensive tutoring, his reading problems persisted. At the time of his last testing at age 19, his oral reading, reading for meaning, and word recognition were only within the third and fourth grade equivalents.

Other testing also revealed moderate difficulties with arithmetic, mild disturbances in right-left discrimination and finger naming, and clumsiness. At age 16, seizures were manifested but were controlled easily with medication.

A dichotic listening test used as a measure of language processing indicated strong lateralization to the left cerebral hemisphere. Interestingly, however, the patient was left-handed.

At autopsy, the brain showed no evidence of trauma associated with the cause of death. Gross examination revealed no obvious neuroanatomical abnormalities. However, the investigations did find anomalies in the planum temporale (part of Wernicke's area in the left temporal region). Geschwind and Levitsky (1968) had suggested that in humans, there is a normal pattern of asymmetry in which the left planum temporale is larger than the right. Geschwind and Levitsky suggested that this enlargement may serve a logical anatomical substrate for linguistic competence. In the young man's case, the planum temporale was approximately equal on both sides of the brain.

More significant abnormalities were found on microscopic examination. Again, the planum temporale was affected, particularly the area directly posterior to the auditory cortex of the left hemisphere. Polymicrogyria (multiple small convolutions) and cellular dysplasia were observed here. Further, when Galaburda and Kemper (1979) compared the cellular findings of this patient with those of normals, they found that the regular columnar arrangement was in disarray.

Galaburda, Sherman, Rosen, Aboitiz, and Geschwind (1985) subsequently have published the findings of three additional postmortem cases. The brains from these three cases were received through the Orton Dyslexia Society Brain Bank. This program comprises several thousand dyslexic persons and their relatives, all of whom have agreed to donate their brain in the event of their death. Each subject was a male ranging in age from 14 to 32 who died suddenly. The medical, social, and educational histories available on these subjects revealed that each performed significantly below grade level on tests of reading and spelling despite average to higher than average intelligence (as measured by the Wechsler Intelligence Scale for Children-Revised, or the Wechsler Adult Intelligence Scale), and each had been placed in available special education programs while in school.

The results of the present postmortem examinations were consistent with the two cases described initially. First, the three subjects showed alterations in the pattern of brain asymmetry in the planum temporale and anomalies of the cerebral cortex affecting preferentially the perisylvian regions of the left hemisphere. Second, neuronal ectopias in layer I, often nodular in appearance (i.e., brain warts) and polymicrogyria were found in the left inferior frontal and left superior temporal regions.

Without additional confirming evidence, it is not possible to determine from these five cases whether or not the anatomical findings have any causative relationship to the clinical findings. The suspicion and presence of seizure disorder in at least two of the examples necessitates caution in the interpretation of the findings. What is significant, however, is that these patients with well-documented reading problems manifested anomalies in the cortical areas repeatedly identified in the acquired alexias. Galaburda et al. (1985) have suggested that at the very least, dysfunction in language-related areas have been implicated in dyslexia.

In addition to the postmortem findings, improved technology in the examination of live brains has provided evidence for cortical involvement in reading and for differences in electrical activity between children who read normally and those who have documented reading disturbances. Electroencephalographic (EEG) measures have been used most frequently in this regard. An EEG is a polygraphic recording of continuous electrical brain activity. A traditional finding is that EEG data tends to be more abnormal with more clinical disturbance. Positive spikes, occipital slow waves, and epileptiform activity (i.e., sharp wave, spike, or spike-and-wave complexes) have been reported to occur more frequently in children with reading problems than normals (Hughes 1978; Prichep, John, Ahn, & Kaye, 1983; Duane, 1986).

However, there are two major inconsistencies in the EEG findings. First, there is a high incidence of "abnormal" wave patterns in asymptomatic children (e.g., Lombroso, Schwartz, Clark, Muench, & Barry, 1966; Bryant & Friedlander, 1965; Prichep et al., 1983); and second, a large percentage of children with identified problems in reading do not display the abnormal patterns (e.g., Hughes & Park, 1968; Prichep et al., 1983).

Fortunately, a recent procedure developed by Duffy (1981) and his colleagues has provided new insights into brain electrical activity. These researchers assert that it is exceedingly difficult to extract clinically useful information by visual inspection of the massive amounts of polygraphic data produced in EEG recordings. Therefore, they developed a method to convert EEG and evoked potential measures (a single-unit recording of electrical changes in brain activity in response to specific visual or auditory stimuli) into a visual display or map. The procedure is called brain electrical activity mapping (BEAM) and uses a computer-driven color video screen to display regional brain activity (Duffy, 1981; Duffy, Denkla, Bartels, & Sandini, 1980; Duffy, Denkla, Bartels, Sandini, & Kiessling, 1980; Duffy, Burchfiel, & Lombroso, 1979). According to these researchers, by utilizing this technique, it has become possible to map and compare the electrical activity of children with reading problems and normal readers under various stimulus conditions.

The typical methodology used by Duffy and his co-investigators (1980) was to identify small, homogeneous groups of male subjects with reading problems. Specifically, the boys were of average intelligence and at least 1.5 years delayed in oral reading from their expected potential. The age range was restricted to between 9 and 11 years to reduce variability. Carefully matched children who were similar in age, sex, intelligence, and socioeconomic status but were reading on grade level were used as controls. Ten different EEG test states (i.e., reading and listening tasks) were utilized: some designed to activate the left hemisphere (e.g., linguistic tasks), some to activate the right hemisphere (e.g., music or spatial stimuli), and others designed to involve both hemispheres (e.g., paired visual-verbal associations). Visual, auditory, and phonological discrimination evoked potential conditions also were included.

Mean image matrices from the EEG and evoked potential conditions were developed. The dyslexics and their matched controls were compared on each point of the matrix using a standard two sample _t_ statistic. Each _t_ was converted to a percentile index and subsequently transformed into topographic images. The resulting colored summary maps demarcated four distinct regions of difference between groups: (1) the medial frontal lobe (supplementary motor area); (2) the left lateral frontal lobe (Broca's area); (3) the left temporal region; and (4) the left posterior quadrant (Wernicke's area, left posterior temporal lobe, and posterior parietal lobe--i.e., the angular gyrus). Additional research demonstrated that the plotted regional differences could be used to correctly classify a new group of subjects as either normal readers or dyslexic.

These investigations by Duffy et al. make a significant procedural contribution to measuring electrical brain activity. It also is noteworthy that the regions which were shown to differ electrophysiologically between the groups of subjects are consistent with those found to be normally involved in speech and reading.

To summarize, this selected review of clinical and neurobiological investigations suggests that reading is a complex, language-related activity. Consistent case descriptions of the behavioral sequelae of brain lesions (and subsequent postmortem verification) in adults, and the evidence indicating cytoarchitectural anomalies and electrophysiological dysfunction in children with documented reading problems suggest that numerous cortical regions or zones (primarily throughout the left cerebral hemisphere) are involved in this activity. At this point, it is necessary to introduce a comprehensive theory which can account for and consolidate these findings.

The Functional System of Reading

While it is acknowledged that numerous models of reading and reading problems have been developed and have yielded useful information (c.f., Torgesen, 1986; Kinsbourne, 1986; Doehring, 1978; Guthrie, 1973; Applebee, 1971), the underlying assumption of this investigation is that reading is a neuropsychological phenomenon. In the initial statement of this position, reading and failure to read were purported to be the result of the concerted function or dysfunction of neuronal systems. This notion of functional systems was articulated most cogently by Luria (1970, 1973, 1980) and will be described in more detail.

Based on the findings of his extensive clinical work with adults, Luria conceptualized the working brain as being organized into three major functional units. The first unit of the brain is composed of the brainstem, including the reticular formation and the midbrain, the posterior portion of the hypothalamus, and the thalamus. This first unit is responsible for the maintenance of cortical tone or arousal.

The second unit of the brain is composed essentially of the area posterior to the central sulcus, and includes the occipital, temporal, and parietal lobes. These cortical regions are responsible for the encoding and analysis of specific types of stimuli: visual or optic, auditory, and kinesthetic or tactile, respectively. Each of these regions is organized into three hierarchical zones. The "primary zone" of each area is responsible for sorting and recording incoming sensory information. The "secondary" zone organizes and codes information from the primary zone. In the "tertiary zone," data are merged from multiple sources and collated as the basis for organizing complex behavioral responses. Most of the cognitive information processing--i.e., reception, analysis, and comprehension--occurs in this second unit.

The third functional unit of the brain is comprised of the cerebrum anterior to the central sulcus or the frontal lobes. This unit is involved in expression, sequencing, the formation of intentions, and the planning and programming of behavior. While the frontal lobes have no primary responsibility for simple sensory or motor functions, they are involved intimately in every complex, higher order behavior in humans. This third unit also is closely tied to the reticular formation. Thus, it is involved in the activation and regulation of the remainder of the cortex, and in focusing and maintaining attention.

In addition to the three fundamental units, Luria also proposed that higher forms of mental activity such as perception, memory, speech, language, writing, arithmetic, and reading have a wide dynamic representation throughout these working units. He compared higher mental processes to the functioning of other biological systems. For example, to complete bodily functions like digestion and respiration, a number of complex organs which carry out specialized activities and sometimes are located in distant parts of the body work together. Similarly, Luria suggested that higher mental processes are comprised of concertedly working complex cortical structures, located in distant areas of the brain, each of which introduces its own particular factor into the functional system.

According to Luria's functional system of reading, reception and initial identification of visual stimulation occurs in the calcarine cortex and the association areas of the occipital lobes. Available linguistic evidence suggests that imageable words may be better processed in the right occipital cortex while letter strings and orientation of the stimuli are processed more efficiently in the left occipital cortex (Hynd, Obrzut, Hayes, & Becker, 1986). Visual information in the form of a grapheme code then is shared with input from the remaining sensory modalities. This occurs in the left inferior parietal lobule or angular gyrus. Since the region of the angular gyrus serves to link input with the appropriate cognitive processes across modalities, the grapheme code is transformed into a phonemic code. The angular gyrus, in turn, sends information to the region of the planum temporale and the left temporal lobe including Wernicke's area. Here the sequence of the phonemic code is analyzed and through further interchanges with the angular gyrus, linguistic and semantic comprehension occur (Heilman, 1985).

The information then can be shared with the inferior premotor region in the left frontal lobe (or Broca's area) via the arcuate fasciculus. Broca's area is involved in programming phonemes in preparation for speech. Oral production of the phonemes--i.e., oral reading--is executed by the motor cortex (precentral gyrus). While described consecutively here, Luria (1980) noted that both simultaneous and sequential processing are involved at different stages. The specific cortical zones and their neurolinguistic processes believed to be involved in reading are depicted in Figures 1

Figure 1. Cortical Zones of the Left Hemisphere

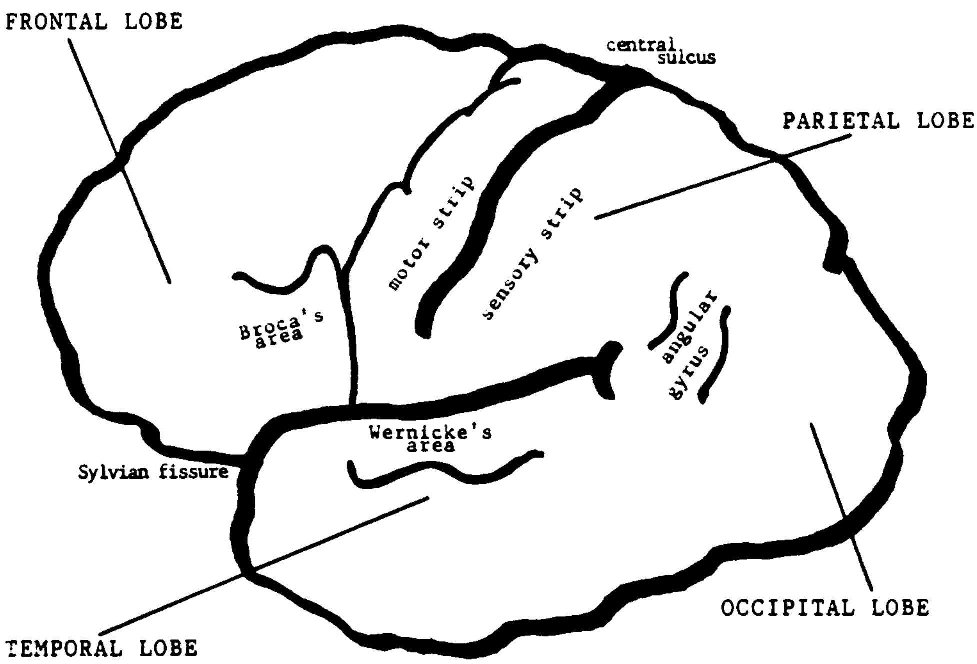

Figure 1: Cortical Zones of the Left Hemisphere
Adapted from Hynd & Cohen, 1983

and 2.

It is essential to note that virtually all of the neuroanatomical substratum implicated in the clinical alexic syndromes are incorporated in this functional system. Thus, this theory can serve as an heuristic model to explain clinical phenomena. To the extent that reading disturbances are similar to the clinical syndromes already identified, the model can be used to conduct further investigations of reading and reading failure in other samples, including school-aged children, and in the identification of subtypes of dyslexia.

To summarize, according to the Luria model, for a complex mental process or behavior to be manifested, the functional systems must be intact. A dysfunction in any one of the general or specific cortical zones may lead to disruption or disintegration of that particular process or activity. The model also proposes that any behavior can be analyzed <u>a priori</u> in terms of the general and specific functional units.

<u>Application of the Functional System of Reading to Dyslexia</u>

Recently, Hynd and his colleagues (Hynd, Obrzut, Hayes, & Becker, 1986; Hynd & Hynd, 1984; Hynd & Cohen, 1983) and Lyon (1983) have called for the application of Luria's functional systems theory to the examination of reading problems in children. Few would deny that there are similarities between childhood reading disorders and adult reading disturbances. However, some might argue that utilizing models developed from investigations on adults with brain damage is

Figure 2. Horizontal Section of the Brain

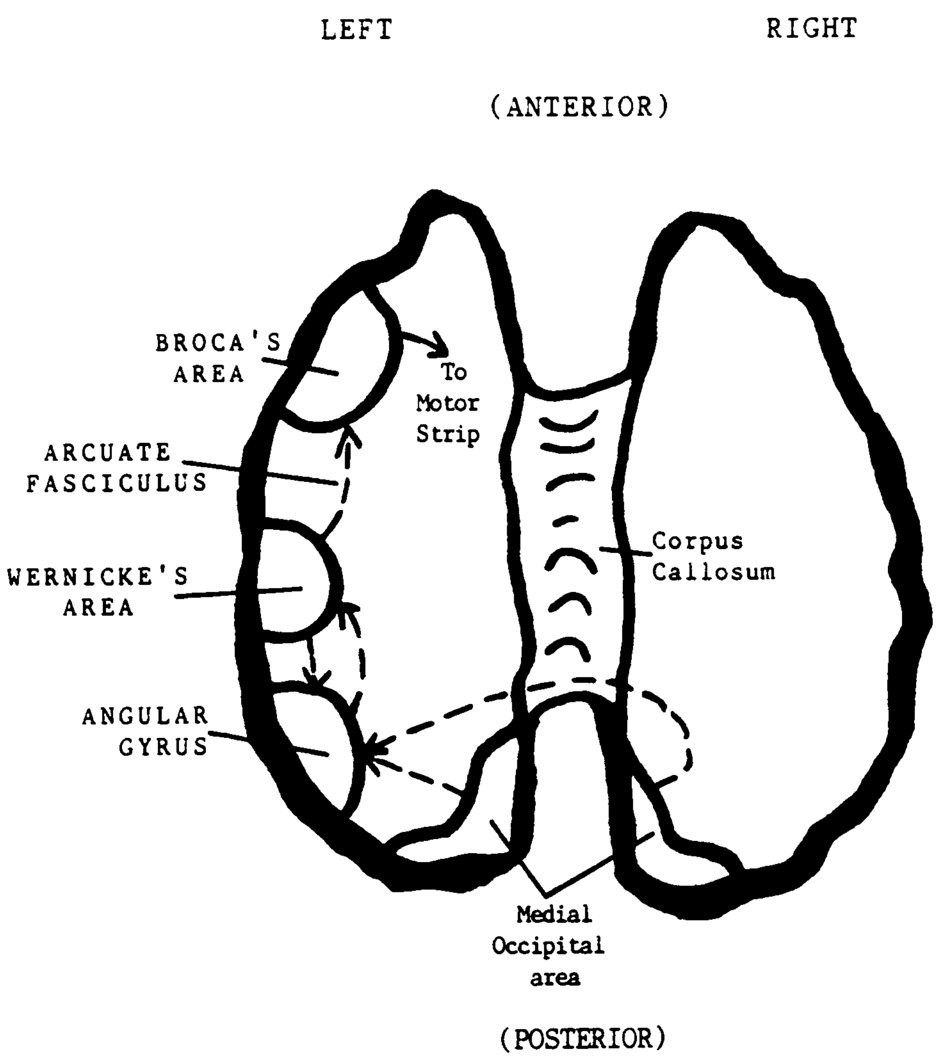

Figure 2: Horizontal Section of the Brain
Adapted from Hynd & Cohen, 1983

inappropriate for use with children in whom no neurological damage has been demonstrated consistently. It is important to note, therefore, that the purpose of this application merely is to serve as a foundation for research, not to provide a definitive statement of causality. How this theory might be useful with dyslexic children is discussed below.

As noted earlier, the examination of reading problems in children has fallen under the purview of the field of learning disabilities. A common paradigm for research within this field has been to compare groups of poor readers and matched controls on academic, achievement, psychological, or neuropsychological tests (Fletcher & Satz, 1985; Morris, 1988). Theories often are not utilized to select the measures or to predict how those measures might be related to reading problems. Instead, if differences are found between the dyslexics and controls, it simply is concluded that any underlying constructs associated with the tests must have some value for explaining why children have difficulties in reading (Taylor, 1988).

Unfortunately, there are a number of problems with this research approach. First, the number of variables on which these dyslexics and normals have been differentiated is quite large. The lack of a priori theories results in essentially unresolvable controversy concerning the nature of reading disorders in children. In addition, the same psychological constructs do not consistently result in differences between the groups even when controls and poor readers are matched on relevant demographic data. This latter problem could be the result of unreliable measures or it could suggest that dyslexia is a heterogeneous problem--i.e., subgroups of children with reading difficulties might exist. In an effort to deal with this apparent intra-subject variability, several researchers have attempted to develop typologies for learning problems in general, and reading problems in particular (c.f., Rourke, 1985).

The search for dyslexic subtypes typically has involved one of two procedures: clinical-inferential assessment or multivariate statistical classification (Lyon, 1983; Lyon & Moats, 1988). Using the traditional clinical approach, children have been classified into homogeneous subgroups on the basis of subjective inspections of related test data. Neuropsychological measures (e.g., Kinsboure & Warrington, 1963; Mattis, French, & Rapin, 1975), reading and spelling achievement scores (e.g., Boder, 1973), or a combination of intellectual, academic achievement, and neuropsychological tasks (e.g., Ingram, Mason, & Blackburn, 1970) have been used to delineate subtypes. However, there are a number of problems associated with the clinical method including: difficulties in establishing reliability and validity of the emergent typologies, and controlling bias in the inspection of psychometric protocols.

The refinement of sophisticated statistical procedures has significantly changed subtyping research. Two classes of multivariate techniques have been used most often. In each case, emerging subtypes are based on measurement theory and depend upon statistical decisions (including how may groups will be identified). The Q-technique of factor analysis forms correlational matrices of subjects' scores on a set of tests and extracts factors that constitute the subtypes. The factors in this analysis represent the common variability on the administered tests shared by the children (Fletcher & Satz, 1985).

The second class of statistical techniques, cluster analysis, uses different algorithms to form groups of subjects that are relatively homogeneous according to a set of classification attributes. Subgroups are generated on the basis of the similarity of each child's scores on a set of measures in comparison with the scores of all other children included in the analysis (Lyon,1983).

A variety of test sets or batteries have been subjected to these statistical procedures. For example, Doehring and his colleagues (Doehring & Hoshko, 1977; Doehring, Trites, Patel, & Fiedorowicz, 1979) were the first to employ the Q-technique to define subtypes of reading problems in terms of performance on 31 tests of rapid reading skills. Petrauskas and Rourke (1979) used the same technique on the data from an extensive neuropsychological battery which incorporated six Reitan categories (tactile, sequencing, motoric, visual-spatial, auditory-verbal, and abstract-conceptual). Others have cluster analyzed small, nonredundant sets of neuropsychological tasks (e.g., Lyon & Watson, 1981; Lyon, Stewart, & Freedman, 1982; Satz & Morris, 1981) or broad arrays of achievement, language, and processing measures (Watson, Goldgar, & Ryschon, 1982). As few as three and as many as six consistent subgroups of reading disabled children have been identified.

The multivariate approach is not without its problems, however. A number of investigators have identified significant statistical limitations with each of the techniques (c.f., Fletcher & Satz, 1985;

Morris, Blashfield, & Satz, 1981; Doehring, Hoshko, & Bryans, 1979). The most significant of these limitations appears to be that attempts to compare results from Q-analysis and cluster analysis have been unsuccessful.

In addition, it is of interest to note that subtyping did not begin until 25 years had elapsed without significant progress being made in the field of learning disabilities. While it appears that the utilization of sophisticated statistical procedures now has become popular, it is important to recognize that the majority of these subtyping investigations are based on retrospective analyses of whatever academic, achievement, or neuropsychological data the researchers happened to have collected on their clinical patients or large groups of school children. As in the common research paradigm described earlier, theories which generate <u>a priori</u> hypotheses about reading and reading failure have been noticeably lacking in subtyping literature as well.

Theory sometimes will be utilized <u>a posteriori</u> to help explain findings. However, since there have been few direct tests of hypotheses, little advancement in terms of understanding the nature of reading disturbances in children has been made.

An alternative to both the clinical and statistical approaches is to rely on a well-formulated theory employed <u>a priori</u>. In general, the theory should delineate the processes involved in reading, provide an explanation as to why failure in reading occurs, account for the existing data including the suspected heterogeneity, and generate research questions. The functional systems theory outlined in the previous sections appears to meet these criteria.

To reiterate, the complex behavior of reading is the result of the concerted functioning of cooperating neuronal systems in the left cerebral hemisphere. All systems in the brain are hypothesized to interact; thus, reading failure could result from disruption in any of the general or specific functional units.

From this neuropsychological perspective, when a reading disturbance like dyslexia occurs, a basic way to examine the disturbance is to assess anterior versus posterior functioning (i.e., Luria's anterior versus posterior functional zones). For left hemisphere language problems, it is traditional to begin with an evaluation of verbal fluency or expressiveness (Benson, 1985). Typically, nonfluent output is associated with anterior dysfunction while fluent output is associated with posterior dysfunction. Interestingly, there is some evidence from the statistical subtyping literature to suggest that a fluency-nonfluency distinction might exist in children identified as learning disabled, in general, and reading disabled, specifically.

Three major research groups involved in attempting to classify learning problems in children recently have used a measure of fluency or expressiveness in their assessment batteries. Inspection of the profiles generated by the cluster or Q-factor analysis suggest that dyslexic children within the various subtypes do not perform the same on fluency (as well as other) measures.

For example, Satz and Morris (1981) classified a large unselected sample of male children from the Florida Longitudinal Project. Two cluster analyses were completed, the first on the reading, spelling, and arithmetic subtests of the Wide Range Achievement Tests for the entire sample. This initial classification procedure identified a group of boys who were approximately one standard deviation or more below the mean on each of the achievement tasks. A second cluster analysis then was completed on five processing-deficiency (language and perceptual) variables for this group of "disabled learners." Verbal fluency was one of the five processing variables. The task required each boy to generate as many words as possible beginning with specified letters of the alphabet in three one-minute trials.

Five subgroups emerged from the cluster analysis. Inspection of the $\underline{z}$ score profiles reveals that disabled learners in three of the subgroups performed one standard deviation or more below the mean on the verbal fluency task. However, the remaining two subgroups performed near or within one standard deviation above the mean.

A second subtyping investigation (Lyon & Watson, 1981) compared children who were described as having a specific learning disability in reading (i.e., they manifested age equivalent deficits on the reading recognition and comprehension sections of the Peabody Individual Achievement Test) with children described as normal readers (i.e., they read at age levels which corresponded to their chronological ages on the same test). Eight diagnostic tests were administered to the children, three of which were described as "auditory expressive tasks" (sound blending, auditory attention, and naming).

A hierarchical cluster analysis technique was employed. Profiles were developed by comparing the standard scores of children with reading problems with the standard scores of the normal readers. Six subgroups were identified. Relevant to this discussion, three of the subgroups displayed expressive scores one standard deviation or more below the mean, while the other three displayed scores at or slightly above the mean.

A third subtyping study of reading disabled children was conducted by Petrauskas and Rourke (1979). Reading disabled and normal children were identified, and a twenty test neuropsychological battery designed to tap a wide range of adaptive abilities was administered. Verbal fluency was assessed using the Reitan test in which children are required to generate words beginning with a particular letter in two one-minute trials.

In this instance, a Q-factor analysis was used to identify types of disabled readers. All scores were converted to t-scores based on normative data and correlation analyses between subjects were determined. The resulting matrices then were factored. The eventual identification of subtypes was completed by calculating additional correlation coefficients between those children who loaded highly on single factors. Three consistent types were identified: one in which the children displayed a significant language disturbance, a second in which sensory integration difficulties predominated, and a third in which children had a primary deficit in conceptual flexibility. Reading disabled children in the first type were described as severely impaired in verbal fluency; while those in the other two types were described as only mildly to moderately impaired.

The actual purpose of these three studies was to statistically classify children with learning and reading problems. However as noted, inspection of the numerous profiles generated by the cluster and factor analyses provided some interesting observations about verbal fluency. Children within the different subgroups did not perform the same on verbal fluency tasks. Indeed, some performed poorly while others did as well as normal readers. These observations are predicted by Luria's model, and indicate that the hypothesized anterior-posterior difference (as reflected in measures of fluency) might exist in dyslexic children. Thus, it should be possible to divide dyslexic children into fluent and nonfluent groups _a priori_, and then measure differences between these groups on tasks which purportedly tap similar functional units.

Pilot Data

In a large project conducted at the Bowman Gray School of Medicine in Winston-Salem, North Carolina, reading disabled (i.e., children with a downward discrepancy of 1.5 years between expected and actual reading achievement level; RD) and control children (NRD) between the ages of 8 and 12 were characterized according to the presence or absence of attention deficit disorder (ADD). The initial purpose of the investigation was to examine the effects of RD and ADD on verbal memory and naming abilities in these children. Results indicated that deficits in memory for recently acquired information occur as a function of ADD rather than RD, while deficits in naming are specific to RD (Felton, Wood, Brown, Campbell, & Harter, 1987).

A verbal fluency task was included as part of the hour and a half neuropsychological battery administered to each child. This task required children to name as may words as possible beginning with the letters F, A, and S in three, 60 second trials. Scores for this test were included in the multivariate analysis in the Felton et al. study, and a main effect was found for RD--i.e., reading disabled children generated significantly fewer words on the average than control children. A main effect for ADD also was found; however, within the RD group, ADD and NADD means were the same.

Working from the assumption that an anterior-posterior distinction can be determined with a fluency task, and encouraged by the RD main effect, a re-examination of the Bowman Gray data was undertaken. An inspection of the percentage of reading disabled children who were fluent versus nonfluent was of particular interest. It was decided that nonfluency would be defined as scores on the verbal fluency test which were one standard deviation or more below the mean of the true comparison group for the project sample ($\underline{M}$ = 30.45, SD = 9.14). This mean was selected because it is consistent with the normative standards for children reported by Gaddes and Crockett (1975; $\underline{M}$ = 28.67, SD = 7.60). One standard deviation below the mean was selected because if verbal fluency scores for all children are distributed normally, only about 16% of the children from a particular sample would be expected to be nonfluent.

The criterion was applied to all children from the Bowman Gray sample and the resulting percentages of nonfluent subjects are displayed in Table 1. Interestingly, 55% of the RD group, regardless of whether or not they had a simultaneous diagnosis of ADD, were identified as nonfluent. This observation suggests that there might be anterior and posterior subtypes of reading disabled children, and that fluency might be a useful grouping variable to assess other related neuropsychological functions.

In the second phase of this preliminary work, the usefulness of the fluency construct was examined. The performance of the RD fluent and nonfluent subgroups was evaluated on two language tasks. These tasks included: (1) Boston Naming Test (BNT; Kaplan, Goodglass, & Weintraub, 1982) which consists of 60 line drawings of objects of varying familiarity; subjects are asked to name the objects orally; the score is determined by the number of correct, unprompted responses made within 15 seconds; and (2) Rapid Automatized Naming (RAN; Denkla & Rudel, 1976) in which subjects are required to name as quickly as possible colors (C), digits (D), common objects (O), and lower case letters (L) presented visually on a chart; scores are recorded in terms of time taken to complete each chart (seconds).

Means and standard deviations for the fluent and nonfluent groups are presented in Table 2. Independent *t*-tests yielded no significant differences. However, some interesting observations can be made. In particular, the RAN is a task which requires rapid verbal output. For each of the stimulus items, the nonfluent group was slower than the fluent group. Nonfluent children also named fewer items on the BNT.

A primary limitation of this preliminary work is that the language tasks were not selected to directly validate the

Table 1. Percentage of Nonfluent Children

TABLE 1

Percentage of Nonfluent Children *

Reading Disabilities Project at Bowman Gray School of Medicine
Winston-Salem, North Carolina

	NADD	ADD	
NRD	20% (8/40)	15% (2/13)	18.9%
RD	55% (11/20)	56% (14/25)	55.5%

NADD = no Attention Deficit Disorder; ADD = Attention Deficit Disorder; NRD = non-Reading Disabled; RD = Reading Disabled.

* Based on the true comparison (NADD/NRD) of the sample:

$\underline{M}$ = 30.40
$\underline{SD}$ = 9.14
-1SD = 21.26

Table 2. Means and Standard Deviations for Reading Disabled Children on Language Tasks

TABLE 2

Means and Standard Deviations for Reading Disabled Children on Language Tasks

	FLUENT	NONFLUENT
BNT	38.00 (5.73)	35.48 (7.65)
RAN-C	48.89 (15.45)	52.16 (10.61)
RAN-D	31.37 (11.49)	34.40 (6.51)
RAN-O	66.79 (21.15)	70.36 (20.04)
RAN-L	35.57 (16.61)	37.60 (9.28)

BNT = Boston Naming Test; a score is the number of drawings correctly named.

RAN = Rapid Automatized Naming; C=Colors, D=Digits, O=Objects, L=Letters; a score is the amount of time in seconds to complete each trial.

anterior-posterior distinction. An investigation to achieve this purpose appears to be warranted.

General Summary and Hypotheses

According to Luria, all complex behavior, including reading, is the result of the adequate functioning of the three general units of the brain (brainstem, posterior cerebrum, and anterior cerebrum), and the specific neuronal systems within these major units. Behavioral difficulties, on the other hand, can result from dysfunction anywhere throughout those units or systems. Traditionally, anterior versus posterior types of language or communication problems in adults (predicted by the Luria model) have been established by assessing verbal fluency. Nonfluent output has been associated most often with anterior dysfunction, while fluent output has occurred with posterior dysfunction. Clinical and statistical evidence suggest that subtypes of reading problems exist in children. Whether the fluency construct can be generalized to children has not yet been established. The primary purpose of the present research was to evaluate the utility of fluency as a dimension on which to classify children with the language problem of dyslexia.

There are several parts to the present investigation. First, groups of dyslexic (DR) and normal (NR) readers were identified. Previous data indicated that dyslexic readers differ on the average from normal readers on measures of verbal fluency (e.g., Felton et al., 1987). The initial purpose of the present study was to replicate this finding. It was hypothesized that dyslexic readers would be less fluent than normal readers.

A second purpose of the present research was to provide refinement for the construct of verbal fluency with children. Based on the procedures established through the pilot work, the DR group was divided into nonfluent and fluent subgroups (i.e., DR-NF and DR-F). The NR group also was included as a comparison. Validity for the fluency construct then was determined by examining children's performance on other language and motor tasks associated with anterior and posterior functioning--e.g., verbal memory, motor strength, perseveration, and vigilance (Stuss & Benson, 1984). In general, the NR group was expected to perform better than the other two groups on all tasks. Compared to both the NR and DR-F groups, the DR-NF group was expected to display the poorest performance on those tasks which purportedly tap anterior functioning. Specifically, DR-NF children were expected to be susceptible to interference on a verbal memory task, generally weaker and more susceptible to fatigue and perseveration on a motor task, less vigilant and unable to attend to one perceptual set while ignoring another, and unable to shift rapidly from one perceptual set to another. The DR-F group was expected to display the poorest performance on those tasks which purportedly tap posterior functioning (e.g., acquisition and recall on verbal memory tasks).

Method

Subjects

Seventy-one children enrolled in the primary schools of the Pulaski County School District in Virginia were recruited to participate in the present investigation. The project conformed with the guidelines and procedures for research with human subjects, and was approved by the Human Subjects Committee and Institutional Review Board of Virginia Polytechnic Institute and State University (see Appendix A). All subjects and their parents provided informed consent prior to participation (see Appendix B).

To be selected as a subject, each child was required to meet a number of initial criteria. The imposition of selection criteria, while limiting the generalizability of results, minimizes the confounding effect of subject differences. Children were selected if they were between the ages of 8 and 12 (96 to 144 months) and had normal hearing and normal corrected or uncorrected vision (as determined by recent school health examinations). Subjects also were required to have an estimated Full Scale IQ within the low average to high average ranges (i.e., 80 to 120) as measured on the short-form of the Wechsler Intelligence Scale for Children-Revised (WISC-R; Kaufman, 1976).

In addition, since the functional system of reading is hypothesized to be lateralized to the left hemisphere, only those subjects who were left hemisphere dominant for language and related functions were included. Traditionally, hemispheric dominance has been determined by measuring other lateralized phenomena such as preferences for limbs and sensory organs. Assessing handedness appears to be the most frequently employed method in this regard (c.f., Fennell, 1986). Based on clinical and laboratory studies of cerebral lateralization, it has become commonly accepted that right-handed people have left hemisphere language presentation. Indeed, in a recent review, Bryden and Saxby (1986) concluded that about 92% of the population are left hemisphere dominant for language, while about 90% of the population are right-handed.

Other researchers assess foot, eye, and ear preferences in addition to establishing handedness (e.g., Coren, Porac, & Duncan, 1979) According to these researchers, demonstrating consistent right-sided preferences within each of these domains strengthens assumptions about left hemisphere dominance. Therefore, subjects selected for this study were required to display an overall right-sided preference as determined by behavioral measures of handedness, footedness, eyedness, and earedness (i.e., a score of at least seven on the Lateral Preference Demonstration Test).

Based on these initial selection criteria, a number of subjects were excluded from participation. Specifically, one child was too young, three children received IQ estimates which were less than 80, and three children displayed a left-sided lateral preference.

In addition to these initial selection criteria, subjects were identified as either dyslexic readers (DR) or normal readers (NR). The basic distinction between these two groups as defined in this project is that DR children have failed to learn to read or experience significant disturbances in reading despite adequate intellectual capacities. Failure or disturbance usually is inferred when a child's measured achievement in reading is not commensurate with his/her general intellectual abilities.

Typically, the procedures used to identify dyslexic readers involve selecting children of average IQ and examining whether there is a difference between expected and actual reading levels on standardized achievement tests. The most popular units of measure to determine differences are age- and grade-equivalents. Children are identified as having a significant reading problem if there is a 1.5 to 2 year downward discrepancy between chronological age and reading age-equivalent or actual grade placement and reading grade-equivalent.

However, as noted by Reynolds (1985), the use of age- and grade-equivalent differences is inappropriate both from a research and a clinical standpoint. A fundamental criticism of these equivalent scores is that they may not represent equal units. Thus, for example, reading at a second grade level when a child is in the fourth grade is not the same in terms of severity of disturbance as reading at an eighth grade level when a child is in the tenth grade. In addition, age- and grade-equivalent scores tend to be based on ordinal scales, not interval scales and therefore should not be submitted to computational procedures.

An alternative to this typical assessment approach is to determine directly whether there is a discrepancy between a reading achievement and an aptitude score for each child. Reynolds (1985) suggests that an algebraic formula be used to test for the significance of a difference between two obtained scores for an individual:

$$z = \frac{IQ - Ach}{\sqrt{2 - r_{IQ} - r_{Ach}}}$$

IQ = the *z*-score on the IQ test

Ach = the *z*-score on the achievement test

r_{IQ} = the internal consistency estimate of the IQ test

r_{Ach} = the internal consistency estimate of the achievement test

z = discrepancy *z*-score

The test statistic is a *z*-score that can be compared to the normal curve. Various levels of significance can be selected which increase the confidence that a reading achievement and aptitude discrepancy is not due to chance or errors in measurement. The major advantage of using the formula is that it provides information on intraindividual variations of aptitude and achievement test performance.

Reynolds (1985) warns that the formula is only as useful as the quality of the input data. He notes that the achievement and aptitude tests selected for assessment must have sound psychometric properties (e.g., should be well-normed on a large random sample that is representative of the population to whom the tests will be administered, and should have adequate test-retest reliability and acceptable construct validity), should be individually administered, and should provide age-based standard scores.

For the present investigation, identifying subjects as either DR or NR involved several steps. Because of student confidentiality and limited access to school records, preliminary identification of subjects was completed by the school system. Children who were judged by their teachers to be of average intelligence but significantly behind in reading (e.g., by two or more years or grades) provisionally were identified and labelled DR, while other children judged to be of average intelligence and reading at grade level provisionally were identified and labelled NR. All of the DR children selected by teachers had been identified previously as "learning disabled" by Virginia educational standards and were receiving special resource or self-contained classroom instruction. The NR children selected by teachers were drawn from regular classrooms.

Parental consent to examine school records and to allow the child to receive additional testing then was obtained. Reading achievement was assessed by the reading achievement cluster from the Woodcock-Johnson Psycho-Educational Battery (W-J; Woodcock & Johnson, 1977). IQ was estimated with the four subtest short-form of the WISC-R (Kaufman, 1976). These measures were selected for several general reasons: (1) they fulfill the criteria required by Reynolds to employ the _z_-score formula; (2) they include standardized administration procedures and require no more than 45 minutes to complete; and

(3) they have been used frequently in academic settings in other research with DR and NR children. In addition, the reading achievement cluster of the W-J was selected over other reading tests (e.g., the reading subtest of the Wide Range Achievement Test, Sucher-Allred Placement Inventory, Classroom Reading Inventory, Gray Oral Reading Test) because it has well-documented standardization, reliability, and validity information which the others often lack. It also assesses a number of skills including letter and word identification, phonics, and comprehension which encompass all aspects of the hypothesized functional system of reading.

The Reynolds formula then was applied to the reading achievement and aptitude measures of each child to verify teachers' identifications of DR and NR children. A one-tailed test and significance level of $p < .10$ was used to determine reading disturbance. To be considered DR, a discrepancy z-score of greater than 1.26 was required. Unlike the federal guidelines for the identification of reading disabled students, extreme severity is not a requirement to evaluate the Luria model. Normal readers consisted of those children who had a discrepancy z-score of 1.00 or less.

With the application of the Reynolds formula criteria, four additional subjects were excluded from participation in the study. Three children identified by their teachers as DR obtained discrepancy z-scores within the normal range. One child identified by his teacher as a normal reader earned a discrepancy z-score of greater than 1.26.

The resulting sample consisted of 60 subjects. Fifty-four of the subjects were male and six were female. All of the children in this sample were white except for one child who was black. The subjects ranged in age from 96 to 142 months, in IQ from 80 to 120, and in lateral preference from 8 to 12 (indicating strong right-sided preference and implying left hemisphere dominance for language). Forty of the subjects were identified as DR, and 20 were identified as NR.

Materials: Classification Measures

Four Test Short Form of the Wechsler Intelligence Scale for Children-Revised (WISC-R; Kaufman, 1976). The four test short form of the WISC-R was developed on the basis of both rational and statistical criteria using data from a representative standardized sample. It is comprised of the Arithmetic and Vocabulary subtests from the Verbal Scale, and the Picture Arrangement and Block Design subtests from the Performance Scale. These subtests are administered in the order and standardized manner recommended by Wechsler (1974). Estimated Full Scale IQ equivalents were developed by converting the sum of the four scaled scores to a deviation quotient with a mean of 100 and a standard deviation of 15. The short form has a number of fine psychometric features which legitimize its use to estimate IQ: (1) average split-half reliability of .92 (used in the Reynolds formula); (2) test-retest stability ranging from .83 to .91 for various age groups; (3) .93 to .95 correlation with the WISC-R Full Scale IQ when all subtests are administered; (4) a standard error of estimate of only 5 points; and (5) evidence of significant relationships with other intelligence tests. In addition, the four subtests represent a diversity of mental operations.

Reading Achievement Cluster from the Woodcock-Johnson Psycho-Educational Battery (W-J; Woodcock & Johnson, 1977). The complete Woodcock-Johnson Psycho-Educational Battery contains 27 subtests organized into three parts: cognitive ability, achievement, and interest level. Only the three reading subtests from the achievement section were utilized in the present research. These reading subtests include letter-word identification, word attack, and passage comprehension. The first subtest requires subjects to identify isolated letters printed in varying scripts, and to pronounce words of increasing difficulty. This subtest seems to assess sight-vocabulary and recognition memory for letters and familiar words. It is not assumed that subjects necessarily know the meaning of a word which has been correctly pronounced. The word attack subtest requires subjects to read nonsense words (letter combinations that are not actual words or are extremely low frequency words in the English language). This task measures subjects' abilities to apply phonics and structural analysis skills in order to pronounce words that may be unfamiliar. The third reading subtest requires subjects to study a short passage and identify a key word missing from that passage. This task apparently draws upon a variety of comprehension and vocabulary skills since subjects must determine a word that is appropriate in the context of the passage. Standardized procedures for administration and scoring were followed for each subject.

To minimize the danger in generalizing from the score for a single narrow behavior (such as "word recognition") to a broad multifaceted ability (such as "reading"), subtest scores are combined into clusters (Woodcock, 1978). Reading achievement is treated as a function of the three reading subtests. Thus, a single composite score--the reading cluster score--was calculated for each subject. Four types of reading cluster scores can be utilized: age-equivalents, grade-equivalents, percentiles, and standard scores. A set of the latter scores is based on a mean of 100 and standard deviation of 15, and constituted the selected score for this study.

The complete W-J battery was standardized on a large sample, carefully chosen to be representative of the population (as reflected by United States census data) with respect to gender, race, occupational status, geographical region, and community (urban, nonurban). Extensive reliability and validity studies have been conducted on all subtests and clusters of the battery (Woodcock, 1978; McGrew & Woodcock, 1985).

The median split-half and test -retest reliabilities for letter-word identification, word attack, and passage comprehension are .95, .92, and .86 respectively. The median reliability for the overall reading cluster is .96 (used in the Reynolds formula).

Concurrent validity was evaluated by examining the correlation between reading cluster scores and scores on other frequently used tests of reading achievement: Iowa Tests of Basic Skills (Total Reading), Peabody Individual Achievement Test (reading recognition and comprehension subtests), and the Woodcock Reading Mastery Test. The concurrent validity coefficients range from .75 to .92.

Intercorrelations among the three W-J reading subtests also were calculated to determine construct validity, and ranged from a somewhat low but satisfactory .56 to .80. According to Sattler (1988), the achievement subtests of the W-J battery indeed appear to be useful in measuring achievement domains such as reading.

Lateral Preference Demonstration. According to Coren, Porac, and Duncan (1979), the techniques used to assess patterns of lateral preference of limbs and sensory organs have varied. Researchers either have questioned subjects directly about their use of a particular hand, foot, eye, and ear to complete certain activities, or have required subjects to demonstrate how they complete those activities. One of these methods is not necessarily superior to the other (Lezak, 1983). Since children are not always reliable self-reporters, it seemed reasonable to request that they demonstrate how they do a number of tasks.

A modification of the self-report and behavioral items developed by Coren, Porac, and Duncan (1979) was used in the present study. Specifically, children were asked to perform a total of 12 activities, e.g., draw a circle, kick a ball, peep through a key hole, listen to a transistor radio on low volume (see Appendix C for the directions for administration). It is important to note that these behavioral measures constituted demonstrations of lateral preference, not measures of skill. Children's displayed preferences on each task were recorded and scored as either right (+1.0) or left (-1.0). The algebraic sum was used to provide an index of lateral preference. This index constitutes an estimate of both side and strength of lateral preference. To be classified as having a right-sided preference, a child's score had to have a positive value of at least 7.

Materials: Neuropsychological Measures

The following instruments were used to assess verbal fluency and to determine concurrent validity for this construct. These measures were selected because they are well-known, frequently used neuropsychological tasks, have been administered successfully to children, and are sensitive to the hypothesized anterior-posterior distinctions being examined in this exploratory study.

FAS Test. Originally developed by Spreen and Benton (1968) as part of the Neurosensory Center Comprehensive Examination of Aphasia, this task assesses oral production of spoken words beginning with a designated letter. It is one of the most frequently used measures of verbal fluency. Also known as the Controlled Oral Word Association Test (Benton & Hamsher, 1976), it consists of three, word-naming trials. The subject is instructed to say as many words as he or she can in one minute beginning with a letter of the alphabet specified by the examiner. Proper names (i.e., words that "start with a capital letter"), numbers, and the same word with a different ending are not permitted. Three letters--F, A, and S--are used (see Appendix D). The total score is the sum of all acceptable words produced across the three, one-minute trials. Available evidence suggests that dysfunction in the anterior portions of the brain--especially the left cerebral cortex--results in depressed fluency scores (Benton, 1968;

Perret, 1974; Bigler, 1987). The FAS was used as a dependent measure to determine whether DR children are less fluent than NR children. Based on the criteria established in the pilot work, scores on the FAS also were used to classify DR children into nonfluent (anterior dysfunction) and fluent (posterior dysfunction) subgroups.

Rey Auditory Verbal Learning (RAVL; Rey, 1964). This test measures immediate verbal memory span as well as learning strategies and retention following a distractor activity. The RAVL is an easily administered test which consists of five presentations with free recall of a 15-word list, one presentation and recall of a second 15-word list, and a sixth recall trial of the first list (see Appendix E). The task requires approximately 15 minutes to complete.

The number of words recalled over the seven total trials of the RAVL allows several different types of scores to be generated including: verbal learning or acquisition over the first five trials, the inability to learn new information because of the interference of old information (proactive interference; recall on trial 6), and the inability to recall old information because of the interference of new information (retroactive interference; recall on trial 7). Individual trials also can be examined for primacy and recency effects by dividing each 15-item word list into thirds and examining which words are recalled more often.

Typically, learning and memory functions are associated with posterior (i.e., perihippocampal and diencephalic subcortical) regions of the brain (Luria, 1980). However, evidence from both animal and human studies suggests that the frontal lobes have close neuroanatomical interconnections with these posterior areas. Therefore, it has been suggested that dysfunction in the anterior cortical structures results in distinct memory deficits. For example, normal performance on tests of memory have been demonstrated by humans with frontal lobe damage except under conditions of interference. Specifically, susceptibility to proactive interference is thought to be an anterior dysfunction (c.f., Stuss & Benson, 1984; Stuss, Kaplan, Benson, Weir, Chiulli, & Sarazin, 1982). In addition, Milner (1982) and Milner and Teuber (1968) assert that adequate functioning of anterior structures is necessary for time-marking and the assessment of temporal sequencing in list-learning and recall trials (i.e., recency effect). Thus, anterior dysfunction is expected to negatively impact on the recency effect. It was predicted that DR children who are fluent would display more difficulties in learning the RAVL word lists than DR-nonfluent or NR children. DR children who are nonfluent, on the other hand, were expected to be more susceptible to proactive interference than the other two groups and to demonstrate less of a recency effect on individual recall trials.

<u>Dynamometer</u> (DYN; Dodrill, 1978a). A dynamometer is a device used to measure grip or hand strength. Subjects are required to grip or squeeze the handle of the instrument (one hand at a time) which provides a measure of pressure or strength in kilograms (Kg). This relatively simple task requires a motor response which has long been recognized as a function of the anterior portion of the brain--i.e., the pre-central and pre-motor areas of the cortex (c.f., Stuss & Benson, 1984). These cortical areas control the distal extremities of

the contralateral side of the body. Individuals typically demonstrate a right-left discrepancy in strength which reflects hemispheric dominance. However, in instances of anterior pathology, this discrepancy may be less pronounced. In addition, perseveration on motor activities and motor fatigue commonly have been associated with anterior dysfunction (Luria, 1965, 1973).

A number of trials and instructions were repeated for each hand to assess these components of motor function. For example, perseveration (starting and failing to stop movement) was examined by requiring subjects to squeeze the dynamometer as hard as they could on a first trial, and then to squeeze only half as hard on an immediately following second trial. A "percent change" score was generated using the following equation for each hand:

$$\%\ \text{CHANGE} = \frac{\text{HARD} - \text{HALF}}{\text{HARD}} \times 100$$

If the hard to half estimate is perfect, the percent change score will equal 50. If the percent change score is less than 50, it reflects perseveration. Lower values indicate greater perseveration.

Fatigue was assessed by requesting subjects to grip the dynamometer as hard as possible over five consecutive trials with minimal delay (see Appendix F). A maximum of 5 minutes was required to complete the two parts of the task. The DR-nonfluent group was expected to be weaker than the DR-fluent or NR children, and to display greater perseveration and fatigue, especially with the right hand.

Stroop Test (STR; Stroop, 1935). This test measures the ease with which a subject can shift his or her perceptual set to conform to changing demands (Lezak, 1983). The test requires concentration and vigilance, and thus also provides a measure of attention (e.g., Dodrill, 1978b). A standardized version of the test has been prepared by Golden (1978). The test consists of three 8 1/2 X 11" pages of 100 items each (see Appendix G). The items are arranged in five columns of 20. The first page (STR1) consists of the words "RED," "GREEN," and "BLUE" arranged randomly and printed in black ink. Subjects are instructed simply to read the words as quickly as possible. The items on page two (STR2) are all written as "XXXX" and are printed in either red, green, or blue ink. No color is allowed to follow itself in a column, or to correspond to an item on the first page. Subjects are instructed to name the colors as quickly as possible. The third page (STR3) consists of the words from page one printed in the colors of page two, blended item for item. In no case does the word match the color in which it is printed. Subjects are instructed to ignore the printed word, and to name the color of the ink. A 45 second time limit is imposed on subjects for each page. Subjects also are instructed to read down the columns beginning on the left side of each sheet. Three basic scores which correspond to the three stimulus pages can be obtained: number of words read correctly, number of colors named correctly, and number of colors named correctly while ignoring the printed words.

While the Stroop test as a whole assesses general left hemisphere functioning for most individuals (Golden, 1978), the third section is associated with pre-frontal cortical functioning. The vigilance needed to attend to one perceptual set (i.e., color) while ignoring another (i.e., printed words) typically is regarded as an anterior function (c.f., Stuss & Benson, 1984). Conversely, the inability to maintain attention and vigilance to tasks is a common observation associated with anterior dysfunction (Hecaen & Albert, 1975). Consequently, DR-nonfluent children were expected to perform more poorly across the three trials of the Stroop (i.e., read fewer words, name fewer colors, and be more susceptible to interference) than either the DR-fluent or NR groups.

Trail Making Test (Trails). This test originally was part of the Army Individual Test Battery (1944). According to Lezak (1983), the test is administered in two parts. Subjects first are asked to draw lines to connect consecutively numbered circles on one worksheet (Part A), and then to connect the same number of consecutively numbered and lettered circles by alternating between the two sequences on a second worksheet (Part B). Subjects are instructed to work as quickly as possible (see Appendix H). Separate scores are obtained for Parts A and B and consist of the length of time in seconds required to complete the connections in each part.

Like the Stroop Test, Trails is a task which requires attention and the ability to shift perceptual sets. It also includes visual-motor tracking and motor speed (Lezak, 1983). These functions have been associated with the activity of the frontal lobes (Stuss & Benson, 1984); and thus, poor performance on the Trails (i.e., longer times to complete each section) is thought to reflect anterior dysfunction. As a result, DR-nonfluent children again were expected to perform more poorly than either DR-fluent or NR children on each trial of this task, and in particular on Part B.

Procedures

As noted, to protect children's confidentiality, provisional selection of subjects and parental consent for their children to participate in the project was completed first by the school system. Teachers identified two groups: one group with average intelligence but reading skills at least two or more years or grades below expected age or grade placements, and another group with average intelligence and reading skills at age or grade level. All of these school-identified subjects then underwent a day of classification testing. This testing took place during regular school hours at each child's school, in a relatively quiet testing office or empty classroom removed from the rest of the school's activities. Each subject completed the Lateral Preference Test, the reading achievement cluster of the W-J, and the four-test short form of the WISC-R. Standardized administration procedures were followed for each test, and the order of test presentation was randomized across subjects. A single session lasting approximately 45 minutes was required to complete the three tests (see Table 3). The Reynolds discrepancy z-score then was calculated using scores from the W-J and WISC-R to classify subjects

Table 3. Classification and Neuropsychological Tests

TABLE 3

Classification and Neuropsychological Tests

	TESTS	APPROXIMATE TIME	
DAY 1	Lateral Preference Demonstration*	5 mins.	
	Reading Achievement from the W-J*	20 mins.	
	Four Test Short Form of the WISC-R*	20 mins.	
		45 mins.	TOTAL
DAY 2	Child Consent Form	3 mins.	
	FAS Test*	5 mins.	
	Rey Auditory Verbal Learning*	15 mins.	
	Dynamometer* §	5 mins.	
	Stroop Test*	5 mins.	
	Trail Making Test*	12 mins.	
		45 mins.	TOTAL

* Order of test presentation randomized across subjects.

§ Hand order randomized across subjects.

as either DR or NR. Any subject who did not meet the age, lateral preference, IQ, and discrepancy z-score criteria was excluded from further testing.

The remaining DR and NR subjects completed a second day of neuropsychological assessment. The same testing locations used on day one were used on day two. The general approach also was similar. First, each child's consent to participate further in the project was secured and a brief introduction to the tasks was provided (see Appendix B, Child Consent Form). Each subject then completed the five neuropsychological tests: FAS, RAVL, DYN, STR, and Trails. Again, standardized administration procedures were followed for each test, and the order of test presentation was randomized across subjects. Of note, hand order for the DYN task also was randomized across subjects, and the DR and NR subject were tested in a random order. All of the testing on day two was completed in one, 45 minute session (see Table 3). At the conclusion of the assessment, subjects were told the general purpose of the project, and were permitted to ask questions about their participation.

Results

FAS Data

The first analysis was used to examine whether or not DR children are less fluent than NR children. The independent grouping variable was reading classification and the dependent variable was fluency as measured by the total number of words generated on the FAS Test. A single t-test showed that the DR group (M = 18.03, SD = 5.98) was significantly less fluent than the NR group (M = 25.85, SD = 5.46), $t(58) = -4.92$, $p < .01$.

To examine the validity of the fluency construct, it was necessary to classify DR subjects into nonfluent (anterior dysfunction) and fluent (posterior dysfunction) subgroups. Procedures similar to those applied in the pilot work were used to divide the DR children these subgroups. Specifically, nonfluency was defined as scores on the FAS Test which were one standard deviation below the mean of the NR group. Based on these criteria, it was determined that children who scored less than 20 on the FAS Test would be considered nonfluent, while children who scored greater than or equal to 20 on the test would be considered fluent. Application of this criterion resulted in the formation of three groups: DR children who were nonfluent (DR-NF; n = 21), DR children who were fluent (DR-F; n = 19), and NR children (n = 20).

It was desirable to conduct the remaining analyses on groups with equal numbers of subjects. Therefore, one child from the NR group was excluded because his FAS score was less than 20, and two DR-NF children were randomly omitted. The resulting three groups each contained 19 subjects (N = 57).

Classification Data

Separate ANOVAs and post hoc pairwise comparisons were conducted on the classification variables of age (months), lateral preference, W-J (standard score), IQ, and FAS. The results indicate that the three groups do not differ significantly in terms of age or lateral preference (see Table 4). However, significant differences among the groups were found for W-J, $\underline{F}(2,54) = 127.96$, $\underline{p} < .0001$, IQ, $\underline{F}(2,54) = 23.88$, $\underline{p} < .0001$, and FAS, $\underline{F}(2,54) = 64.94$, $\underline{p} < .0001$. Pairwise comparisons using Duncan's Multiple Range Test (MRT; Duncan, 1955; Kirk, 1982) at the .05 level of significance revealed that the DR nonfluent and fluent groups did not differ significantly from each other in terms of W-J or IQ performance. However, both DR groups earned significantly lower scores on these tests than the NR group (see Table 4). The DR-F and NR groups did not differ significantly from each other on the FAS; but both groups differed significantly from the DR-NF group which generated the fewest responses (see Appendix I).

Neuropsychological Tasks

In order to validate the construct of verbal fluency, a series of mixed and one-way ANOVAs and appropriate post hoc pairwise comparisons were completed for each of the neuropsychological tasks. In all cases except one, Duncan's MRT at the .01 level of significance was used to

Table 4. Group Means and Standard Deviations of Classification Variables

TABLE 4

Group Means and Standard Deviations of Classification Variables

GROUP	AGE	LAT	W-J	IQ	FAS
DR-NF					
Mean	117.37	10.47	77.05	90.89	12.68
SD	14.95	1.47	5.60	7.45	3.06
DR-F					
Mean	124.95	10.58	79.16	95.00	23.37
SD	10.05	1.43	6.12	8.77	2.77
NR					
Mean	120.26	10.32	110.42	109.63	26.26
SD	13.42	1.11	9.31	9.96	5.28

complete pairwise mean comparisons for the reliable interaction effects. The same posthoc test at the .05 level of significance was used to complete pairwise mean comparisons for each reliable main effect. Intercorrelations among selected neuropsychological variables for the DR (combined) and NR groups are presented in Tables 5 and 6.

RAVL. A series of mixed and one-way ANOVAs were completed on the RAVL data to assess: (1) learning across the first five trials; (2) the effects of proactive and retroactive interference; and (3) the presence of primacy and recency effects across all seven trials. First, a 3 x 5 (Group x Trial) mixed ANOVA was conducted. The five initial trials of the RAVL served as the repeated variable. The total number of words recalled on each trial constituted the dependent measure. Although no Group x Trial interaction was found, the main effects of Group, $F(2,54) = 9.21$, $p < .001$, and of Trial, $F(4,216) = 199.48$, $p < .0001$ were significant (see Figure 3). Pairwise comparisons using Duncan's MRT revealed that across trials, the DR-NF ($M = 8.39$) and DR-F ($M = 9.06$) groups did not differ significantly from each other. However, they both differed significantly from the NR group ($M = 10.20$). Additional post hoc testing revealed that across groups all five of the trials differed significantly from each other, with the highest number of words recalled on Trial 5 and the lowest number on Trial 1 (means in descending order: 11.58, 10.63, 9.95, 8.33, and 5.59).

A one-way ANOVA then was calculated to determine whether the three groups differed in their responses to proactive interference. The number of words recalled on Trials 6 served as the dependent

Table 5. Intercorrelations Among Selected Classification and Neuropsychological Variables for the DR Group

TABLE 5

Intercorrelations Among Selected Classification and Neuropsychological Variables for the DR Group

VARIABLE	1	2	3	4	5	6	7	8	9	10	11	12	13
1. AGE	——												
2. W-J	-.239	——											
3. IQ	-.301	.582§	——										
4. RAVL1	-.017	.181	.143	——									
5. RAVL6	-.011	.278	.446§	.328*	——								
6. RAVL7	.279	.029	.047	.303*	.185	——							
7. RHALF	.484§	-.035	-.361*	.076	-.277	.262	——						
8. RFATIGUE	.569§	-.031	-.005	.065	-.096	.151	.589§	——					
9. LHALF	.347*	.137	-.241	.183	-.362*	-.028	.716§	.452*	——				
10. LFATIGUE	.596§	-.050	-.047	.058	-.032	.171	.563§	.868§	.491§	——			
11. STR1	.474§	.341*	.050	.345*	.027	.179	.433§	.432§	.542§	.357*	——		
12. STR2	.318*	.177	.011	.199	-.098	.169	.397§	.286	.444§	.264	.726§	——	
13. TRAILB	-.246	-.323*	-.279	-.310*	-.208	-.249	-.013	-.261	-.057	-.271	-.372*	-.311*	——
14. FAS	.286	.179	.153	.307*	.214	.234	-.058	.089	-.018	.144	.286	.332*	-.344*

* $p < .05$ § $p < .01$

Table 6. Intercorrelations Among Selected Classification and Neuropsychological Variables for the NR Group

TABLE 6

Intercorrelations Among Selected Classification and Neuropsychological Variables for the NR Group

	VARIABLE	1	2	3	4	5	6	7	8	9	10	11	12	13
1.	AGE	——												
2.	W-J	-.218	——											
3.	IQ	-.332	.829§	——										
4.	RAVL1	-.080	-.141	-.238	——									
5.	RAVL6	.324	.058	-.232	.106	——								
6.	RAVL7	.124	-.137	-.115	.140	.058	——							
7.	RHALF	.019	-.009	-.380	.057	.162	.177	——						
8.	RFATIGUE	.535§	-.041	-.237	.061	.153	.123	.278	——					
9.	LHALF	.306	-.139	-.238	.121	-.078	-.167	.379*	.407*	——				
10.	LFATIGUE	.488*	.083	-.070	.046	.368	-.198	.155	.785§	.486*	——			
11.	STR1	.623§	-.052	-.228	-.078	.586§	.188	.051	.154	-.027	.310	——		
12.	STR2	.747§	-.137	-.288	.031	.498*	.283	-.097	.479*	-.031	.481*	.784§	——	
13.	TRAILB	-.599§	.204	.265	-.085	-.257	-.604§	-.103	-.293	.044	-.155	-.535§	-.641§	——
14.	FAS	-.053	.409*	.344	.174	.114	-.346	-.256	-.389	-.259	-.137	.002	-.077	.096

* $p < .05$ § $p < .01$

Figure 3. Group by Trial Interaction for the Learning Trials of the RAVL

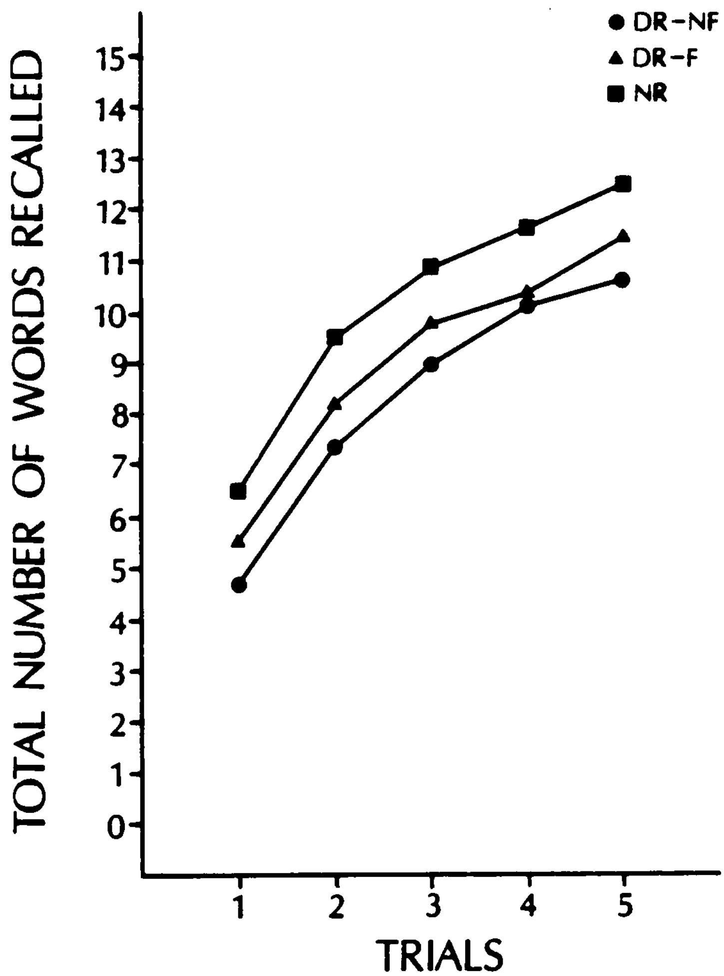

Figure 3: Group by Trial Interaction for the Learning Trials of the RAVL (n.s.)

measure for these analyses. Significant differences among the groups were found for the data on this trial, F (2,54) = 6.87, $p < .002$. Pairwise comparisons using Duncan's MRT revealed that the DR-NF (M = 3.84) and DR-F (M = 4.53) groups did not differ significantly from each other on this Trial 6; however, both groups differed significantly from the NR group (M = 5.63).

An additional set of analyses consisted of a 3 x 3 x 7 (Group x Location x Trial) mixed ANOVA. Both Location and Trial constituted repeated measures. Each RAVL list was divided into thirds, with Location 1 corresponding to the first five words in the list, Location 2 corresponding to the second five words in the list, and Location 3 corresponding to the last five words in the list. In general, more words were expected to be recalled at Location 1 (primacy effect) and Location 3 (recency effect) than at Location 2. The number of words recalled in each of the seven trials within each of the locations constituted the dependent measure.

The Group x Location interaction was the only interaction found to be significant, $F(4,108) = 3.41$, $p < .01$ (see Figure 4). Pairwise comparisons using Duncan's MRT revealed that at Location 1, the DR-NF and DR-F groups, and the DR-NF and NR groups were not significantly different from each other. However, the DR-F and NR groups were significantly different. The subjects in the DR-F group recalled the fewest number of words at Location 1, while the NR subjects recalled the most. At Location 2, while the DR-NF and DR-F groups, and DR-F and NR groups were not significantly different from each other, the DR-NF and NR groups were significantly different. All groups recalled

Figure 4. Group by Location Interaction across the Seven Trials of the RAVL

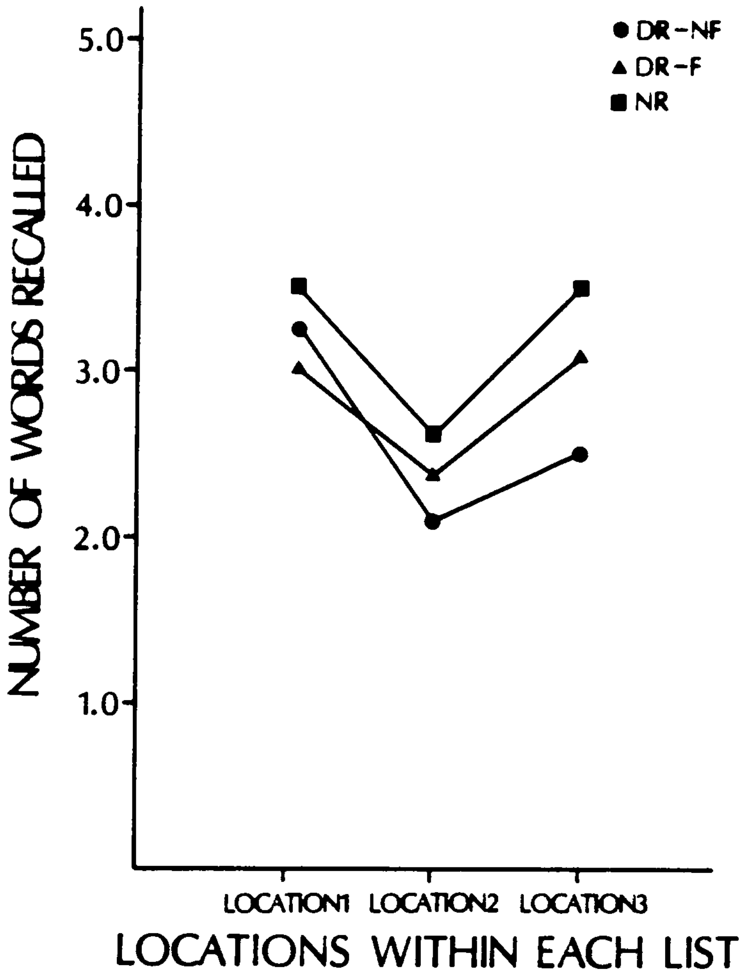

Figure 4: Group by Location Interaction across the Seven Trials of the RAVL

significantly fewer words at Location 2 than at Location 1. At Location 3, the DR-F and NR groups were not significantly different from each other. The DR-NF group was significantly different from both the DR-F and NR groups, with subjects from the nonfluent group recalling the fewest number of words at Location 3 (see Appendix I).

Significant main effects also were found for Group, $F(2,54) = 9.64$, $p < .001$, Location, $F(2,108) = 55.46$, $p < .0001$, and Trial, $F(6, 324) = 202.60$, $p < .0001$. Post hoc comparisons using Duncan's MRT revealed that across location and trials, the DR-NF and DR-F groups did not differ significantly from each other; however, they both differed reliably from the NR group. The NR subjects consistently recalled more words on the average per location across trials than each of the DR groups. Across groups and trials the highest number of words was recalled from the first third of the list, followed by the last third, and finally the second third. Across groups and locations all of the trials differed significantly from each other except for Trials 3 and 7. The highest number of words was recalled on Trial 5, and the lowest number on Trial 6. The specific descending order included: Trial 5, Trial 4, Trial 7, Trial 3, Trial 2, Trial 1, and Trial 6.

DYN. The dynamometer task was included to assess three phenomena: (1) strength, (2) perseveration, and (3) fatigue. In each case, a raw score of pressure in kilograms for each hand constituted the dependent measure.

A 3 x 2 x 2 (Group x Hand x Trial) mixed ANOVA was calculated first to examine perseveration. Hands (right and left) and Trial (hard squeeze and half-as-hard squeeze) constituted the repeated variables. A significant Group x Trial interaction was obtained, $F(2,54) = 3.46$, $p < .05$ (see Figure 5). Post hoc pairwise comparisons using Duncan's MRT (at the .05 rather than .01 level) revealed that across hands, there was one significant pairwise difference at Trial 1: the DR-NF was significantly weaker than the NR group). No significant pairwise differences occurred at Trial 2.

Significant main effects also were found for Hand, $F(1,54) = 15.04$, $p < .001$, and Trial, $F(1,54) = 208.28$, $p < .0001$. Post hoc comparisons suggest that across all three groups and trials, the right hand ($M = 14.28$) was significantly stronger than the left hand ($M = 13.13$); and across hands and groups, subjects squeezed harder on the first trial ($M = 16.51$) than on the second trial ($M = 10.90$).

Percent change scores also were calculated and used as dependent measures to assess perseveration for each hand. A 3 x 2 (Group x Hand) mixed ANOVA was computed. Hand (right and left) constituted the repeated variable. No significant main or interaction effects were found (see Figure 6); however, the DR-NF group demonstrated less of a percent change (indicating greater perseveration) for each hand than both the DR-F and NR groups.

Finally, a 3 x 2 x 5 (Group x Hand x Trial) mixed ANOVA was calculated to examine fatigue. Hands (right and left) and the five consecutive trials constituted the repeated variables. Although no Group x Trial interaction was found, the DR-NF group showed the weakest responses on each of the trials (see Figure 7). Significant main effects were obtained for Hand, $F(1,54) = 41.47$, $p < .0001$, and

Figure 5. Group by Trial Interaction on the Perseveration Task with the DYN

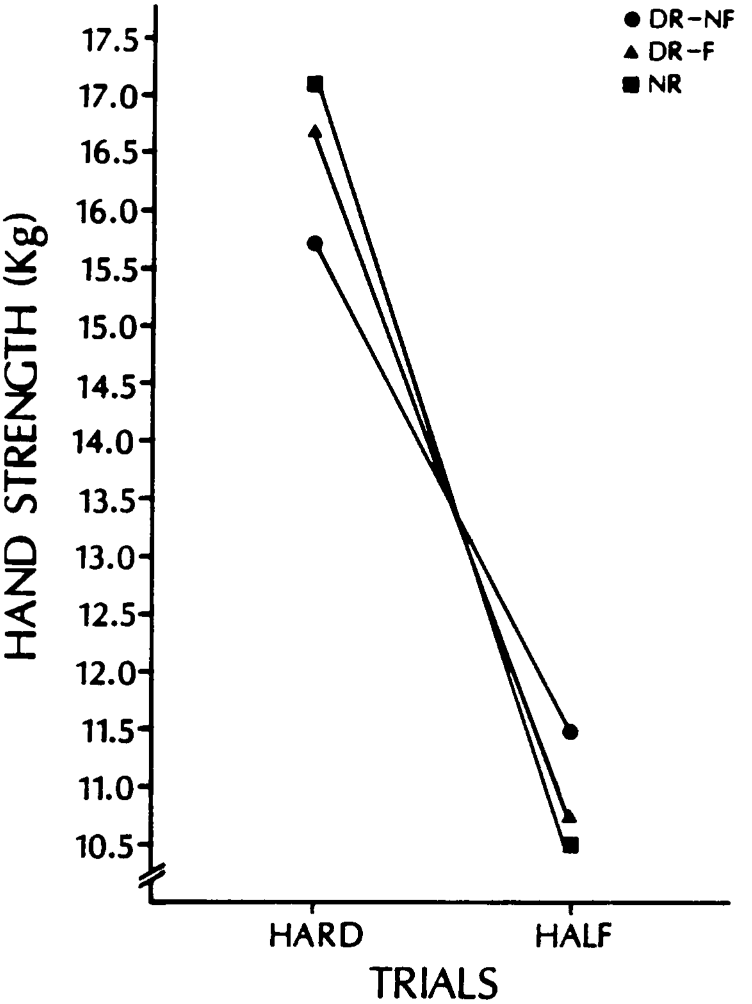

Figure 5: Group by Trial Interaction on the Perseveration Task with the DYN

Figure 6. Group by Hand Interaction on the Perseveration Task with the DYN

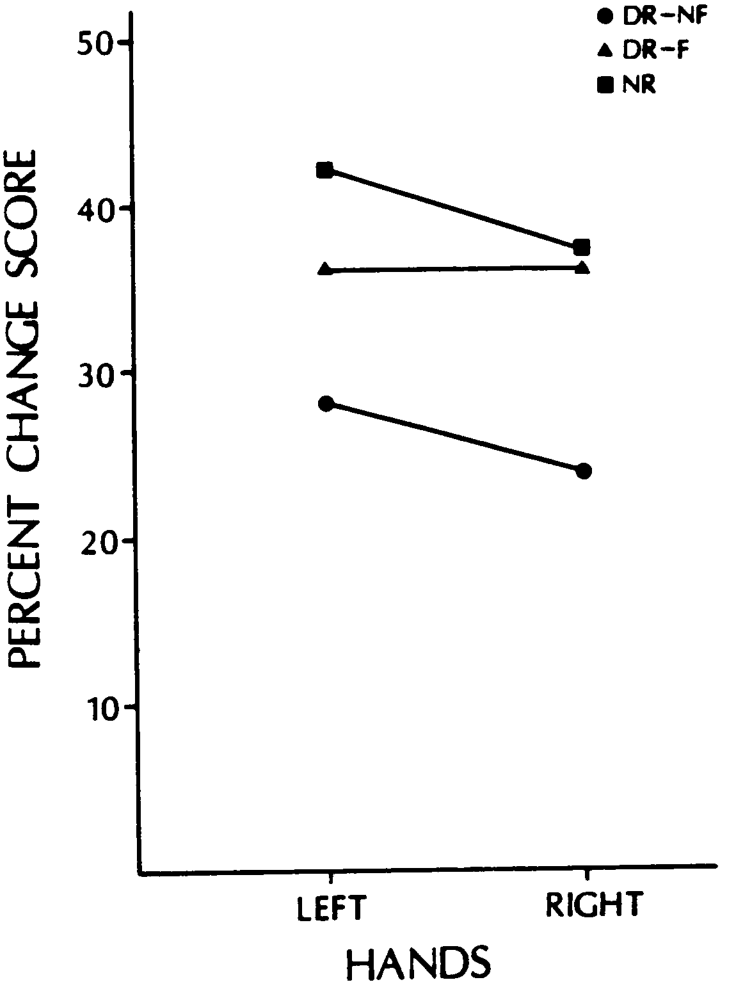

Figure 6: Group by Hand Interaction on the Perseveration Task with the DYN (n.s.)

Figure 7. Group by Trial Interaction on the Fatigue Task with the DYN

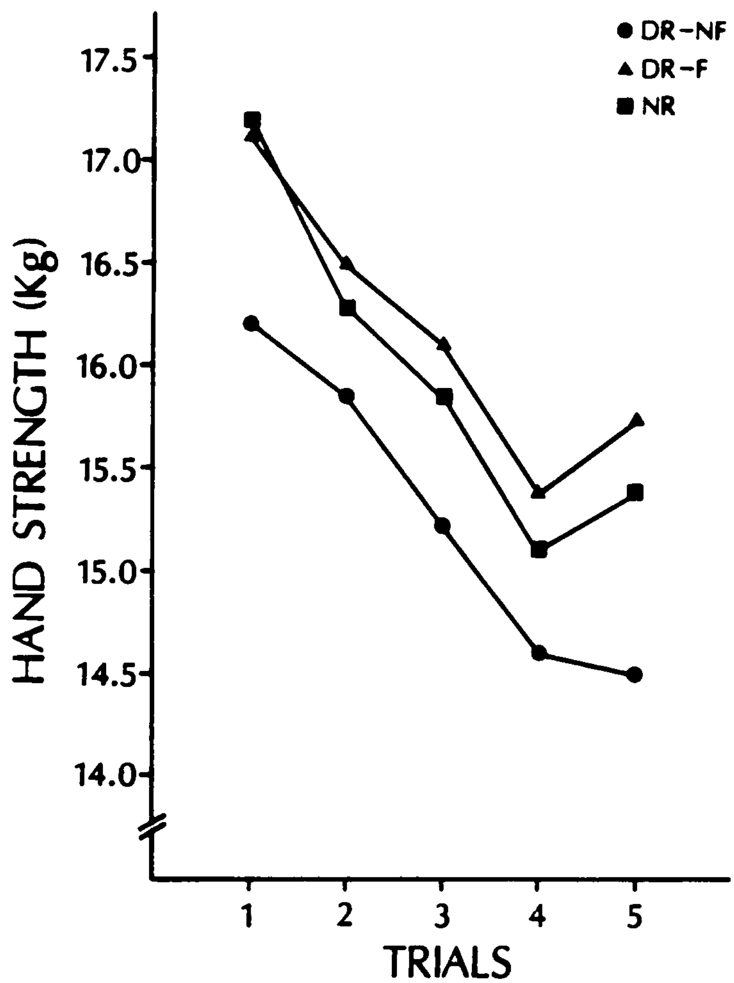

Figure 7: Group by Trial Interaction on the Fatigue Task with the DYN (n.s.)

Trial, $F(4,216) = 42.32$, $p < .0001$. Post hoc pairwise comparisons using Duncan's MRT revealed that across all groups, the right hand ($M = 16.55$) displayed significantly less fatigue than the left hand ($M = 15.09$), and that fatigue decreased significantly from Trial 1 through Trial 5 (although responses were the weakest on Trial 4, not 5).

STR. A 3 x 3 (Group x Trial) mixed ANOVA was computed on the raw score Stroop data. Trial (words read on page one, colors named on page two, colors named while ignoring printed words on page three) constituted the repeated variable. The dependent measure consisted of the number of correct responses for each trial. A significant Group x Trial interaction was obtained, $F(4,108) = 8.35$, $p < .0001$ (see Figure 8). Post hoc pairwise mean comparisons using Duncan's MRT revealed that at Trial 1, all three of the groups were significantly different from each other. The DR-NF group read significantly fewer words than both the DR-F and NR children. The DR-F group also read significantly fewer words than the NR group. At Trial 2, the DR-NF subjects named significantly fewer colors than both the DR-F and NR subjects, but the DR-F and NR groups were not significantly different from each other. At Trial 3, only the DR-NF and NR groups were significantly different from each other (i.e., the DR-NF children named fewer colors while ignoring the printed word than the NR children.)

Significant main effects also were found for Group, $F(2,54) = 15.75$, $p < .0001$, and Trial $F(2,108) = 535.68$, $p < .0001$. Post hoc comparisons revealed that across trials, the DR-NF group ($M = 38.96$)

Figure 8. Group by Trial Interaction on the STR

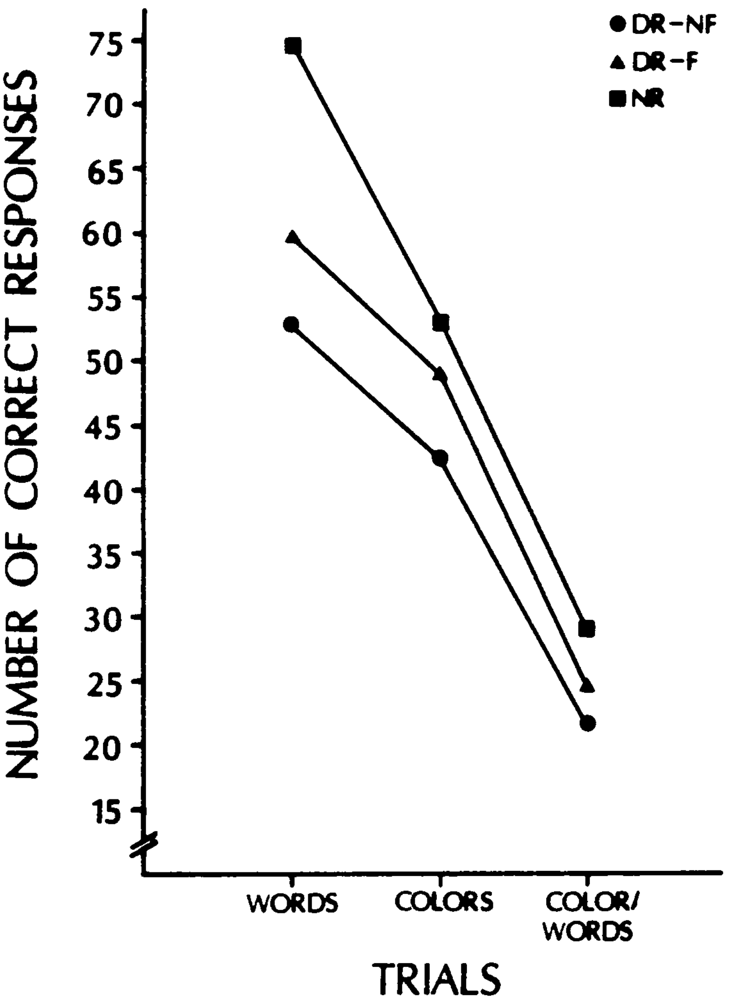

Figure 8: Group by Trial Interaction on the STR

had significantly fewer correct responses than the DR-F group ($\underline{M}$ = 44.25). Both DR groups had significantly fewer correct responses than the NR group ($\underline{M}$ = 52.12). Across groups, significantly more correct responses were obtained on Trial 1 ($\underline{M}$ = 62.44) than on Trial 2 ($\underline{M}$ = 47.91). Both Trials 1 and 2 resulted in significantly more correct responses than Trial 3 ($\underline{M}$ = 24.98).

Trails. A 3 x 2 (Group x Trial) mixed ANOVA was calculated for the data from the Trail Making Test. Trial (Parts A and B) constituted the repeated variable. The dependent measure was time in seconds to complete each part. A reliable Group x Trial interaction was obtained, $\underline{F}(2,54) = 8.08$, $\underline{p} < .001$ (see Figure 9). Post hoc pairwise mean comparisons using Duncan's MRT revealed that at Trial 1 (Part A), none of the group means were significantly different from each other, although the DR-NF group was the slowest. At Trial 2 (Part B), the DR-NF group was significantly slower than both the DR-F and NR groups. However, the DR-F and NR groups did not differ significantly from each other (see Appendix I).

Reliable main effects also were obtained for Group, $\underline{F}(2,54) = 10.55$, $\underline{p} < .0001$, and Trial, $\underline{F}(1,54) = 175.11$, $\underline{p} < .0001$. Post hoc comparisons indicated that across trials, the DR-NF group ($\underline{M}$ = 109.00) was significantly slower than both the DR-F ($\underline{M}$ = 83.82) and NR groups ($\underline{M}$ = 68.89), but that the DR-F and NR groups did not differ. Across groups, it took significantly less time to complete Trial 1 ($\underline{M}$ = 48.65) than Trial 2 ($\underline{M}$ = 125.83).

Figure 9. Group by Trial Interaction on the TRAILS

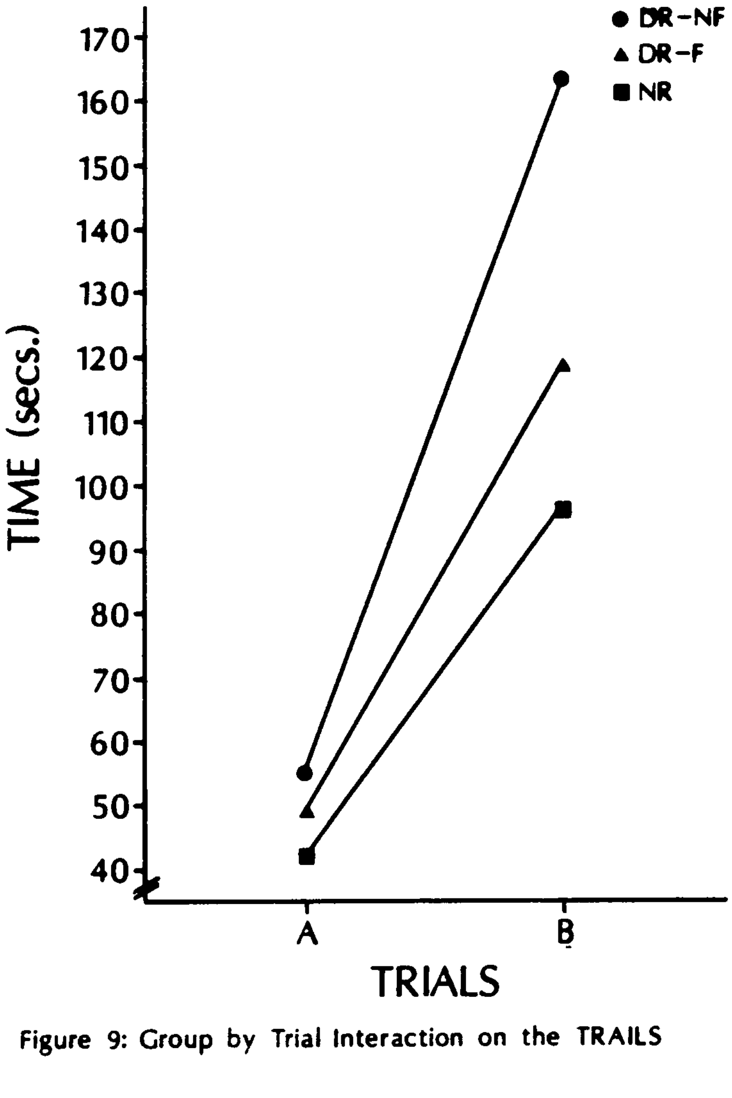

Figure 9: Group by Trial Interaction on the TRAILS

Discussion

The general purpose of the present exploratory study was to determine the utility of fluency as a dimension on which to classify children with the language problem of dyslexia. To achieve this purpose, it first was necessary to establish that children who have failed to learn to read or who experience significant disturbances in reading despite adequate intellectual capacities (DR children) differ significantly from normal readers (NR) on a traditional measure of verbal fluency. DR and NR groups of children were identified using the Reynolds (1985) formula in which intra-individual variations of aptitude and reading achievement were assessed. Verbal fluency, then, was determined using the FAS test. Consistent with previous findings (e.g., Felton et al., 1987), and as predicted for the present investigation, the DR group was found to be consistently less fluent than the NR group.

Based on the mean and standard deviation of the NR group, the DR children subsequently were divided into reliable nonfluent (NF) and fluent (F) subgroups. Consistent with the pilot work to this project, approximately half of the DR children (53%) were identified as nonfluent.

The resulting DR-NF and DR-F groups did not differ significantly from each other in terms of reading achievement or IQ. Both of these DR groups did earn lower scores on reading achievement and IQ measures than the NR group. Of note, however, is the fact that despite the IQ and achievement differences, the identified DR-F group did not differ from the NR group in terms of verbal fluency. In addition, verbal fluency did not correlate significantly with age or IQ measures for any group. This suggests that verbal fluency is not merely a product of general aptitude (i.e., IQ), reading skill, or a function of age, and therefore could prove useful as a classification variable for reading disability.

The second purpose of the present study was to provide refinement for the fluency construct. To determine whether the nonfluent-fluent dimension constitutes a valid means for classifying DR children in terms of anterior versus posterior dysfunction, a series of neuropsychological tests purported to assess those functional units were administered to all subjects. Specific hypotheses were made about the children's expected performances on each of the tasks based on the type of group into which each child was classified. The majority of the predictions were made in terms of the DR-NF group. This group was expected to perform more poorly and to experience specific types of deficits on each task as compared to the DR-F and NR groups. In addition, one specific prediction was made regarding performance of the DR-F group on the verbal memory task. The NR group also was expected to perform better than both the DR-NF and DR-F groups on all tasks. The results indicate that the predictions for the DR-NF and NR groups generally were supported and provide initial validation for the fluent-nonfluent distinction for reading disabled children. Each of the hypotheses and findings will be discussed below.

An initial set of hypotheses was made for the three groups of children on the RAVL task. First, it was predicted that DR-F children would display more difficulties learning the word lists (reflected in fewer numbers of words recalled on the first five trials) than either the DR-NF or NR children. Results indicated that this hypothesis was not supported. The DR-F and DR-NF groups did not differ significantly from each other across the five trials. However, both DR groups recalled significantly fewer words than the NR group. In addition, at least from a numerical standpoint, the DR-NF group, not the DR-F group, recalled the fewest number of words on each trial (see Figure 3).

A second prediction involved examining subjects' susceptibility to interference or irrelevant information. Since individuals with frontal lobe damage have demonstrated memory deficits under conditions of proactive interference (Stuss et al., 1982), it was expected that the DR-NF group would recall fewer words than either the DR-F or NR groups on the RAVL trial purported to reflect proactive interference (i.e., Trial 6). Results indicated that again the DR-F and DR-NF groups did not differ significantly from each other on this trial; but both DR groups again consistently recalled fewer words than the NR group.

Taken together, these results seem to suggest that DR children suffer some general learning deficit, at least as reflected in a verbal list-learning task. These children recalled fewer words overall on the first five trials of the RAVL than the NR children, and appeared to suffer from proactive interference. Since verbal "learning" occurs throughout both the anterior and posterior left cerebrum and the DR-NF and DR-F groups purportedly experience dysfunction within these units respectively, the findings of impaired learning are not unusual. However, in addition, these results seem to indicate that predictions involving "learning" might not be very useful in providing validation for the fluency construct.

In a third hypothesis for the RAVL task, it was predicted that the DR-NF children would demonstrate less of a recency effect across all seven of the individual recall trials. This prediction was made because Milner and her colleagues (1982, 1968) have suggested that time-marking and the assessment of temporal sequencing in list-learning and recall trials (i.e., the recency effect) requires the adequate functioning of anterior structures. To test this assertion, each list was divided into thirds. Significant differences occurred among the groups at each location. Of primary interest for the present hypothesis was the final third of each list (Location 3), the recall of which corresponds to the recency effect. Results indicated that the DR-NF group recalled significantly fewer words in Location 3 than both the DR-F and NR groups (see Figure 4). Importantly, these latter two groups did not differ significantly from each other. Thus, as predicted, the DR-NF group displayed a specific type of memory deficit associated with anterior dysfunction by displaying less of a recency effect than the DR-F and NR groups.

A second set of hypotheses was generated for the three groups on the DYN task. This task required a motor response which has long been recognized as a function of the anterior cerebrum (c.f., Stuss and

Benson, 1984), and included assessment of three phenomena: overall strength, perseveration (starting a movement and being unable to stop it), and fatigue. It was predicted that the DR-NF group would be weaker and would display greater perseveration and fatigue than the DR-F and NR groups. The results generally were in the predicted directions, but not always to a statistically significant degree. For example, the first trial of the perseveration section of the DYN was used to assess overall strength. Results indicated that as predicted, the DR-NF group was the weakest (numerically), followed by the DR-F group, and then the NR group. However, only the DR-NF and NR groups were significantly different from each other. It is noteworthy that on the second trial of the perseveration task, there were no significant differences among the three groups, but the DR-NF group squeezed harder than both the DR-F and NR groups (see Figure 5). Having the weakest squeeze on the first trial, and then squeezing the hardest on the second trial is indicative of greater perseveration by the DR-NF group.

Perseveration also was examined by generating percent change scores from the raw scores on each trial. The farther away subjects' scores were from 50%, the greater the perseveration. Again, it is clear from Figure 6 that the DR-NF group had lower percent change scores for both the right and left hands than both the DR-F and NR groups.

Finally, fatigue was examined. While the three groups did not differ significantly from each other on any of the five trials of the fatigue task, the DR-NF group consistently was the weakest (see

Figure 7). Interestingly, this task is the only one in which the NR group did not perform better than either the DR-F and DR-NF groups.

Of note, on each of the DYN tasks, a main effect was found for the hand variable. This indicated that across groups and trials, subjects' right hands were significantly stronger on the average than their left hands. This finding was to be expected in light of the fact that all subjects were required to demonstrate a right-sided lateral preference.

Overall, the DYN produced significant results in the predicted directions for the DR-NF group in terms of strength and perseveration. The ranges of the scores for all subjects on each of the trials of the fatigue task were very small which perhaps decreased the likelihood that mean differences would be found among the three groups.

A third set of specific hypotheses was made regarding the performance of the three groups on the STR and Trails tasks. Each of these tasks required concentration, vigilance, and attention--abilities which have been associated with frontal and pre-frontal cortical functioning (c.f., Stuss and Benson, 1984). Thus, in general, the DR-NF group was expected to perform more poorly than both the DR-F and NR groups over all of the trials within these tests.

In addition, each of these tasks included components on which the DR-NF group was expected to perform especially poorly. For example, the third page of the STR required subjects to attend to one perceptual set (i.e., color) while ignoring another (i.e., printed words). Failure to maintain the vigilance needed to complete this task has been associated with anterior dysfunction (Hecaen & Albert, 1975). Part B of the Trails task also required subjects to rapidly shift perceptual sets (i.e., numbers to letters), another specific anterior function.

Significant differences were found among the three groups for each trial of the STR (see Figure 8). As predicted, the DR-NF group read significantly fewer words and named significantly fewer colors than both the DR-F and NR groups. The DR-F children also read significantly fewer words than the NR children. On the critical third trial, however, only the DR-NF and NR groups differed significantly. The performance of the DR-NF and DR-F groups was not statistically different, although the DR-NF group had the fewest number of correct responses on this trial.

Failure to find significant differences between the DR-NF and DR-F groups on the third trial of the STR could be due to the fact that the fluency construct does not reliably differentiate types of DR subjects. However, it also could be the result of a floor effect related to the method in which the task was administered. As noted, the third page of the STR test requires considerable attention and vigilance to be completed. It also is the type of task with which few subjects have had any experience. Allowing only 45 seconds in which to complete this page may not have provided an adequate period of time for subjects to respond correctly and reliably. It seems reasonable to predict that as the time period is extended and all subjects become more familiar with the task, the DR-F and NR subjects will begin to increase their number of correct responses. However, it also would be expected that the DR-NF children still will suffer vigilance difficulties because of their anterior dysfunction and will not demonstrate an appreciable increase in their number of correct responses. Additional testing with a modification in administration appears warranted before conclusions from the STR can be used to evaluate the validity of the fluency construct in classifying DR children.

Finally, reliable differences were found among the three groups of subjects on the Trails test (see Figure 9). Of note, the groups did not differ significantly on Trail A, although as expected, the DR-NF group required a longer time to complete this section than either the DR-F and NR groups. Also, as predicted, the DR-NF group was significantly slower than the DR-F and NR groups on the critical Part B trial. On this section of the task which required the ability to rapidly shift perceptual sets, the DR-NF group demonstrated the poorest performance. Importantly, the DR-F and NR groups did not differ significantly from each other on this trial.

To summarize, the present investigation produced several significant findings. First, two subtypes of dyslexic readers (fluent and nonfluent) were reliably identified. As noted, the measure of verbal fluency did not correlate with IQ, reading ability, or age which suggests that it constitutes an independent construct in children.

A second important finding in the present study suggests that the verbal fluency construct can be used to classify children with the language problem of dyslexia in a manner similar to the anterior and posterior classification of language problems in adults. Preliminary validation of the construct was provided by demonstrating that the DR-NF (anterior dysfunction) children suffered specific deficits on neuropsychological tasks purported to assess anterior functioning while DR-F (posterior dysfunction) and NR children did not. Particularly noteworthy were the findings on the verbal memory test (i.e., the absence of a recency effect for the DR-NF group), the Trails test (i.e., exceptionally slow performance by the DR-NF group on the second trial of this task which requires vigilance and the ability to rapidly shift perceptual sets), and the DYN test (i.e., greater perseveration and overall weaker performance by the DR-NF group).

Although not a stated purpose of the present investigation, speculation as to why the DR-NF children demonstrated this particular cluster of anterior deficits appears warranted. A reasonable place to begin is with an examination of the nature of the neuropsychological tasks and the commonalities among them. Obviously, these tasks were selected because of their demonstrated utility in assessing anterior functioning and dysfunctioning. Interestingly, the components of each of the tasks on which the DR-NF children experienced their most significant deficits also required subjects to complete two or more anterior cortical activities concurrently.

The clearest example from the present set of neuropsychological tasks in which this simultaneous responding occurred is the second trial (Part B) of the Trails test. Subjects were required to rapidly shift from one perceptual set (numbers) to another (letters). In each case, a "memory" of the just completed connection in one domain (e.g., number 1 to number 2) had to be maintained as the corresponding connection was executed in the second domain (e.g., letter A to letter B), and so on in an alternating fashion.

The second trial of the perseveration task also required at least two simultaneous anterior responses. Subjects had to maintain the "memory" of the initial motor response (i.e., the hard squeeze), and at the same time execute a controlled motor response that was only half as hard as the initial response.

Even the trials of the RAVL can be viewed as requiring at least two responses. Specifically, subjects had to store words from the initial part of each list in memory, while attending to the remaining words at the end of each list.

Kinsbourne and his colleagues (Kinsbourne & Hiscock, 1983; Kinsbourne & Hicks, 1978) have hypothesized that in general, particular regions of the brain, such as the anterior cerebrum, are comprised of highly interconnected neuronal tissue. These interconnections allow for the economical and efficient execution of the countless variations of human responses. However, the extensive interconnections also make it difficult for individuals to complete an activity that requires two or more responses, especially if those two responses have similar neural networks (e.g., the responses required to complete Part B of the Trails test and the perseveration task). According to Kinsbourne, performance on one task will preempt the other because its neural activity overrides that of the other, or performance on neither task will be accomplished efficiently because of mutual interference.

Importantly, this dual processing model asserts that all subjects will experience some decrease in performance as the number of tasks competing for the same neural tissue within a particular region increases. In addition, if a neural region is dysfunctional prior to the presentation of a dual task (e.g., nonfluent), the effect of interference on performance may be heightened as a result of the increased neural competition for the remaining "functional space" (Kinsbourne & Hiscock, 1983).

In the present study, dual processing theory might be useful to explain the performance of the children on the two trials of the Trails test, and on the fatigue and perseveration tasks of the DYN. For example, Part A of the Trails test simply requires subjects to connect numbers consecutively. The DR-NF, DR-F, and NR groups did not differ significantly from each other in terms of the time needed to complete this trial. Subjects performed this task reasonably quickly. On Part B, however, with the increase in concurrent activities, all subjects required significantly longer times to complete the trial. The group of children who apparently suffer from anterior dysfunction (i.e., the DR-NF group) also required a significantly longer time to complete the trial than both the DR-F and NR children.

The same type of finding emerged on the DYN tasks. The three groups of children did not differ significantly from each other on any of the fatigue trials. This task simply required subjects to complete a single motor response--i.e., squeeze the dynamometer as hard as they could five times in a row. On the average, subjects responded consistently, with slight decrements in strength from one trial to the next. On the perseveration task, however, when subjects were required to complete concurrent responses, their performance was less efficient. No group was able to estimate the half-as-hard squeeze perfectly (indicating that all subjects perseverated). Again, as expected, the DR-NF group perseverated to the greatest extent.

It is essential to note, however, that the findings of the present study and their hypothesized explanation can only be considered to be preliminary. There are important limitations to the present investigation (e.g., the failure to include tasks purported to tap posterior functioning). While it was important to demonstrate that the DR-F group did not experience deficits on anterior tasks, to further validate the verbal fluency construct it also is necessary to demonstrate that this group suffers particular deficits on posterior tasks. In addition, it is essential to establish that DR-NF subjects perform better than DR-F subjects on those same posterior tasks.

Only one hypothesis was made in the present investigation regarding the performance of the DR-F group: these children were expected to display the poorest performance on the learning trials of the RAVL. This hypothesis was not supported. However, as noted, the potentially diffuse representation of verbal "learning" especially throughout the left cerebrum suggests that children with any anterior or posterior dysfunction would perform more poorly when compared to normal children.

Clearly, additional assessment should be completed and more direct hypotheses should be made regarding the performance of fluent and nonfluent dyslexic readers on tasks which have been associated with the posterior cerebrum. Specifically, this unit of the brain consists of the area posterior to the central sulcus, and includes the occipital, temporal, and parietal lobes (Luria, 1973). These cortical regions are responsible for the analysis and encoding of visual, auditory, and kinesthetic or tactile stimuli respectively. Therefore, it might be expected that DR-F children will perform more poorly than DR-NF and NR on any number of tasks associated with these areas in the left hemisphere.

For example, Gerstmann (1940) first described a syndrome characterized by a disturbance of body schema which he believed resulted from parietal lobe disease. The symptoms of the syndrome included agraphia (a disorder of writing), finger agnosia (an impairment in the ability to identify the fingers of either one's own hand or the those of another person), acalculia (a disturbance in computation), and right-left disorientation. The "Gerstmann syndrome" subsequently was recognized by neurologists as a clinical entity with localizing significance for the left posterior parietal lobe (Levin & Spiers, 1985). Consequently, it could be hypothesized that compared to DR-NF and NR children, DR-F subjects would: (1) make more errors on tasks such as writing to dictation or copying words, sentences, or paragraphs; (2) have greater difficulty identifying touched fingers without the aid of vision, and localizing touched fingers on a schematic representation of the hand; (3) present with a greater number of concomitant math achievement difficulties; and (4) make more errors on tasks such as the Map Tracing Test in which subjects are required to trace a path through a mapped city and indicate whether turns at various street corners are to the right or to the left.

DR-F children also might be expected to display deficits in particular visual or auditory processing tasks. For example, auditory stimuli typically are processed by the cortex initially in the area of the temporal lobes known as Heschel's gyrus. Dichotic listening techniques frequently are used to assess auditory processing (Benson, 1985). In dichotic listening tasks, two different auditory messages are presented concurrently to the two ears, and subjects are asked to recall what they have heard (Kimura, 1967; Duane, 1986). Stimuli generally are better recalled when presented to the ear contralateral to the hemisphere that is dominant for processing the stimuli (Benson, 1985). For most individuals, linguistic stimuli are processed most efficiently in the left hemisphere. Thus, verbal information entering the right ear is more likely to be recalled than information entering the left ear. It could be predicted that DR-F children, because of their hypothesized left posterior dysfunction, might fail to display a right ear advantage for verbal stimuli.

In addition, visual stimuli typically are processed by the cortex initially in the area of the occipital lobes known as the calcarine cortex. Tachistoscopic methods can be used to assess visual processing (c.f., McKeever, 1986). In tachistoscopic tasks, subjects are asked to fixate both eyes on a central, distant point. Very brief views of stimulus materials then can be presented either to the right or left of the fixation point, or to both sides concurrently. These presentation areas correspond to the right and left visual half-fields of humans. The right visual field (RVF) is sensed by the nasal hemiretina of the right eye and temporal hemiretina of the left eye which have projections to the left hemisphere. The left visual field (LVF) is sensed by the nasal hemiretina of the left eye and the temporal hemiretina of the right eye which have projections to the right hemisphere. Accumulating evidence suggests that verbal stimuli such as letters, words, phrases, and sentences are identified more accurately when presented to the RVF than the LVF (McKeever, 1986). Thus, it could be predicted that DR-F children, because of their hypothesized left posterior dysfunction, might make more errors in identifying verbal stimuli presented to the RVF than both DR-NF or normal children.

Finally, Luria's model (1973) suggests that most of the cognitive information processing (particularly the analysis and comprehension of sensory stimuli) occurs in the posterior cerebrum. As a result, DR-F children also might be expected to perform more poorly on the comprehension sections of reading achievement tasks and to be less aware of their problems than either DR-NF or NR groups.

Obviously, many potential hypotheses regarding the performance of the DR-F children can be generated. Additional assessment utilizing tasks which purportedly tap posterior functioning and dysfunctioning is needed to further validate the fluency construct.

Treatment Implications

Despite the limitations of the present investigation in terms of the DR-F group, the results have some direct implications for the

DR-NF group with regard to teaching, potential remediation, and other future research. First, it appears that DR-NF children have significant problems with verbal expression. The fluency test itself was an extremely difficult task for these children. Indeed, three minutes (the time required for the FAS Test) passed very slowly and uncomfortably when a child was able to generate only twelve words. Anecdotally, it was observed that the FAS Test often was identified by children from the DR-NF group as the most difficult and least-liked of all the neuropsychological tests. Many of the DR-NF subjects also seemed to acknowledge their poor performance on this task with statements such as "I have trouble with this kind of test."

If DR-NF children displayed significant expressive difficulties in this brief, structured task, and perhaps recognized that their performance was not very good, it is reasonable to conclude that similar difficulties might occur for these children in the classroom. For example, DR-NF children might be less likely to ask and answer questions in class, and thus be perceived as less interested or motivated by their teachers and parents. They also might have difficulties initiating and carrying-on conversations, and thus be less liked by their peers and viewed as shy and socially reticent by adults. In light of their problems with expression, DR-NF children also might be less responsive to remedial reading techniques which emphasize oral reading drills and social skills training which emphasizes verbal techniques. Furthermore, DR-NF children might experience significant levels of anxiety and/or depression and lower self-esteem in situations in which they are required to express themselves verbally. Certainly, the behavioral and emotional responses of these children observed by teachers and parents or reported by the children themselves in the classroom, home, and other social environments warrant further empirical investigation.

The performance of the DR-NF children on the other neuropsychological tasks also has some immediate implications for assisting these children in the classroom or at home. For example, the absence of the recency effect on the verbal memory task suggests that when DR-NF children are orally given lists or series of things to remember or do (e.g., spelling words, instructions to carry-out some activity), it is likely that they will forget the items at the ends of those lists. The lack of a recency effect also could have implications for reading. For example, DR-NF children might have problems remembering words or phrases read at the end of a sentence, paragraph, or page, which in turn, could affect their comprehension of passages or stories. In addition, the especially poor performance by the DR-NF children on Part B of the Trails test and the perseveration task suggests that these children are not able to respond efficiently when given more than one task to do at a time. Strategies such as presenting a series of instructions in a step-by-step progression, writing instructions down to be checked-off as completed, permitting multiple opportunities for practice, and dividing complex tasks into simple, single components might be useful to circumvent those deficits. These proposed strategies are not new. However, the fluency construct appears to be useful in identifying which DR children might respond to them.

Conclusions

Luria (1973, 1980) proposed that behavioral difficulties such as an inability to read despite adequate intellectual capacities, can result from dysfunction occurring anywhere throughout the three general functional units of the brain (i.e., brainstem, posterior cerebrum, and anterior cerebrum) or the specific neuronal systems within these units. In adults, a traditional way to assess language dysfunction has been to examine the anterior versus posterior units of the left hemisphere by using the construct of verbal fluency--with nonfluent output associated with anterior dysfunction, and fluent output associated with posterior dysfunction.

Clinical and statistical evidence suggest that subtypes of reading problems exist in children. It was reasonable to hypothesize that different types of reading problems in children are the result of dysfunction at different points within the functional system of reading. The general purposes of the present exploratory investigation were first to establish that DR children are significantly less fluent than NR children on a traditional measure of verbal fluency, and subsequently to determine the validity of utilizing verbal fluency as a dimension on which to classify children with the language problem of dyslexia.

The principal findings of this study indicated that fluent and nonfluent dyslexic readers could be reliably identified. In addition, preliminary validation of the verbal fluency construct was obtained by demonstrating that the DR-NF (anterior dysfunction) children suffered specific deficits on neuropsychological tasks purported to assess anterior functioning while DR-F (posterior dysfunction) and NR children did not.

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Appendix A

Human Subjects Committee Approval

Approval for this study was received on 10/27/87.

The project code number is 131-87.

Appendix B

Informed Consent Forms

PARENT/GUARDIAN CONSENT FORM

This is to certify that I, _______________, hereby give permission to have my child, _______________, participate as a volunteer in a scientific investigation entitled "Assessment of Reading Problems in Children" conducted by Rose M. Huntzinger, M.A. and David W. Harrison, Ph.D. of Virginia Polytechnic Institute and State University. The procedures to be followed are outlined below, and I have read and understand them. They are as follows:

1. I understand that my child's individual and/or group achievement and IQ scores will be obtained from school records. The scores will be used to make preliminary determination of my child's reading level.
2. I understand that my child will complete a short reading achievement test and brief intellectual assessment in one session (requiring 30-45 minutes) to verify the school's records.
3. I understand that my child then will take a group of tests in another session (lasting between 30-60 minutes) at school during regular school hours. These tests may include measures of attention, verbal fluency (expressiveness), verbal memory, hand strength, and hand dominance.
4. I understand that there are no anticipated negative effects associated with the testing.
5. I understand that if desired, a copy of the test results will be shared with my child's teacher.
6. I understand further that my child's test scores will be kept for the investigators' research purposes, but that his/her responses will remain confidential. My child's name will be removed from all data, and no one outside of the project will see the specific results of my child's testing.
7. Finally, I understand that I am free to withdraw my consent and terminate my child's participation at any time without penalty.

_______________________________ ________

Signature of Parent/Guardian Date

cont.

Note: This project has been approved by the Human Subjects Research Committee and Institutional Review Board at Virginia Polytechnic Institute and State University. Any questions about the project should be directed to:

Rose M. Huntzinger, M.A.
Graduate Research Assistant (or)

David W. Harrison, Ph.D.
Assistant Professor & Project Director
(Office Phone: 961-4422)

Stephen J. Zaccaro, Ph.D.
Chairperson, Human Subjects Committee
(Office Phone: 961-6581)

Charles D. Waring, Chairperson
Institutional Review Board
(Office Phone: 961-5284)

(Keep the duplicate copy of the consent form for your records.)

CHILD CONSENT FORM

This is to show that I, ______________, agree to participate as a volunteer in a scientific study.

1. I understand that the purpose of this study is to learn why some children might have problems learning to read.

2. I know that I will be taking some tests that will last about 30-60 minutes. I won't get a grade, and it won't matter if I don't know all of the answers. I know that my scores on these tests will not affect my school grades.

3. I understand that nothing will be done that could hurt me in this study. I also know that I can quit at any time if I decide that I don't want to be in the study any more.

______________________________ ________
Signature of the Child Date

______________________________ ________
Signature of the Investigator Date

Appendix C

Lateral Preference Demonstration

Directions:

HAND	1.	DO--place a ball at mid-line in front of the child.	SAY--"Throw (toss) the ball to me."
	2.	DO--place a pencil and a sheet of paper at mid-line in front of the child.	SAY--"Pick up the pencil and draw a circle."
	3.	DO--place an eraser and the same sheet at mid-line in front of the child.	SAY--"Pick up the eraser and erase the circle."
	4.	DO--place a pile of ten playing cards at mid-line in front of the child.	SAY--"Pick up the pile of cards and deal one to me and one to you until all the cards have been given out."
FOOT	1.	DO--place a ball in front of and mid-way between the two feet of the standing child.	SAY--"Kick the ball."
	2.	DO--have the child stand in front of a low chair. (Note--record the foot that is placed on the chair first.)	SAY--"Carefully, step up onto the chair."
	3.	DO--place a replica of an insect on the floor and mid-way between the two feet of the (standing) child.	SAY--"Stomp on the bug."

cont.

EYE	1.	DO--have the child stand in front of a door with the knob and key hole at the mid-line.	SAY--"Bend over and peep through the key hole."
	2.	DO--place an empty, dark bottle at mid-line in front of the child.	SAY--"Look into this bottle, and tell me what you see at the bottom."
	3.	DO--place a hollow tube at mid-line in front of the child.	SAY--"Look at me through this hollow tube."
EAR	1.	DO--have the child stand in front of a closed door.	SAY--"Put an ear to the door, as if you wanted to listen to people talking in the next room."
	2.	DO--out of sight of the child, turn a transistor radio on at low volume; then place the radio at mid-line in front of the child.	SAY--"Put an ear to the radio, and tell me whether or not it is turned on."

* Administer the items in a random order.

In each case, record the hand, foot, eye, and ear used by the child to perform each task. Score (+1.0) for the right side and (-1.0) for the left side.

Appendix D

FAS Test

Administration

The following instructions will be given to each child:

I AM GOING TO SAY A LETTER OF THE ALPHABET AND I WANT YOU TO SAY AS QUICKLY AS YOU CAN ALL THE WORDS YOU CAN THINK OF THAT BEGIN WITH THAT LETTER. FOR INSTANCE, IF I SAY "B," YOU MIGHT SAY "BAD, BATTLE, BED..." OR OTHER WORDS LIKE THAT. I DO NOT WANT YOU TO USE WORDS WHICH ARE PROPER NAMES (WORDS THAT BEGIN WITH A CAPITAL LETTER), SUCH AS "BOSTON, BETTY, OR BUICK." ALSO, DO NOT USE THE SAME WORD AGAIN WITH A DIFFERENT ENDING, SUCH AS "BEAT" AND "BEATING." DO YOU HAVE ANY QUESTIONS? (pause) OKAY, BEGIN WHEN I SAY THE LETTER. THE FIRST LETTER IS "F." GO AHEAD.

Timing begins immediately, with one minute allowed for each letter. If a child stops before the end of the minute, he will be encouraged to try to think of more words. If there is a silence of 15 seconds, the basic instructions and the letter are repeated. (However, no extension of the time limit is made in the event that the instructions are repeated during the course of the administration.) After the first minute, the test is continued with the letters "A" and "S," allowing one minute for each. The child's responses are recorded verbatim, and the score is the total number of acceptable words produced over the three minutes.

Appendix E

Rey Auditory Verbal Learning

Administration

TRIAL 1--INSTRUCT:

I AM GOING TO READ A LIST OF WORDS TO YOU. PLEASE LISTEN CAREFULLY. WHEN I STOP, YOU ARE TO SAY BACK AS MANY OF THE WORDS AS YOU CAN REMEMBER. SAY THE WORDS IN ANY ORDER YOU REMEMBER. JUST TRY TO REMEMBER AS MANY AS YOU CAN.

TRIAL 1--DO:

Read list A at a rate of one word per second. Put a check beside each word recalled correctly. If a child asks if he repeated a word, tell him. Otherwise, don't.

TRIAL 2--INSTRUCT:

NOW I AM GOING TO READ THE SAME LIST AGAIN. WHEN I STOP, AGAIN I WANT YOU TO TELL ME AS MANY WORDS AS YOU CAN REMEMBER, (stress) INCLUDING WORDS YOU SAID THE FIRST TIME. IT DOESN'T MATTER IN WHAT ORDER YOU SAY THEM. JUST SAY AS MANY WORDS AS YOU CAN REMEMBER WHETHER OR NOT YOU SAID THEM BEFORE.

TRIAL 2--DO:

Reread the same list for Trials 3, 4, and 5 using Trial 2 instructions. After Trial 5 read list B and instruct as on Trial 1. Next, ask for recall from the first list. Mark a check beside correctly repeated words. Write "I" (intrusion) for words not on the list.

Record Form

LIST A	A1	A2	A3	A4	A5	LIST B	B1	A1
Drum	__	__	__	__	__	Desk	__	__
Curtain	__	__	__	__	__	Ranger	__	__
Bell	__	__	__	__	__	Bird	__	__
Coffee	__	__	__	__	__	Shoe	__	__
School	__	__	__	__	__	Stove	__	__
Parent	__	__	__	__	__	Mountain	__	__
Moon	__	__	__	__	__	Glasses	__	__
Garden	__	__	__	__	__	Towel	__	__
Hat	__	__	__	__	__	Cloud	__	__
Farmer	__	__	__	__	__	Boat	__	__
Nose	__	__	__	__	__	Lamb	__	__
Turkey	__	__	__	__	__	Gun	__	__
Color	__	__	__	__	__	Pencil	__	__
House	__	__	__	__	__	Church	__	__
River	__	__	__	__	__	Fish	__	__
TOTALS:	__	__	__	__	__		__	__

Appendix F

Dynamometer Task

Administration--Perseveration

INSTRUCT: I WANT YOU TO SQUEEZE THIS AS HARD AS YOU CAN WITH YOUR RIGHT HAND, AND THEN I AM GOING TO ASK YOU TO SQUEEZE IT JUST HALF AS HARD.

DO: Test right hand with scale turned away from the subject.

INSTRUCT: NOW I WANT YOU TO DO THE SAME THING WITH YOUR LEFT HAND.

DO: Test left hand with scale turned away from the subject.

Administration--Strength and Fatigue

INSTRUCT: NOW I WANT YOU TO SQUEEZE IT AS HARD AS YOU CAN WITH YOUR RIGHT HAND FIVE TIMES. I WILL TAKE A READING AFTER EACH TRIAL.

DO: Keep scale turned away from the subject, score, and reset scale for the five trials.

INSTRUCT: NOW I WANT YOU TO SQUEEZE IT AS HARD AS YOU CAN WITH YOUR LEFT HAND FIVE TIMES.

DO: Keep scale turned away from the subject, score, and reset scale for the five trials.

DYNAMOMETER DATA RECORD

RIGHT __________; RIGHT (1/2) __________.

LEFT __________; LEFT (1/2) __________.

TRIAL	RIGHT HAND	TRIAL	LEFT HAND
1	__________	1	__________
2	__________	2	__________
3	__________	3	__________
4	__________	4	__________
5	__________	5	__________

Appendix G

Stroop Test

INSTRUCTIONS--PAGE 1

THIS IS A TEST OF HOW FAST YOU CAN READ THE WORDS ON THIS PAGE. AFTER I SAY BEGIN, YOU ARE TO READ DOWN THE COLUMNS STARTING WITH THE FIRST ONE UNTIL YOU COMPLETE IT AND THEN CONTINUE WITHOUT STOPPING DOWN THE REMAINING COLUMNS IN ORDER. IF YOU FINISH ALL THE COLUMNS BEFORE I SAY "STOP," THEN RETURN TO THE FIRST COLUMN AND BEGIN AGAIN. REMEMBER, DO NOT STOP READING UNTIL I SAY "STOP." READ OUT LOUD AS QUICKLY AS YOU CAN. IF YOU MAKE A MISTAKE, I WILL SAY "NO" TO YOU. CORRECT YOUR ERROR AND CONTINUE WITHOUT STOPPING ARE THERE ANY QUESTIONS?

READY? THEN BEGIN.

STOP (after 45 seconds).

ANSWERS:

RED	BLUE	GREEN	RED	BLUE
GREEN	GREEN	RED	BLUE	GREEN
BLUE	RED	BLUE	GREEN	RED
GREEN	BLUE	RED	RED	BLUE
RED	RED	GREEN	BLUE	GREEN
BLUE	GREEN	BLUE	GREEN	RED
RED	BLUE	GREEN	BLUE	GREEN
BLUE	GREEN	RED	GREEN	RED
GREEN	RED	BLUE	RED	BLUE
BLUE	GREEN	GREEN	BLUE	GREEN
GREEN	RED	BLUE	RED	RED
RED	BLUE	RED	GREEN	BLUE
GREEN	RED	BLUE	RED	GREEN
BLUE	BLUE	RED	GREEN	RED
RED	GREEN	GREEN	BLUE	BLUE
BLUE	BLUE	RED	GREEN	RED
RED	GREEN	BLUE	RED	GREEN
GREEN	RED	GREEN	BLUE	BLUE
RED	BLUE	RED	GREEN	RED
GREEN	RED	GREEN	BLUE	GREEN

INSTRUCTIONS--PAGE 2

THIS IS A TEST OF HOW FAST YOU CAN NAME THE COLORS ON THIS PAGE. YOU WILL COMPLETE THIS PAGE JUST AS YOU DID THE PREVIOUS PAGE, STARTING WITH THE FIRST COLUMN. REMEMBER TO NAME THE COLORS OUT LOUD AS QUICKLY AS YOU CAN.

READY? THEN BEGIN.

STOP (after 45 seconds).

ANSWERS:

BLUE	RED	BLUE	GREEN	RED
RED	BLUE	GREEN	RED	BLUE
GREEN	GREEN	RED	BLUE	GREEN
BLUE	RED	BLUE	GREEN	RED
GREEN	GREEN	RED	RED	BLUE
RED	BLUE	GREEN	BLUE	GREEN
GREEN	GREEN	RED	GREEN	RED
RED	RED	BLUE	RED	BLUE
BLUE	BLUE	GREEN	BLUE	GREEN
RED	RED	RED	GREEN	BLUE
BLUE	BLUE	GREEN	BLUE	GREEN
GREEN	GREEN	BLUE	RED	RED
RED	BLUE	RED	BLUE	BLUE
GREEN	GREEN	GREEN	RED	GREEN
BLUE	RED	BLUE	GREEN	RED
GREEN	GREEN	GREEN	BLUE	BLUE
BLUE	RED	RED	GREEN	RED
RED	BLUE	BLUE	RED	GREEN
GREEN	RED	GREEN	BLUE	BLUE
BLUE	GREEN	BLUE	RED	RED

INSTRUCTIONS--PAGE 3

THIS PAGE IS LIKE THE PAGE YOUR JUST FINISHED. I WANT YOU TO NAME THE COLOR OF THE INK THE WORDS ARE PRINTED IN, IGNORING THE WORD THAT IS PRINTED IN EACH ITEM. FOR EXAMPLE (point to the first item of the first column), THIS IS THE FIRST ITEM: WHAT WOULD YOU SAY? If the subject is correct, go on with the instructions. If incorrect say, NO, THAT IS THE WORD THAT IS SPELLED THERE. I WANT YOU TO SAY THE COLOR OF THE INK THE WORD IS PRINTED IN. NOW, WHAT WOULD YOU SAY TO THIS ITEM (point to the same item)? THAT'S CORRECT. (Point to the second item.) WHAT WOULD THE RESPONSE BE TO THIS ITEM? If correct, proceed; if incorrect, repeat the same instructions outlined above as many times as necessary until the subject understands or it becomes clear that it is impossible to go on.

YOU WILL DO THIS PAGE JUST LIKE THE OTHERS, STARTING WITH THE FIRST COLUMN AND THEN GOING ON TO AS MANY COLUMNS AS YOU CAN. REMEMBER, IF YOU MAKE A MISTAKE, JUST CORRECT IT AND GO ON.

READY? THEN BEGIN.

STOP (after 45 seconds).

ANSWERS:

BLUE	RED	BLUE	GREEN	RED
RED	BLUE	GREEN	RED	BLUE
GREEN	GREEN	RED	BLUE	GREEN
BLUE	RED	BLUE	GREEN	RED
GREEN	GREEN	RED	RED	BLUE
RED	BLUE	GREEN	BLUE	GREEN
GREEN	GREEN	RED	GREEN	RED
RED	RED	BLUE	RED	BLUE
BLUE	BLUE	GREEN	BLUE	GREEN
RED	RED	RED	GREEN	BLUE
BLUE	BLUE	GREEN	BLUE	GREEN
GREEN	GREEN	BLUE	RED	RED
RED	BLUE	RED	BLUE	BLUE
GREEN	GREEN	GREEN	RED	GREEN
BLUE	RED	BLUE	GREEN	RED
GREEN	GREEN	GREEN	BLUE	BLUE
BLUE	RED	RED	GREEN	RED
RED	BLUE	BLUE	RED	GREEN
GREEN	RED	GREEN	BLUE	BLUE
BLUE	GREEN	BLUE	RED	RED

Appendix H

Trail Making Test

Administration--Trails A

(Sample) YOU SEE HERE ON THE PAPER THAT THERE ARE NUMBERS INSIDE OF CIRCLES. WHAT I WANT YOU TO DO IS CONNECT ALL THESE NUMBERS WITH ONE LINE. START HERE AT #1, THEN GO TO #2, FROM #2 TO #3 (demonstrate for the subject), AND SO ON IN ORDER UNTIL YOU REACH THE END AT #8 (point to it). DO IT AS QUICKLY AS YOU CAN. READY? GO.

Begin timing as soon as the subject starts attending to the task. Record time in seconds and errors in parentheses. If the subject completes the sample correctly, and in a manner which shows that he knows what to do, continue with Part A. If he does not, repeat the instructions, take his hand and guide his pencil (eraser end down) through the trail. Then have him do it by himself with pencil point down. If he succeeds this time, go on to Part A. If not, repeat the procedure again until he does succeed, or it becomes evident that he cannot do it.

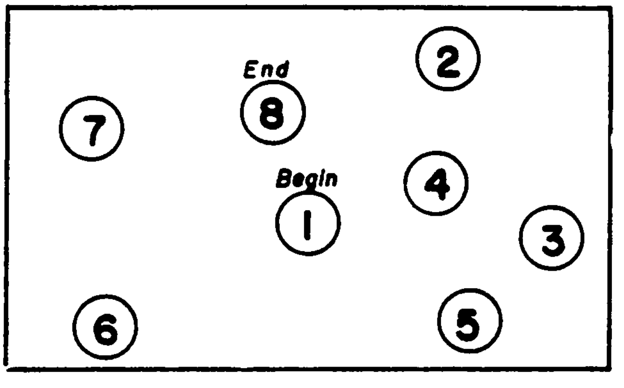
(Part A) I WANT YOU TO DO THE SAME THING ON THIS PAGE, THERE ARE JUST MORE NUMBERS. START HERE (point) AT #1 AND DRAW A LINE TO #2, FROM #2 TO #3, FROM #3 TO #4 AND SO ON UNTIL YOU REACH THE END AT #25 (point). DO IT AS QUICKLY AS YOU CAN. READY? GO.

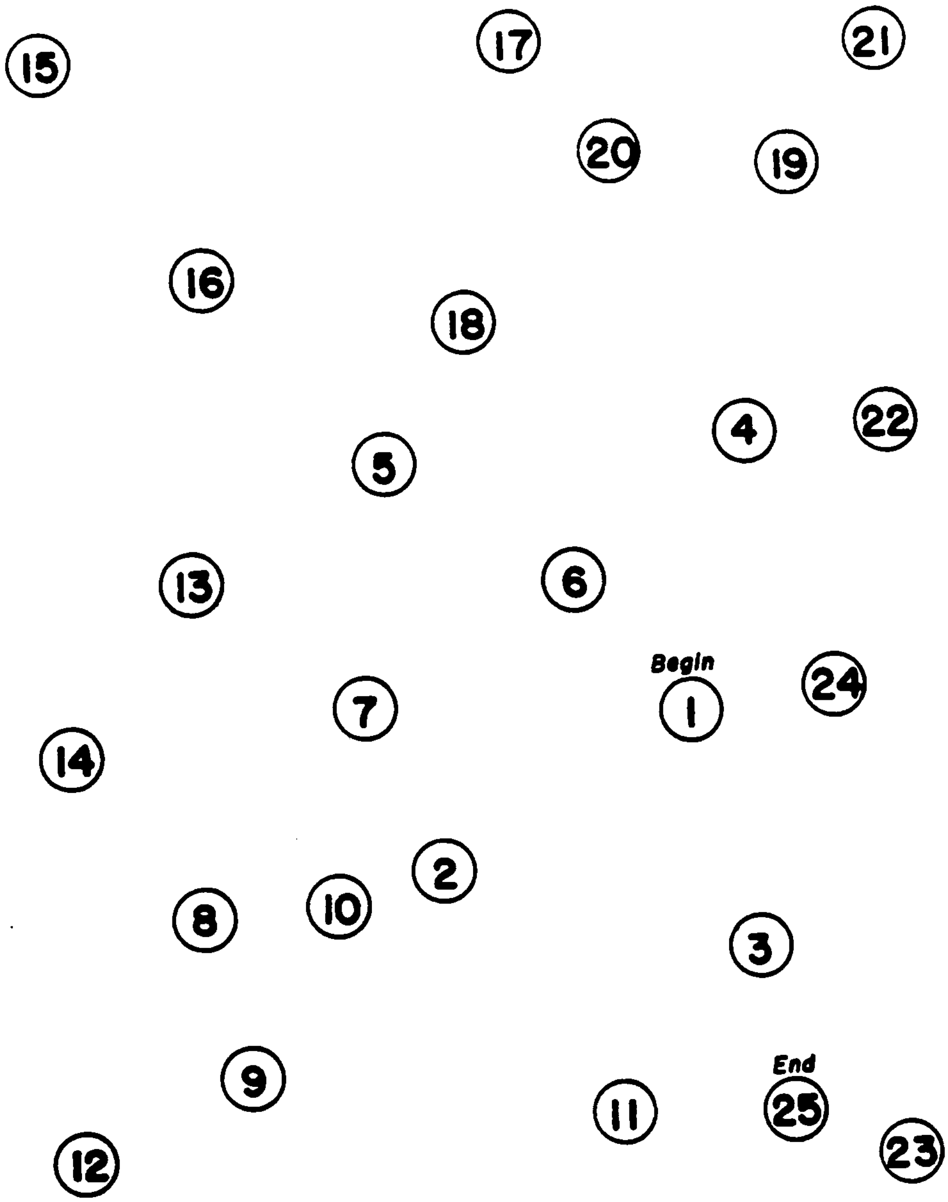
Begin timing as soon as the subject starts attending to the task. If he makes an error, call it to his attention immediately, and have him put his pencil back to the point immediately preceding the mistake. Help him to understand and correct his mistake and to continue with the task. When the subject completes the task, remove the test sheet, record the time in seconds and the number of errors in parentheses. If the subject does not complete the task within 5 minutes, discontinue at that point.

TRAIL MAKING

Part A

SAMPLE




Begin
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
End
25

Administration--Trails B

(Sample) THIS ONE IS A LITTLE DIFFERENT BECAUSE THERE ARE BOTH NUMBERS AND LETTERS. THIS TIME I WANT YOU TO START WITH #1 AND GO TO THE FIRST LETTER A, THEN TO #2 AND THE SECOND LETTER B, THEN TO THE #3 AND THE THIRD LETTER C (demonstrate for the subject) AND SO ON UNTIL YOU REACH THE END AT LETTER D. JUST LIKE YOU COUNT AND SAY THE ALPHABET--BACK AND FORTH BETWEEN THE TWO. DO IT AS QUICKLY AS YOU CAN. READY? GO.

Begin timing as soon as the subject starts attending to the task. Record the time in seconds and errors in parentheses. If the subject completes the sample correctly, and in a manner which shows that he knows what to do, continue with Part B. If he does not, proceed as instructed in Trails A.

(Part B) I WANT YOU TO DO THE SAME THING ON THIS PAGE. THERE ARE JUST MORE NUMBERS AND LETTERS. START HERE AT #1 AND GO TO THE FIRST LETTER A, THEN #2 AND THE SECOND LETTER B, THEN TO #3 AND THE THIRD LETTER C (demonstrate for the subject) AND SO ON UNTIL YOU REACH THE END (point) AT #13. FIRST GO TO A NUMBER AND THEN THE CORRESPONDING LETTER. DO IT AS QUICKLY AS YOU CAN. READY? GO.

Begin timing as soon as the subject starts attending to the task. Record the time in seconds and errors in parentheses. If the subject makes an error, call it to his attention immediately and have him put his pencil back to the point where the mistake occurred. Help him to understand and correct his mistake and to continue with the task by repeating instructions or saying any of the following:

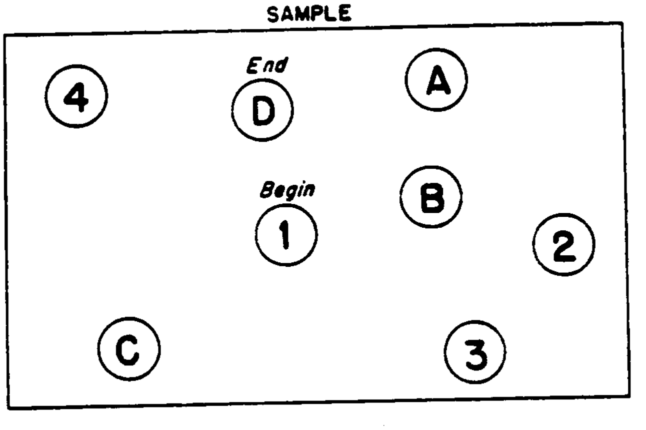
1. DO YOU WANT TO GO TO A NUMBER OR A LETTER?
2. WHAT WAS THE LAST NUMBER (LETTER)?
3. WHICH NUMBER (LETTER) COMES NEXT?
4. COUNT (OR SAY THE ALPHABET) AND SEE WHAT COMES NEXT.
5. THIS IS A NUMBER (LETTER); YOU SHOULD GO TO A LETTER (NUMBER) NEXT.

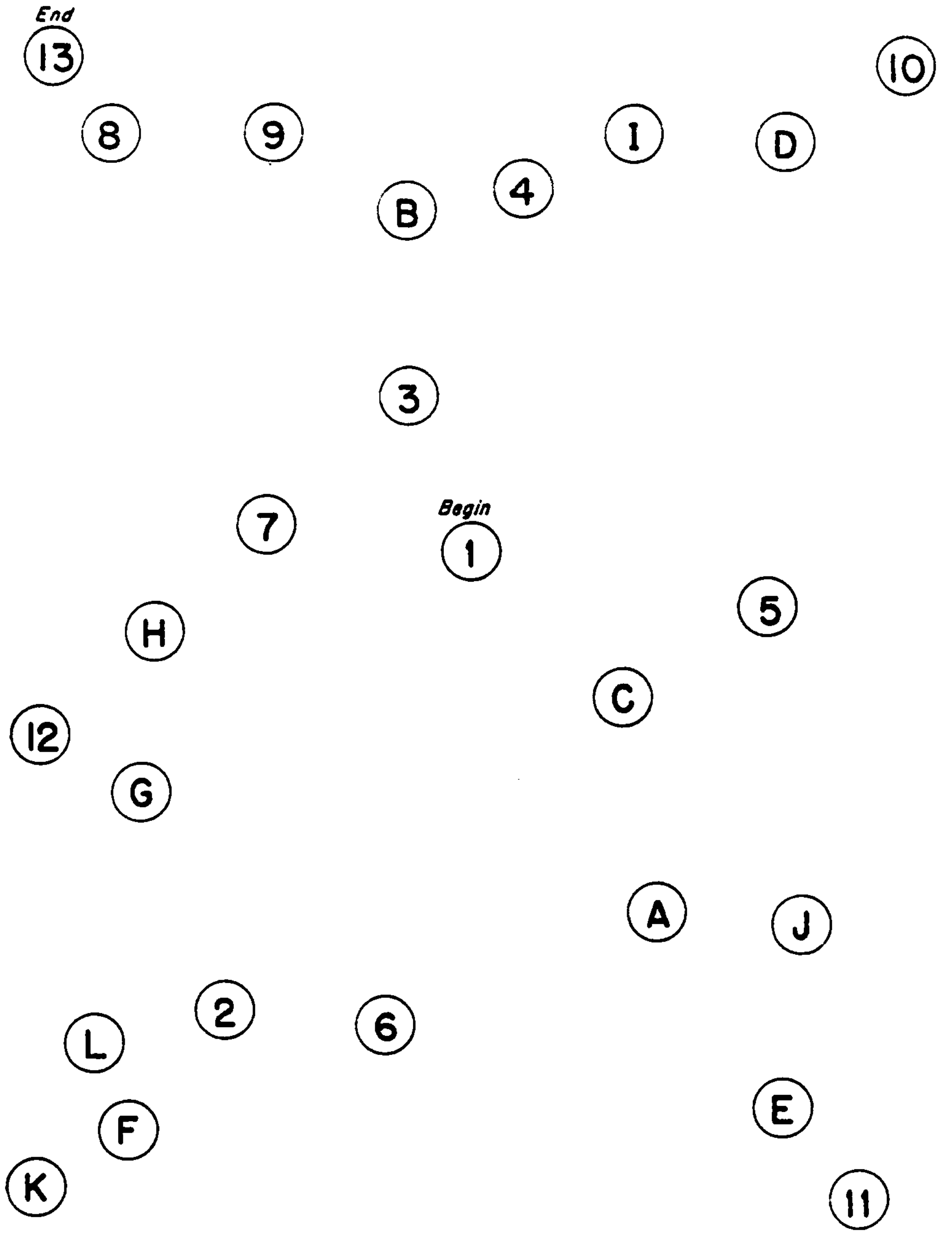
If the subject does not complete the task within 5 minutes, discontinue at that point.

TRAIL MAKING

Part B

SAMPLE




End
13
8
9
10
I
D
4
B
3
Begin
1
7
5
H
C
12
G
A
J
2
6
L
E
F
K
11

APPENDIX I

Separate ANOVAs were conducted on the classification variables of IQ and FAS. The results indicate that the DR-NF, DR-F, and NR groups differ reliably on these two tasks. Post hoc comparisons using Duncan's MRT at the .05 level of significance revealed that while the DR-NF and DR-F groups did not differ significantly from each other in terms of IQ performance, both differed significantly from the NR group. Of note, children from the DR-NF group earned the lowest IQ scores. On the FAS test, the DR-F and NR groups did not differ significantly from each other. However, both of these groups differed reliably from the DR-NF group which generated the fewest number of responses.

These findings have important implications for the DR-NF group and the use of verbal fluency as the variable on which to classify the DR children. Specifically, the DR-NF children earned the lowest IQ scores and generated the fewest number of responses on the verbal fluency task. It was assumed that the DR-NF children performed more poorly than the DR-F and NR children on the FAS test because they are "nonfluent." However, an alternative explanation could be that they simply have lower intellectual capabilities. Indeed, the extent to which IQ correlates with all of the dependent variables thought to be reflective of anterior dysfunction (and thus thought to provide validation for the fluency construct) must be determined.

Correlation coefficients were calculated for all subjects (n = 57) using those variables which were purported to tap anterior dysfunction and which later were found to provide support for the validity of verbal fluency. These variables included: Location 3 from the RAVL task (corresponding to the recency effect), the hard and half-as-hard trials for each hand from the DYN perseveration task, the third page from the STR task (in which subjects are asked to name colors while ignoring printed words), and Part B from the Trails Test (in which subjects are required to rapidly shift from numbers to letters). Total scores from the FAS test also were included in the correlation matrix. Results from these additional analyses reveal that IQ scores do correlate significantly with FAS total scores, and also with Location 3 from the RAVL test and Part B from the Trails test (see Table 7).

In light of these findings, an ANACOVA was conducted using group as the independent factor, the FAS scores as the dependent variable, and IQ as the covariate. A significant difference was found among the groups for this variable, $\underline{F}(2,53) = 41.37$, $\underline{p} < .0001$. This indicates that when the mean FAS scores are adjusted for each group to remove the effects of IQ, there is still a reliable difference among the groups. Post hoc pairwise comparisons using the adjusted means and generalized studentized range distribution (Kirk, 1982) revealed that the DR-F and NR groups did not differ significantly from each other. However, both of these groups differed significantly from the DR-NF group. The results of this ANACOVA suggest that verbal fluency is not merely a product of general aptitude (i.e., IQ) and therefore can be used as a variable on which to classify dyslexic readers.

Table 7. Intercorrelations Among Selected Classification and Neuropsychological Variables for All Subjects

TABLE 7

Intercorrelations Among Selected Classification and Neuropsychological Variables for All Subjects

	VARIABLE	1	2	3	4	5	6	7	8	9	10
1.	AGE	—									
2.	W-J	-.139	—								
3.	IQ	-.275*	.824§	—							
4.	LOC3	.093	.487§	.344*	—						
5.	RHARD	.543§	.151	.062	.161	—					
6.	RHALF	.373§	-.056	-.196	.044	.587§	—				
7.	LHARD	.503§	.095	.024	.066	.844§	.478§	—			
8.	LHALF	.328*	-.070	-.235	-.046	.460§	.640§	.539§	—		
9.	STR3	.322*	.429§	.176	.319*	.170	-.015	.091	.034	—	
10.	TRAILB	-.278*	-.418§	-.359§	-.406§	-.313*	-.004	-.259*	.002	-.337*	—
11.	FASTOTAL	.125	.597§	.506§	.495§	.102	-.112	.108	-.117	.451§	-.417§

* $p < .05$ § $p < .01$

It also is noteworthy that significant correlations were found between IQ and Location 3 from the RAVL test, and between IQ and Part B of the Trails test. Results from the mixed ANOVAs calculated on these RAVL and Trails test data indicated that as predicted, DR-NF children demonstrated less of a recency effect (reflected by low scores on the Location 3 measure) and required significantly longer periods of time to complete the number/letter connections on Part B of the Trails test than both the DR-F and NR children. It was concluded that the DR-NF group experienced a specific type of verbal memory deficit and an inability to rapidly shift from one perceptual set to another, both indicative of anterior dysfunction. However, before it can be established that these results do indeed provide support for the fluency construct, it will be necessary to conduct additional ANACOVAs to control for the potentially confounding effects of IQ.

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