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# Testing a five factor model of visual-spatial, motor, and psychomotor functioning and a three factor model of verbal functioning in learning-disabled children.

Joanna Margaret. Hamilton
*University of Windsor*

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# TESTING A FIVE FACTOR MODEL OF VISUAL-SPATIAL, MOTOR, AND PSYCHOMOTOR FUNCTIONING AND A THREE FACTOR MODEL OF VERBAL FUNCTIONING IN LEARNING-DISABLED CHILDREN

by

Joanna M. Hamilton

B.Sc. Trent University, 1985
M.A. University of Windsor, 1989

A Dissertation
Submitted to the Faculty of Graduate Studies
Through the Department of Psychology
in Partial Fulfillment of the
Requirements for the Degree of
Doctor of Philosophy at the
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*For Stewart and Emily*

# ABSTRACT

A series of three studies was conducted in order to continue investigations into the construct validity of a modified Halstead-Reitan Neuropsychological Battery (HRNB) in children. Factors of motor, psychomotor, visual-spatial, and language ability were investigated in two groups of learning-disabled children in order to determine: (1) their predictive validity; (2) the existence of a potential hierarchical arrangement of abilities within the motor and visual-spatial factors; and (3) the exact nature of the language factors. Results obtained from investigations of the predictive validity of the factors revealed that a combination of factors representing primary neuropsychological assets and deficits (as outlined in the NLD model proposed by Rourke, 1991) best discriminated between the groups and predicted group membership.

Although the existence of a hierarchical arrangement of the motor and visual-spatial factors could not be fully established, there was partial evidence to suggest that these factors of cognitive functioning were arranged in a manner beginning with primary neurocognitive skills followed by measures demanding more integrative (and complex) processing abilities.

Investigation into the nature of the language factors revealed that at least two different areas of verbal ability are assessed by the modified version of the HRNB in children. The first factor represents those more rote, overlearned language skills, whereas the second factor measures novel language processing, including auditory perception and phonemic analysis.

The results obtained from these three studies were discussed with respect to the NLD model and results obtained from earlier research. Implications for remediation were presented as were suggestions for future research in this area.

# ACKNOWLEDGEMENTS

This dissertation could not have been completed without input and guidance from several individuals. I wish to thank everyone who helped in this process.

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Completing a dissertation "long distance" presents special challenges that are more easily overcome with the help of friends. Thank you to all my friends in Windsor and other parts of Canada who provided lodging, food, moral support, input, and reinforcement.

Special thanks are also extended to my family for their encouragement and continued belief in me. I am also grateful to my extended family in England who have always taken tremendous interest in my endeavours.

Maintaining the balance between the demands of graduate school and the rest of life is never an easy task. I would like to express my love and thanks to my "little leveller", Emily, who helped me maintain that balance by constantly reminding me that there is so much more to life than research and writing.

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# CHAPTER I

# INTRODUCTION

Over the past twenty years Rourke and his colleagues have been investigating a subtype of learning disabled children who have been labelled as having "nonverbal learning disabilities" (NLD; Brandys & Rourke, 1991; Ozols & Rourke, 1988; Rourke, 1975, 1976a, 1976b, 1978, 1981, 1983, 1985, 1988a; Rourke, Dietrich, & Young, 1973; Rourke & Finlayson, 1978; Rourke & Strang, 1978; Rourke & Telegdy, 1971; Rourke, Young, & Flewelling, 1971; Strang & Rourke, 1983). These children have outstanding deficits in visual-spatial-organizational, tactile-perceptual, psychomotor, and nonverbal problem-solving skills in the presence of exceptional strengths in rote verbal and psycholinguistic skills. In addition to exhibiting specific impairments in mechanical arithmetic skills, difficulties in psychosocial functioning are also observed (Casey, Rourke, & Picard, 1991; Del Dotto, Fisk, McFadden, & Rourke, 1991; DeLuca, Rourke, & Del Dotto, 1991; Ozols & Rourke, 1985, 1991; Rourke, 1988b, 1993; Rourke, Del Dotto, Rourke, & Casey, 1990; Rourke & Finlayson, 1978; Rourke & Fisk, 1988; Rourke & Fuerst, 1991; Rourke & Strang, 1978; Rourke, Young, & Leenaars, 1989; Strang & Rourke, 1983, 1985a, 1985b).

Rourke (1982, 1987, 1988b, 1989; Rourke & Fisk, 1988) has proposed a developmental neuropsychological model as an explanation for the phenomena of NLD. This model, derived from a theoretical position advanced by Goldberg and Costa (1981), is designed to account for the entire range of cognitive abilities and disabilities exhibited by an individual, as well as the three principal axes of brain-behavior relationships, "namely, the progression from lower to higher centres, that from the posterior regions of the cerebrum to the anterior regions, and the right-hemisphere → left-hemisphere progression" (Rourke, 1989, p. 60). The main theoretical tenets of this model that explain the phenomena of NLD in children include the following: the amount of white matter destruction or dysfunction; the developmental stage of destruction or dysfunction; and the development and maintenance of learned behavior. Therefore, destruction or dysfunction of white matter responsible for intermodal integration is considered to be the underlying neurological mechanism necessary for the manifestation of the NLD syndrome (Rourke, 1989).

Although the pattern of adaptive strengths and weaknesses exhibited by children with NLD syndrome has been well documented, diagnosis relies on a comprehensive examination of their neuropsychological abilities. Neuropsychological assessment is a sophisticated and comprehensive method of examining brain-behavior relationships which has been developed and refined during the second half of this century. Along with this development, there comes a need to better understand the instruments used as assessment tools. Information about the psychometric properties of an assessment battery, and its structural content, is important in providing adequate knowledge about the measures under consideration.

Recent confirmatory factor analytic studies examining the structural content of neuropsychological tests administered to children have suggested the possibility of a hierarchical arrangement of motor, psychomotor, and visual-spatial abilities (Francis, Fletcher, Rourke, & York, 1992) and revealed a differentiation between semantic and acoustic language and verbal abilities (Davidson, 1992). If, in fact, the motor and psychomotor factors are hierarchical in arrangement and if the language factors represent different verbal processing skills, then specific, and predictable, implications derived from the NLD model should be supported.

In the following sections, investigations leading to the development of the NLD model will be reviewed, followed by a presentation of the model. Studies investigating implications of this model will also be presented. Results of recent confirmatory factor analytic studies of a modified Halstead-Reitan Neuropsychological Battery for Children will then be reviewed. Finally, the purpose and design of the present study will be described.

## Neuropsychological significance of patterns of academic achievement: The advent of NLD

The NLD syndrome was identified through a series of studies conducted by Rourke and his associates focusing on the differentiation of groups of learning disabled children based on their patterns of academic performance.

This area of research emerged from studies investigating the relationship between selected neuropsychological measures and discrepancies between Verbal and Performance Intelligence Quotients (VIQ and PIQ, respectively) on the Wechsler Intelligence Scale for Children (WISC; Wechsler, 1949). On the basis of observations that, in adults, left-hemisphere lesions are associated with low VIQ scores and right-hemisphere lesions are associated with low PIQ scores, it was hypothesized that children who showed selective impairment on the Verbal or Performance subtests of the WISC would also demonstrate impairment of the left or right cerebral hemispheres, respectively. In order to test this hypothesis, behavioral measures known to reflect the functional integrity of the cerebral hemispheres were utilized.

Rourke, Young, & Flewelling (1971) investigated the relationship between VIQ and PIQ discrepancies and the performance of children on measures of verbal, auditory-perceptual, visual-perceptual, and problem-solving abilities. All children were between the ages of 9- and 14-years-old and had been referred for neuropsychological assessment because of suspected learning disabilities. They met the standard criteria for "learning disabilities" used in Rourke's laboratory (Rourke, 1975, 1978) which is as follows: they were markedly deficient in at least one school subject area; their WISC Full Scale IQs (FSIQ) were within the roughly normal range; they were free from primary emotional disturbance; they possessed normal visual and auditory acuity; there was no evidence of socioeconomic deprivation; they had attended school regularly since the age of 5 1/2 or 6 years; and English was their native language. Ninety subjects were divided into three groups based on the nature of their VIQ-PIQ discrepancy. The first group (HP-LV) consisted of those subjects whose PIQ exceeded their VIQ by at least 10 points. The second group (V=P) was composed of subjects whose VIQ and PIQ were within four points of each other. The third group (HV-LP) was made up of subjects whose VIQ was at least 10 points higher than their PIQ. The three groups did not differ from each other with respect to their age or FSIQ.

As expected, the performance level of the HV-LP group exceeded the HP-LV group on the verbal, language, and auditory-perceptual measures, and the performance of the HP-LV group was superior to the HV-LP group on measures of visual-perceptual abilities. The performance of the V=P group fell between the other two groups on most of the dependent measures. Although the difference was not significant, the HP-LV group performed in a superior manner to the HV-LP group on a measure of nonverbal problem-solving ability.

Of particular interest were two additional findings. First, the HV-LP group performed well on the Trail Making Test (TMT), Part B, relative to Part A (Reitan & Davison, 1974), whereas the HP-LV performed better on TMT Part A, relative to Part B. It was suggested that the subjects in the HV-LP group performed better on TMT Part B relative to Part A because they were more adept at the complex verbal and symbolic processing abilities necessary for success on this measure despite their relative deficiencies on visual-perceptual measures. Secondly, an *a posteriori* comparison of the Wide Range Achievement Test (WRAT; Jastak & Jastak, 1965) performance of the three groups revealed that the HV-LP scored significantly higher on the Reading and Spelling subtests than on the Arithmetic subtest. On the other hand, the HP-LV group showed a trend (although non-significant) towards higher scores on the Arithmetic subtest in comparison to scores on the Reading and Spelling subtests. The results of this study indicated that the relationship between WISC VIQ and PIQ was of greater importance than the overall level of psychometric intelligence when assessing older learning-disabled children.

Further examination of these three groups of children was conducted using measures of motor and psychomotor abilities (Rourke & Telegdy, 1971). Children who exhibited a HP-LV pattern were superior to the other two groups on most of the measures of complex motor and psychomotor abilities. This was most evident on a measure of complex psychomotor abilities (Grooved Pegboard Test; Kløve, 1963). Although the HP-LV and HV-LP groups did not differ in terms of differential hand superiority on the measures utilized, as was hypothesized, there was support for the expectation that the HP-LV group would exhibit superior performance on tasks involving complex visual-motor coordination and spatial visualization and memory, due to their demonstrated superiority on visual-spatial measures.

Developmental implications of VIQ-PIQ discrepancies were also examined (Rourke et al., 1973). In this study, 82 learning-disabled children, aged between 5- and 8-years-old were divided into three groups using the same criteria as set out by Rourke et al. (1971) and Rourke and Telegdy (1971). The three groups were matched for FSIQ (which ranged from 79 to 120) and for age. The measures employed in this study were similar to those used in the previous two studies and included verbal, auditory-perceptual, visual-perceptual, problem-solving, motor, and psychomotor tests. Unlike the results of the previous studies, few significant differences were evident in the patterns of performance exhibited by the three groups of children, although the pattern of group differences on measures of verbal, auditory-perceptual, visual-perceptual, and problem-solving tests were similar to that observed by Rourke et al. (1971). Despite this trend, the absence of any strong indications of motor and psychomotor patterns, coupled with the large variability in performance exhibited by the younger children, made it difficult to determine any meaningful developmental patterns.

The results of these three studies suggested that VIQ-PIQ discrepancies on the WISC reflected the differential functional integrity of the two cerebral hemispheres, particularly in older learning-disabled children. The HV-LP group performed in a superior manner to the HP-LV group on tasks measuring abilities thought to be subserved primarily by the left cerebral hemisphere, while the HP-LV group was superior on tasks measuring abilities ordinarily thought to be subserved by the right cerebral hemisphere. When the results from the Rourke et al. (1973) study were also considered, it was apparent that further examination of the differential integrity of the left- and right-cerebral hemispheres should utilize older children as subjects, as younger children do not exhibit patterns of neuropsychological functioning that are as clear as those seen in older children. This is most likely due to their developmental stage of functioning.

One particularly interesting finding from the Rourke et al. (1971) and Rourke and Telegdy (1971) studies was the fact that older learning-disabled children who exhibited differential patterns of VIQ-PIQ discrepancies also exhibited differential patterns of performance on the WRAT Reading, Spelling, and Arithmetic subtests. Since this performance appeared to be related to different patterns of neuropsychological abilities and deficits, further indepth investigation of groups of learning-disabled children exhibiting these patterns of performance was conducted (Rourke & Finlayson, 1978; Rourke & Strang, 1978; Strang & Rourke, 1983).

At this point it should be noted that during the investigation of these groups of learning-disabled children and the development of the NLD model, the descriptive labels applied to the groups were changed in order to provide a classification term representative of their specific patterns of academic performance on the WRAT. In the initial series of studies (Rourke & Finlayson, 1978; Rourke & Strang, 1978; Strang & Rourke, 1983) they were referred to as Group 1, Group 2, and Group 3 children. However, these labels were changed to Group R-S-A, Group R-S, and Group A, respectively, as the NLD model developed. For the ease of the current presentation the latter designations will be utilized, even though they were not used in the earlier studies.

In the series of investigations of the relationship between differential patterns of academic functioning and neuropsychological performance, three groups of children (two in the Strang & Rourke, 1983, study), aged between 9- and 14-years, were utilized. They were selected on the basis of their performance patterns on the WRAT Reading, Spelling, and Arithmetic subtests (15 children in each group). Group R-S-A children were defined as those who exhibited uniform deficiencies on all three subtests. Their grade-equivalent scores were at least 2.0 years below their expected grade placement on each subtest. The centile scores for these three subtests did not exceed 18, nor was there more than a 0.9 year grade-equivalent discrepancy between any two of the three WRAT subtests. Group R-S children had deficient Arithmetic scores but even more deficient scores on the Reading and Spelling subtests. The WRAT Reading and Spelling subtest grade-equivalent scores were at least 1.8 years below their WRAT Arithmetic grade-equivalent score, and centile scores for the three subtests did not exceed 14. The children in Group A exhibited normal Reading and Spelling subtest scores, but performed at impaired levels on the Arithmetic subtest. Their grade-equivalent score on the Arithmetic subtest was at least 2.0 years below the grade-equivalent scores for Reading and Spelling. All three groups had deficient scores on the Arithmetic subtest, relative to age-based norms; however, Groups R-S and A were superior to

Group R-S-A on this subtest and did not differ from each other. All three groups were equated for age and FSIQ.

In the first study of this series, Rourke and Finlayson (1978) compared the three groups on various measures of verbal and visual-spatial abilities. The results of this study indicated that Group A children exhibited superior performances, relative to both Groups R-S-A and R-S, on measures of verbal and auditory-perceptual functioning, but were deficient, relative to Groups R-S-A and R-S, on measures of visual-perceptual and visual-spatial ability. The pattern of Group R-S children was the reverse of the Group A children, in that Group R-S children were deficient on measures of verbal and auditory-perceptual functioning, while exhibiting strengths on measures of visual-perceptual and visual-spatial skills. Group R-S-A children performed in a manner similar to Group R-S children. With respect to VIQ-PIQ discrepancies, it was noted that all subjects in Group R-S-A had a lower VIQ than PIQ, 14 of the 15 subjects in Group R-S had a lower VIQ than PIQ (with the remaining subject having equivalent IQ scores), and that all Group A children exhibited a higher VIQ than PIQ score.

The results of the Rourke and Finlayson (1978) study indicated that children in Groups R-S-A and R-S performed in a manner similar to that expected from groups of older learning-disabled children who exhibited a pattern of HP-LV scores on the WISC, and that Group A children performed in a manner consistent with that observed in children who exhibited a WISC pattern of HV-LP (Rourke et al., 1971). Since the pattern of WISC VIQ-PIQ discrepancies were felt to reflect the underlying functional integrity of the cerebral hemispheres, it appeared that the basis on which the groups were determined in the Rourke and Finlayson (1978) study also reflected hemispheric integrity. Thus, the findings were consistent with the view that children in Group A exhibited poor performance in visual-perceptual and visual-spatial abilities due to compromised functioning of systems within the right cerebral hemisphere, whereas children in Groups R-S-A and R-S exhibited poor performance in verbal and auditory-perceptual tasks due to compromised functioning of systems within the left cerebral hemisphere. This was borne out by the fact that Group A children did poorly only on measures thought to be subserved primarily by the right cerebral hemisphere, whereas children in Groups R-S-A and R-S did poorly only on measures thought to be subserved primarily by the left cerebral hemisphere.

In order to further examine the differential functional integrity of the cerebral hemispheres in these groups of children, Rourke & Strang (1978) compared their performance on various motor, psychomotor, and tactile-perceptual measures. It was expected that Group A children would perform at lower levels than Groups R-S-A and R-S children on motor and psychomotor measures and, since it was felt that Group A children had compromised functioning of the right cerebral hemisphere, they were expected to have particularly poor performance on these measures with their left hand. Children in Groups R-S-A and R-S, however, were expected to show relatively intact motor and psychomotor skills, with any deficiencies evidenced by poor performance for their right hand. The results indicated that the three groups did not differ significantly from each other on the motor measures, although each group performed significantly better on right-handed than left-handed measures (consistent with expectations given that all subjects were exclusively right-handed). The hypothesized superiority of Groups R-S-A and R-S over Group A was evident on two complex psychomotor measures (Maze and Grooved Pegboard Tests; Kløve, 1963). Only the Tactual Performance Test (TPT; Reitan & Davison, 1974) revealed differential hand superiority. Groups R-S-A and A had poor left-hand performance, relative to right-hand performance, on this measure, whereas Group R-S children exhibited the opposite pattern of performance. However, on the "both hands" measure of the TPT, the performance of children in Groups R-S-A and R-S was superior to that of children in Group A. Results from a composite measure of tactile-perceptual abilities revealed that Groups R-S-A and R-S outperformed Group A for both the right- and left-hands, and that Group A children had a tendency to perform better with their right-hand than with their left.

Overall, the results indicated that children in Group A had marked deficiencies in some psychomotor and tactile-perceptual abilities, relative to both age-expectations and children in Groups R-S-A and R-S. The marked discrepancy between Groups R-S and A on the TPT offered support for the hypothesis of differential hemispheric integrity advanced by Rourke and Finlayson (1978). Again, Group A children performed lower than expected on measures of abilities thought to be subserved primarily by the right cerebral hemisphere and in an age-appropriate manner on measures thought to be subserved by the left cerebral hemisphere. The opposite pattern of performance was observed in Group R-S children.

The final study in this series (Strang & Rourke, 1983) compared the performance of the Group R-S and A children on the Halstead Category Test (Reitan & Davison, 1974; Reitan & Wolfson, 1985). Group R-S-A was excluded from this study since other research suggested that they might by composed of several discrete subtypes of learning-disabled children (Fisk & Rourke, 1979). The results indicated that Group A children made more overall errors than Group R-S children on this measure. In addition, their level of performance was approximately one standard deviation below age expectation (Knights & Norwood, 1980). Closer examination of the number of errors made on the individual subtests of the Category Test indicated that Group A children performed in an inferior manner to Group R-S on the last three subtests (although there was no significant difference between the groups on subtest 5). However, when results from subtests 4 and 5 of the Category Test were combined, Group R-S children performed in a superior manner to Group A children. These two subtests appear to be the most complex in terms of their requirements for visual-spatial analysis. Examination of the errors made on the last subtest (the review subtest) revealed that Group R-S children appeared to benefit from practice and earlier exposure to items, while Group A children showed little ability to benefit from experience.

The results of these three studies (Rourke & Finlayson, 1978; Rourke & Strang, 1978; Strang & Rourke, 1983) indicated that children who differ in their patterns of academic performance (as measured by the WRAT) exhibit different patterns of performance on neuropsychological measures. The results generally suggest that Group R-S children are deficient on tasks measuring abilities thought to be subserved primarily by the left cerebral hemisphere, whereas Group A children exhibit deficits on tasks measuring abilities thought to be subserved primarily by systems within the right cerebral hemisphere. Group R-S children present with outstanding deficits on verbal and auditory-perceptual measures in conjunction with average to above average visual-spatial and visual-perceptual skills, good psychomotor and tactile-perceptual abilities, and intact problem solving skills. Group A children, on the other hand, exhibit deficits in visual-spatial and visual-perceptual processing, have bilateral psychomotor difficulty, show bilateral impairment for tactile-perceptual measures (more pronounced for the left side of the body), and relatively poor problem-solving skills. However, their performance on verbal and auditory-perceptual measures is superior to that observed in Group R-S children.

The differences observed between these two groups of learning disabled children are clearly related to their patterns of academic performance rather than to their levels of performance as both groups were equated for deficient arithmetic performance. If these two groups had been combined to form one group who was "arithmetically learning-disabled", comparisons between their performance and a "normal arithmetic" group would have masked the differences in verbal and visual-spatial abilities seen in these two learning-disabled groups. It would appear, then, that Group R-S children exhibit difficulties in arithmetic due to language difficulties, whereas Group A children have trouble as a result of "visual-spatial" deficits. In order to examine this, Strang and Rourke (1985b) conducted a qualitative analysis of Group A children's errors on the Arithmetic subtest of the WRAT. They determined that these children made a large number, and a wide range, of arithmetic errors. These errors included: (1) difficulties in spatial organization (e.g., misaligning numbers in columns) and directionality (e.g., subtracting the minuend from the subtrahend in a subtraction question); (2) visual detail errors (e.g., misreading the mathematical sign); (3) procedural errors (e.g., misapplying mathematical rules); (4) failure to shift psychological set; (5) graphomotor difficulties; (6) judgment and reasoning errors (e.g., attempting questions clearly beyond their current level of capability); and (7) memory difficulties (although this type of error was not predominant among these children). In contrast, Group R-S children have been found to make fewer errors on the WRAT Arithmetic subtest than is typically encountered in other arithmetically disabled children. Group R-S children tend to avoid unfamiliar questions and operations and their mistakes tend to reflect difficulties remembering procedural steps or mathematical tables. These children also tend to avoid problems requiring the reading of the written word. In general, then, the mathematical difficulties encountered by Group R-S children fall into two areas of difficulty: reading disability and inexperience (Rourke, 1989).

Developmental considerations of the neuropsychological significance of differential patterns of academic performance have also been investigated (Ozols & Rourke, 1988, 1991). In these studies, three groups of learning-disabled (15 in each group) children between the ages of 7- and 8-years-old were selected according to their patterns of academic performance. Results indicated that children in Groups R-S-A and R-S performed in an inferior manner to Group A children on measures of verbal and auditory-perceptual functioning but in a superior manner to Group A children on some visual-perceptual and visual-spatial measures. Although statistically significant differences among the three groups were not observed on motor, psychomotor, and tactile-perceptual measures, Group A children performed at lower levels than Group R-S children on the majority of the tasks employed. In contrast to Strang and Rourke's (1983) findings, younger Group A children performed in a significantly superior manner to the other groups on a measure of elementary concept formation. It is, however, highly likely that the younger children's version of the Category Test taps different abilities than those assessed by the older children's version, as younger children are still functioning in the stage of concrete operational thought (Piaget, 1954). In general, the results of the two studies investigating the neuropsychological significance of patterns of academic achievement in younger children were quite comparable to those obtained from older children with respect to verbal, auditory-perceptual, visual-spatial, and visual-perceptual abilities. Less clear cut, however, are results obtained from measures of motor, psychomotor, and tactile-perceptual functioning.

In addition to examining the neuropsychological patterns of assets and deficits in these groups of children, Rourke and his associates have also examined their psychosocial functioning (Del Dotto et al., 1991; DeLuca et al., 1991; Ozols & Rourke, 1985; Rourke, 1988a; Rourke et al., 1989, 1990; Rourke & Fisk, 1981; Rourke & Fuerst, 1991; Strang & Rourke, 1985a). In general, the results of these investigations reveal that Group A children are more likely to be described as having emotional or behavioral disturbances. Internalized forms of psychopathology (such as withdrawal, depression, anxiety, and poor social skills) are more likely and these children also have difficulty understanding nonverbal descriptors of social situations and events. In contrast, Group R-S children are rarely described as maladjusted and they do not appear to exhibit significant socioemotional disturbances.

## Validation Research

The results of the series of investigations conducted by Rourke and his associates indicate that there are reliable, and externally valid, subtypes of learning-disabled children who can be selected according to patterns of academic functioning. Learning-disabled children who are selected on this basis can be shown to exhibit different patterns of neuropsychological strengths and weaknesses with consequences that are not solely confined to the classroom.

Other researchers have used similar classification schemes to further validate these subtypes of learning-disabled children (Fletcher, 1985; Loveland et al., 1990; Mattson, Sheer, & Fletcher, 1992; Share, Moffitt, & Silva, 1988; Stelmack & Miles, 1990; White, Moffitt, & Silva, 1992). Fletcher (1985) demonstrated that children selected according to patterns of academic achievement differ in terms of their verbal and spatial memory abilities. The results of this study were in the direction expected based on previous findings, in that Group R-S children performed significantly better than Groups R-S-A and A children on a spatial memory task, and had relative difficulty on a verbal memory task. Group A children experienced difficulty, relative to both controls and Group R-S children, on the spatial memory task but performed similarly to controls on the verbal component. Comparable observations on memory measures have been made by Brandys and Rourke (1991).

Differences between groups of learning-disabled children selected according to their patterns of academic abilities have also been observed on tasks involving comprehension and production of verbal and nonverbal communications (Loveland et al., 1990). Loveland et al. (1990) compared two groups of learning-disabled children (an arithmetic-disabled group and a reading-arithmetic disabled group) and normal controls on a set of tasks involving comprehension and production of verbally and nonverbally presented situations. Results indicated that the reading-arithmetic disabled group made more errors than the arithmetic disabled group with verbal presentation and response, whereas the arithmetic disabled group made more errors than the reading-arithmetic group for nonverbal presentations and an "enact" response.

Subtypes of learning-disabled children (similar to those identified by Rourke and his colleagues) have also been compared on electrophysiological measures (Mattson et al., 1992; Stelmack & Miles, 1990). Mattson et al. (1992) investigated and compared the evoked potentials of two groups of learning-disabled children and a control group. The first group had a specific impairment in arithmetic (similar to Group A children). The second group was specifically reading impaired and resembled a combination of Groups R-S-A and R-S children. Evoked potentials were recorded while subjects engaged in either a verbal or nonverbal task. Results indicated that children who were specifically disabled in arithmetic generated less right-hemisphere activity than control or reading disabled children during a nonverbal task. In contrast, the reading disabled children exhibited less left-hemisphere activity than the other two groups of children during the verbal task. It was concluded that different types of processing deficits were associated with different types of learning-disabilities.

Stelmack and Miles (1990) compared the visual event-related potentials (ERPs) of normals and a group of disabled readers that were selected using the same criteria determined for Group R-S children in the series of studies by Rourke and his colleagues. The children were presented with a recognition memory task under primed and unprimed conditions. Results revealed that the Group R-S children had lower ERPs than the normals, notably at posterior electrode sites (lateral parietal and occipital), under unprimed conditions. Under primed conditions both groups showed a reduced ERP. The pattern of ERPs exhibited by the Group R-S children was interpreted as reflecting difficulties in long-term semantic memory in the context of intact short-term psycholinguistic processing.

Further evidence of the validity of these subtypes comes from statistical studies employing cluster analysis in order to identify subtypes of learning disabilities (Fletcher & Satz, 1985; Korhonen, 1991; Lyon & Watson, 1981; Morris, Blashfield, & Satz, 1986; van der Vlugt, 1991; ver der Vlugt & Satz, 1985; Watson, Goldgar, & Ryshon, 1983). Fletcher and Satz (1985) identified subtypes of learning-disabled children similar to Groups R-S-A, R-S, and A in their cluster analysis of WRAT performance in a larger group of learning disabled children. Morris et al. (1986), Lyon and Watson (1981), and Watson et al. (1983) have also identified a group of reading-disabled children similar to Group R-S children through cluster analytic techniques. In addition, subtypes similar to Groups R-S and A children have been identified in non-North American samples of children (Korhonen, 1991; van der Vlugt, 1991; van der Vlugt & Satz, 1985).

Taken together, the results of these studies demonstrate the reliability and validity of the method of classifying learning-disabled children according to their patterns of academic achievement (see also Rourke, 1991). Thus, children who are chosen on the basis of their patterns of academic performance have been shown to have very different patterns of neuropsychological strengths and weaknesses.

## Summary and Comparison of Groups R-S and A

In order to summarize the general findings of studies examining the performance of these groups of learning-disabled children, specific comparisons between children in Group R-S and children in Group A will be made. Group R-S-A is excluded from further discussion as it is likely composed of several different subtypes of learning-disabled children (Fisk & Rourke, 1979; Petrauskas & Rourke, 1979).

The pattern of neuropsychological performance exhibited by children in Group A reveals that they have average to above average abilities in the **rote** aspects of verbal skills (such as recall of information and word definitions), whereas, Group R-S children exhibit some (often no more than mild) deficiencies in this area. On measures of more complex semantic-acoustic aspects of language and auditory-verbal skills (memory for sentences and auditory analysis of words), Group R-S children have outstanding difficulties. Group A children, while they show below average performance on these measures (particularly when the tasks involve processing of novel, complex, and/or involve meaningful material), perform at superior levels to Group R-S children.

Group A children exhibit exceptional difficulty on measures of visual-spatial-organizational, psychomotor, and tactile-perceptual abilities. While the deficits exhibited by these children on psychomotor and tactile-perceptual tasks are typically evidenced bilaterally, more difficulty is observed for performance on the left side of the body when there is evidence of a lateralizing impairment. Once again, Group A children are found to have greater difficulty, relative to age-based norms, on more novel tasks. In contrast, Group R-S children perform within average limits on these measures.

On measures of complex, nonverbal problem-solving tasks, older Group R-S children (aged between 9- and 14-years) perform within normal limits and have no difficulty benefitting from experience or using feedback to modify their behavior. In contrast, older Group A children experience significant difficulty on these measures and show little or no ability to benefit from feedback or experience. Specific conclusions regarding the problem-solving abilities of younger (ages 7- and 8-years) Groups R-S and A children, are difficult to draw, given their stage of developmental functioning.

Comparison of the performance of younger and older Groups R-S and A children on the remaining measures of cognitive functioning indicates that the younger children tend to exhibit similar patterns of performance (both inter- and intra-group) to the older group on tasks measuring verbal, auditory-perceptual, and visual-spatial-organizational abilities. Interestingly, younger Group R-S children perform at worse levels, relative to norms, on measures of rote verbal skills than older Group R-S children. Results from psychomotor and tactile-perceptual measures do not reveal the marked differences between groups observed in the older children. In general, the findings obtained from studies investigating the differences between Groups R-S and A at younger age levels are not as clear as those observed at older age levels.

An additional point of interest is that the overall pattern of performance that emerges for Group A children resembles that seen in the Gerstmann syndrome (Benson & Geschwind, 1970; Kinsbourne & Warrington, 1963), with Group A children exhibiting deficits in arithmetic, visual-spatial orientation (including right-left discrimination), psychomotor dyscoordination, and tactile-perceptual problems that include finger agnosia. It is stressed, however, that the pattern of performance exhibited by Group A children is most compatible with hypothesized deficient right-hemispheric systems rather than left-hemispheric systems, as proposed by Benson and Geschwind (1970).

The pattern of neuropsychological performance exhibited by children in Group A lead to the descriptive label of "nonverbal learning disabilities". This term was first applied by Myklebust (1975) to describe deficits in nonverbal abilities ("visual cognitive processing", p. 118) observed in four learning-disabled children. In addition, deficits in auditory abilities, orientation, and social interactions were noted. In contrast, verbal abilities in these children were found to be better developed than their nonverbal skills. Thus, these children appeared to have a pattern of cognitive abilities reflecting right-hemisphere deficits in conjunction with intact left-hemisphere systems. Children in Group A closely resemble the children described by Myklebust (1975) in that their pattern of neuropsychological performance is also suggestive of compromised right-hemispheric systems.

## Characteristics of the NLD Syndrome

The results of the series of investigations presented above delineated the pattern of neuropsychological and adaptive strengths and weaknesses exhibited by children having NLD syndrome. This syndrome, which is easily discernible by the age of 8- or 9-years, has the following characteristics (Rourke, 1987, 1989):

1. Bilateral tactile-perceptual deficits, more marked on the left side of the body.
2. Bilateral psychomotor coordination deficiencies, often more marked on the left side of the body.
3. Outstanding difficulties on measures of visual-spatial-organizational

ability.

4. Marked difficulty on measures of nonverbal problem-solving, concept-formation, and hypothesis-testing. Significant deficits in their capacity to benefit from feedback (both positive and negative) in novel or complex situations. In addition, significant difficulties dealing with cause-effect relationships and inability to appreciate incongruities are present.

5. Well developed rote verbal capacities, including rote verbal memory skills.

6. Extreme difficulty adapting to novel and complex situations. Overreliance on rote (and, therefore, inappropriate) behaviors in such situations.

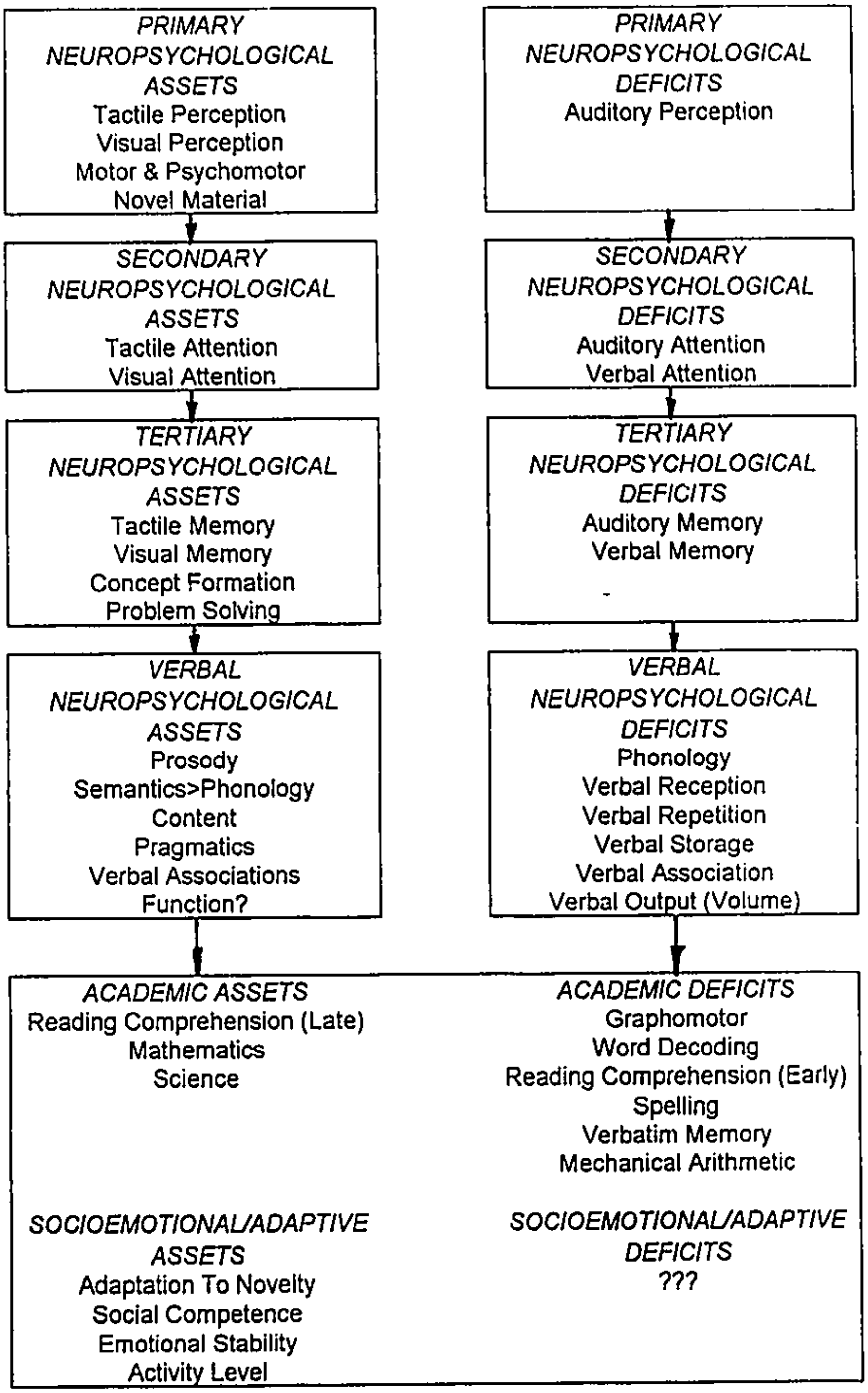
7. Outstanding difficulties in mechanical arithmetic relative to their proficient reading (word-recognition) and spelling skills.

8. Repetitive, straightforward, rote verbosity. Language is characterized by poor psycholinguistic pragmatics. Misspellings are almost always phonetically accurate. Little or no speech prosody. Reliance on language as their principal means of gathering information, relating socially, and relieving anxiety.

9. Significant deficits in social perception, social judgment, and social interaction skills. As they get older, there is a tendency to become socially withdrawn or socially isolated.

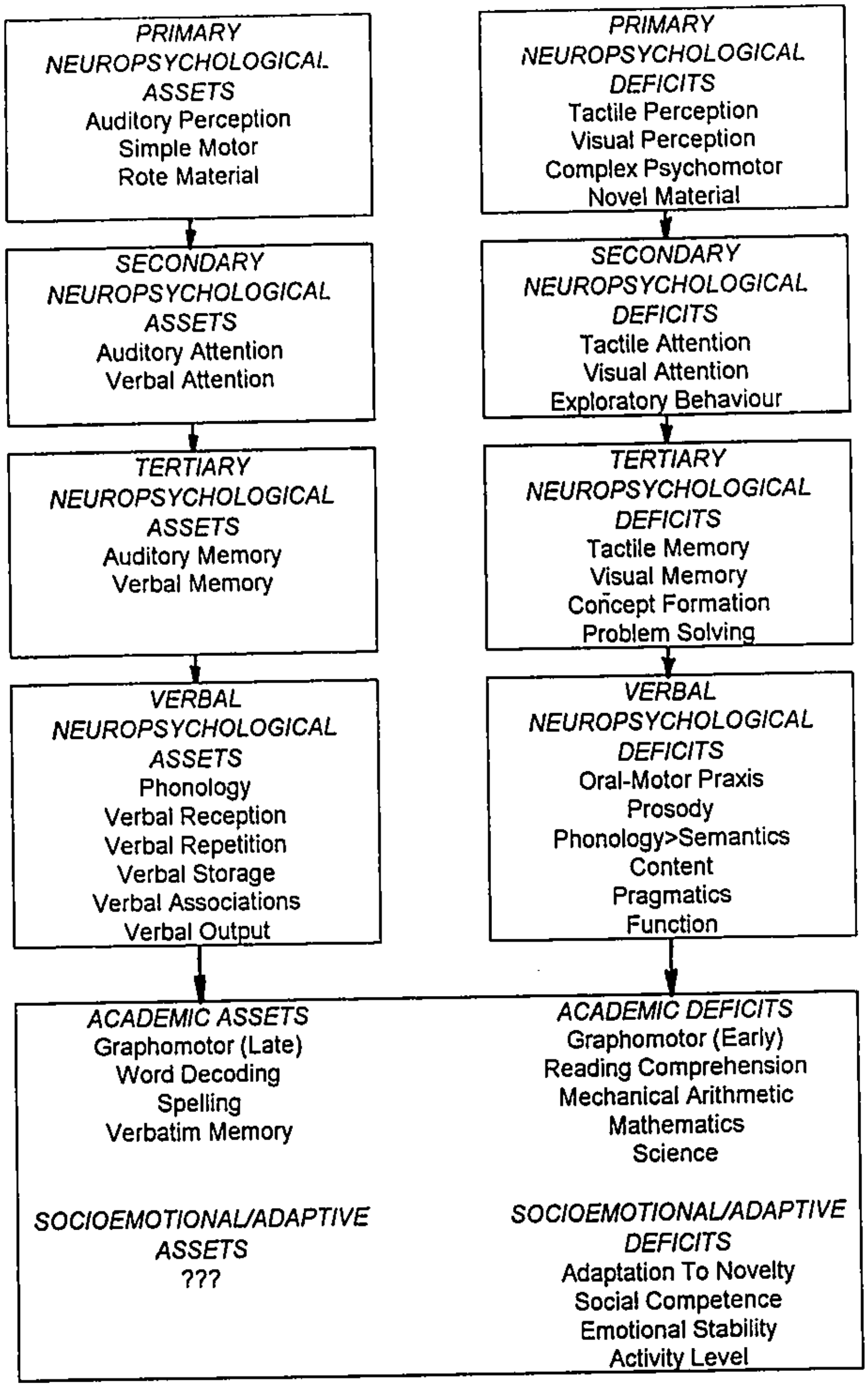
Figures 1 and 2 (taken from Rourke, 1993) outline the characteristic

Figure 1: Summary of Group R-S Characteristics



From Rourke, B. P. (1993). Arithmetic disabilities, specific and otherwise: A neuropsychological perspective. Journal of Learning Disabilities, 26, 216-224.

Figure 2: Summary of Group A (NLD) Characteristics



From Rourke, B. P. (1993). Arithmetic disabilities, specific and otherwise: A neuropsychological perspective. Journal of Learning Disabilities, 26, 216-224.

neuropsychological assets and deficits exhibited by Group R-S children and those with NLD (Group A). It should be noted that the primary assets and deficits are thought to lead to the secondary assets and deficits, which lead to the tertiary ones, and so on. Moreover, it is the pattern of assets and deficits that is seen as the causative agent for the academic and socioemotional/adaptive aspects of the NLD syndrome.

A recent investigation (Harnadek & Rourke, 1992, 1994) into the discriminant validity of the NLD syndrome sought to identify the principal features of NLD. Using stepwise linear discriminant function analysis, it was found that deficits in visual-perceptual-organizational, psychomotor coordination, and complex tactile-perceptual abilities best discriminated between children with NLD, children with reading and spelling disabilities (Group R-S), and a group of non-clinical children. Closer examination of these findings indicates that the principal features that distinguish between groups of NLD and R-S children can be characterized as "primary neuropsychological deficits" (see Figure 2).

The line of investigation leading to the identification of the NLD syndrome emphasizes that atheoretically driven research comparing homogeneous groups of learning-disabled and normal children can yield nothing to further the understanding of the nature of learning disabilities. Model development is necessary in order to account for the results of research and to develop theories about interactions that occur between patterns of neuropsychological functioning on the one hand, and learning difficulties and socio-emotional disturbances on the other (Rourke, 1989).

## The NLD Model

The original model presented by Rourke in the early 1980's provided a context for the interpretation of the findings of the series of studies presented above (Rourke & Finlayson, 1978; Ozols & Rourke, 1985; Rourke & Strang, 1978; Rourke et al., 1986; Strang & Rourke, 1983; 1985a). Differences between systems within the right and left cerebral hemispheres were emphasized and adapted as a model of neuropsychological functioning. Rourke's (1982) model had as its framework, a theoretical position originally proposed by Goldberg and Costa (1981). As this position is important in the development of the NLD model, it will be reviewed at this time.

Goldberg and Costa (1981) presented a view of hemispheral asymmetry that, they argued, followed from the neuroanatomical differences observed in the adult human brain. Whereas traditional views of cerebral asymmetry have emphasized "linguistic-nonlinguistic", "sequential-simultaneous", and "analytic-gestalt" dichotomies, Goldberg and Costa's (1981) view highlighted basic processing differences: intermodal vs. intramodal processing.

Goldberg and Costa (1981) concluded that results from neuroanatomical measures suggested that, for all three main sensory modalities, distinct intramodal representations are more prominent in the left- than right-hemisphere. In addition, intermodal associative areas are more common in the right-hemisphere (i.e., temporoparietal and prefrontal regions). The left-hemisphere has more areas of sensory- and motor-specific representation, whereas the right-hemisphere possesses greater areas of associative cortex. Thus, a pattern of intraregional connectivity is seen in the left-hemisphere and interregional connectivity in the right-hemisphere.

Further neuroanatomical findings revealed that the grey matter to white matter ratio is higher in the left-hemisphere than in the right-hemisphere. Conversely, there is more white matter and relatively less grey matter in the right-hemisphere. Goldberg and Costa (1981) argued that this ratio (grey-to-white matter) could be used as a marker of the underlying organizational feature of a neuronal structure with respect to intramodal as opposed to intermodal integration.

Taken together, these findings suggest that, in general, the left-hemisphere is best suited for processing simple, unimodal information and executing discrete motor acts, due to its pattern of intramodal connections, whereas the right-hemisphere appears best suited for dealing with informational complexity as it is characterized by intermodal connections. In addition, the right-hemisphere has a greater ability to process many modes of representation within a single task, and the left-hemisphere is better able to process tasks requiring a single mode of representation or execution.

Goldberg and Costa (1981) also stated that, from a developmental perspective, their model emphasized a progression from right- to left-hemisphere lateralization of functions. While their model would appear to stand in contrast to models suggesting left- to right-hemisphere lateralization (e.g., Corballis & Morgan, 1978), Goldberg and Costa (1981) point out that the latter model emphasizes morphogenesis rather than the development of cognitive functioning. As such, the two models are not mutually contradictory as the associative cortex is the last to mature in ontogenesis (Yakovlev, 1962; Yakovlev & Lecours, 1967). Given that the right-hemisphere has more associative cortex than the left, it follows that it would be the latest hemisphere to develop from a cytoarchitechtural sense (Goldberg & Costa, 1981).

The observation made by Goldberg and Costa (1981) that the left-hemisphere was best suited for intramodal integration implies that it is best suited for the processing, elaboration, and stereotypic usage of learned codes or descriptive systems, where a descriptive system denotes any set of discrete encoding units or transformation rules that can be successfully applied to processing a certain type of stimulus information. Conversely, the observation that the right-hemisphere was best suited for processing tasks that required intermodal integration implies that systems within this hemisphere are necessary for "novel information processing demands for which the individual has no preexisting code" (Rourke, 1989, p. 63).

Rourke (1982) modified Goldberg and Costa's (1981) model of hemispheric processing in order to address and incorporate developmental factors and to address a wide variety of behavioral phenomena. At this stage of the development of the NLD model only differences between and within the left- and right-hemispheres were addressed. The following principles of neurodevelopment were felt to fit with the results of neuropsychological investigations of the adaptive strengths and weakness of learning-disabled children up to that time:

> "1. There is an ontogenetic progression from the salience of right-hemisphere functions to that of left-hemisphere functions.
> 2. The evident change in children's conceptualizations from global to specific is a reflection of this right- to left-hemisphere ontogenetic development.
> 3. The development of right-hemisphere systems is a prerequisite for the adequate development of left-hemisphere systems.
> 4. In the normal course of affairs in the formation of constructs and concepts, left-hemisphere systems are particularly geared to their articulation, elaboration, and stereotypic application.
> 5. Diminished access to or disordered functioning of right-hemisphere systems is especially debilitating with respect to the development of adaptive abilities." (Rourke, 1982, p. 4).

Rourke (1982) demonstrated that this model of hemispheric functioning could account for variations in normal reading skills, spelling disabilities, mechanical arithmetic ability, and social learning. However, the model only focused on aspects of right- and left-hemisphere involvement. A complete neuropsychological model of central processing deficiencies should account for both the entire spectrum of children's perceptual and learning disabilities, as well as considering the right-left, down-up, and back-front dimensions of neurodevelopment. The NLD model was extended to include developmental dimensions other than the right-left dimension (Rourke, 1987, 1988b, 1989).

Disturbance in white matter development and/or functioning is the hypothesized "final common pathway" for the eventuation of the NLD syndrome. In its final form the NLD model is couched in terms of three main theoretical principles. These are related to: (1) the amount of white matter destroyed or rendered dysfunctional; (2) the type and developmental stage at which destruction or dysfunction occurs; and (3) the development and maintenance of learned behavior (Rourke, 1987, 1988, 1989). Thus, the more white matter (relative to total brain mass) that is lesioned, removed, or dysfunctional, the greater the likelihood that the NLD syndrome will be manifested. In addition, the type of white matter destroyed or dysfunctional is directly relevant to the manifestations of the NLD syndrome. Finally, because right-hemisphere white matter is viewed as being crucial for the development and maintenance of specific functions, (e.g., intermodal integration), particularly under situations requiring novel information processing, significant or permanent damage of right-hemisphere white matter would interfere with an individual's ability to acquire new descriptive systems at any stage of development. In contrast, left-hemisphere white matter, although essential for the development of specific skills, is not necessarily required for the maintenance of those skills. Nevertheless, early damage to left-hemisphere white matter would be expected to hinder or prevent the development of language (Rourke, 1989).

The theoretical principles of the NLD model suggest that a significant lesion of the right-hemisphere is a sufficient, although not necessary, condition for the NLD syndrome. The necessary condition for the manifestation of the NLD syndrome is the destruction or dysfunction of white matter responsible for intermodal integration.

## Implications of the NLD Model

The NLD model has far reaching clinical, developmental, and treatment implications. Clinical dimensions and implications of the NLD model are evident through investigation of various forms of neurological disease, disorder, and dysfunction. While characteristics of the NLD syndrome were first identified in research examining the neuropsychological significance of differences in patterns of academic achievement, they have also been observed in other groups of children in a manner consistent with the tenets of the NLD model. The forms of neurological insult include moderate to severe head injuries (Ewing-Cobbs, Fletcher, & Levin, 1985); hydrocephalus (Fletcher, Bohan, et al., 1992; Fletcher, Francis, et al., 1992; Rourke et al., 1983, pp. 290-297); myelomeningocele (Wills, Holmbeck, Dillon, & McLone, 1990); metachromatic leukodystrophy (Shapiro, Lipton, & Krivit, 1992); callosal agenesis (Casey, Del Dotto, & Rourke, 1990; Rourke, 1987); children who have received large doses of X-irradiation over prolonged periods of time for treatment of acute lymphocytic leukemia and other childhood cancers (Brown, et al., 1992; Fletcher & Copeland, 1988; Taylor, 1987; Taylor, Albo, Phebus, Sachs, & Bierl, 1987); children with insulin-dependent diabetes mellitus (Rovet, Ehrlich, Czuchta, & Akler, 1993); autism (Szatmari, Tuff, Finlayson, & Bartolucci, 1990); and children with significant tissue removal from the right-hemisphere (Rourke et al., 1983, pp. 230-238). In addition, children with Turner's syndrome (Rovet & Netley, 1982; Williams, Richman, & Yarbrough, 1992), Williams syndrome (Udwin & Yule, 1991), and Asperger's syndrome (Stevens & Moffit, 1988) have clinical profiles that resemble the one seen in children with NLD. Underlying all these disorders is the assumption that they involve dysfunction or disturbance of cerebral white matter.

The theoretical principles of the model suggest that the NLD syndrome should be exhibited in any situation where there is significant disruption of functioning for right-hemisphere systems including general deterioration of white matter, destruction of white matter within the right-hemisphere, and/or access to communication fibers between systems. Rourke (1989) also argued that the NLD syndrome would be manifested under conditions where one or more of the three opercula (grey matter and short association fibers) of the left hemisphere responsible for intramodal functioning, were isolated from each other and/or right-hemisphere systems. This latter situation would, in effect, hinder the development of new descriptive systems and would increase the likelihood of the application of rote, stereotypical responses in novel situations.

Developmental implications are consistent with the observation that individuals with NLD syndrome become progressively more debilitated over time. The syndrome is less apparent in younger children (Ozols & Rourke, 1988, 1991) than in older children (Rourke & Finlayson, 1978; Rourke & Strang, 1978; Strang & Rourke, 1983) and is even more debilitating in adulthood (Rourke, Young, et al., 1986, 1989).

Casey et al. (1991) have examined the developmental course of NLD. Children exhibiting characteristics of the NLD syndrome were used as subjects. The subjects were divided into two groups, on the basis of age, with the younger group ranging in age from 5.9 to 10.5 years and the older group ranging in age from 10.8 to 14.9 years. It was expected that age-appropriate development (reflected by relatively stable scores, compared to norms) would be seen in measures of rote verbal skills, reading (word identification), spelling, and simple motor and tactile-perceptual abilities. On the other hand, a relative decline (or failure to make age-appropriate gains) was expected for measures of visual-perceptual and problem-solving skills, mechanical arithmetic, and complex psychomotor and tactile-perceptual abilities.

Results of cross-sectional data confirmed these hypotheses. There was evidence of age-appropriate gains in the development of verbal, simple tactile, and simple motor skills in conjunction with gains in reading (word recognition) and spelling. However, no evidence for age-appropriate gains was seen on measures of visual-perceptual, complex tactile and psychomotor, and problem solving abilities. These results were consistent with expectations based on the NLD model stating that rote, overlearned skills are those in which NLD children become particularly adept while they are expected to encounter increasing difficulty on tasks that are more novel or complex in nature. Interestingly, it was on measures classified as reflecting "primary neuropsychological deficits" (tactile perception, complex psychomotor, and novel information processing) that the NLD children showed their greatest lack of age-appropriate gains of behavior.

The results of longitudinal analysis, in contrast, were not consistent with the proposed predictions. In general, children performed better at the second assessment on measures that were predicted to remain stable and showed a similar level of performance on those measures expected to decline. However, all eight children in this group had experienced some form of remediation, consistent with one designed specifically for NLD children (Strang & Rourke, 1985a; Rourke, 1989). Casey et al. (1991) concluded that the results from the longitudinal data suggested that the implementation of an appropriate remedial program had a beneficial effect for the children with NLD.

Based on the results of this study, coupled with observations made by Rourke et al. (1986), Casey et al. (1991) concluded that the features of the NLD syndrome develop during childhood. The pattern of changes observed is one of stability of verbal skills in conjunction with a decline of visual-spatial-organizational abilities. As children with NLD become older, greater difficulties with novel or otherwise complex tasks is seen, particularly on tasks involving problem-solving and concept-formation skills.

Implications of the model aimed at treatment of individuals with NLD suggest that attacking the deficits exhibited by an individual is beneficial if the syndrome is manifested in early development. However, if the syndrome occurs later in an individuals development, or if it has not been identified early, the use of compensatory strategies would be most beneficial as part of treatment. Results obtained by Casey et al. (1991) also indicate that the implementation of an appropriate remediation plan can, in fact, be beneficial in improving performances in certain areas of neuropsychological functioning.

The NLD model appears to be a comprehensive theoretical model of brain-behavior relationships capable of dealing with developmental and adaptive dimensions of learning abilities and disabilities (Rourke, 1989). Investigations examining the implications of this model, particularly in groups of children who exhibit various forms of neurological insult (e.g., Fletcher, Bohan et al., 1992; Fletcher, Francis et al., 1992), have demonstrated its external validity. Construct validity of the NLD syndrome and model has also been demonstrated (Casey & Rourke, 1991; Casey et al., 1991; Harnadek & Rourke, 1992, 1994). In addition, investigations of the association between hypothesized white matter damage or dysfunction and the NLD syndrome have been presented (Casey et al., 1990; Del Dotto, Barkley, & Casey, 1989; Fletcher, Thompson, & Miner, 1989). These findings suggest that the NLD syndrome represents a valid subtype of learning disability.

While it is known that children with NLD exhibit their primary neuropsychological difficulties in the areas of visual-perceptual-organization, tactile-perceptual, complex psychomotor, and novel information processing, in conjunction with primary assets in the area of simple motor, and processing of rote material (including rote language skills), the diagnosis, and treatment, of NLD rests on a comprehensive and thorough examination of an individuals cognitive and neuropsychological abilities. Until recently, little was known about the underlying structure of the most widely used neuropsychological test battery, the Halstead-Reitan Neuropsychological Battery and allied procedures, particulany in children.

In the following sections literature pertaining to the theoretical underlying constructs of the Halstead-Reitan Neuropsychological Battery will be presented with a particular emphasis on results of confirmatory factor analytic studies in children.

## The underlying structural content of neuropsychological measures for children: Confirmatory factor analytic studies

Neuropsychological assessment has developed over the past fifty years into a sophisticated and comprehensive method of examining brain-behavior relationships. Along with this development comes a need to understand the instruments used as assessment tools, which ultimately will provide a better understanding of brain-behavior relationships (Franzen, 1989). Information about the psychometric properties of an assessment battery, including its structural content, is important in providing both the clinician and researcher with adequate knowledge about the measures under consideration. This then allows for appropriate selection of tests to be administered in a clinical setting or to be included in research programs. Despite the obvious need for this type of information, there has been a relative dearth of studies evaluating the structural content of the Halstead-Reitan Neuropsychological Test Battery, particularly when administered to children (Francis, Fletcher, & Rourke, 1988). However, three recent studies have investigated the underlying structure of the tactile, motor, psychomotor, visual-spatial, and verbal tests of the Halstead-Reitan Neuropsychological battery administered to a group of primarily learning-disabled children (Davidson, 1992; Francis et al., 1988; Francis et al., 1992). These studies represent the first attempts at determining the structural content of the Halstead-Reitan Neuropsychological Battery, and allied procedures, for children.

These studies have used confirmatory factor analytic procedures in order to investigate the psychometric properties (construct validity and discriminant validity) of the Halstead-Reitan Neuropsychological Battery and allied procedures in children. Discriminant validity is considered to be a component of construct validity (Anastasi, 1988) and has been defined as the degree to which the constructs measured by a set of tests can be distinguished from one another (Campbell & Fiske, 1959). If two constructs are perfectly correlated, then they would not appear to measure different processes and one could be considered redundant.

While the construct validity of the Halstead-Reitan Neuropsychological Battery has been examined through the use of exploratory factor analytic techniques (e.g., Barnes & Lucas, 1974; Batchelor, Sowles, Dean, & Fischer, 1991; Crockett, Klonoff, & Bjerring, 1969; D'Amato, Gray, & Dean, 1988; Fowler, Richards, Berent, & Boll, 1987; Fowler, Zillmer, & Newman, 1988; Gamble, Mishra, & Obrzut, 1988; Goldstein & Shelly, 1972; Klonoff, 1971; Swiercinsky, 1978, 1979; Swiercinsky & Hallenbeck, 1975; Swiercinsky & Howard, 1982), confirmatory factor analytic approaches are viewed as the next step in theory building and investigation of construct validity. Confirmatory factor analysis allows for the testing of more specific hypotheses regarding underlying constructs than those tested for using exploratory approaches. It is a statistical procedure whereby causal relationships between observed behavior and underlying constructs (not directly observable) are proposed. Obtained data can then be tested for the adequacy of fit of these a priori specifications (Bollen, 1989; Cole, 1987; Francis, 1988; Francis et al., 1988). It differs from exploratory factor analysis in that the variables that load on a factor and the factors that correlate are specified by the researcher. In addition, while exploratory procedures result in an undetermined number of possible solutions, confirmatory approaches require the stipulation of a model prior to analysis.

In the first study of this series, Francis et al. (1988) investigated the discriminant validity of left- and right-handed sensorimotor tests from a modified Halstead-Reitan Neuropsychological Battery and Kløve (1963) battery of motor abilities. It is a long held tenet in clinical neuropsychology that right- and left-handed scores from sensorimotor measures are effective in diagnosing lateralized brain damage. Early studies (Boll, 1974; Reed, Reitan, & Kløve, 1965; Reitan, 1971a, 1971b; Selz & Reitan, 1979) have demonstrated that brain-damaged children can be discriminated from normals on the basis of their performance on neuropsychological measures. When closer inspection of the data obtained from these studies is conducted, with respect to sensorimotor measures, it becomes clear that the Finger Tapping Test (both hands) and the Nondominant Grip Strength measures are the only measures to consistently distinguish children with brain damage from normals across studies. Measures of sensory perception are more variable in their discrimination ability. For example, while Reitan (1971a) found that these measures did differentiate between normals and children with brain damage, Boll (1974) failed to find any evidence that sensory measures (e.g., Finger Agnosia, Fingertip Number Writing) obtained from either side of the body discriminated between groups. Although there is some evidence for sensorimotor measures to discriminate between groups of children, researchers have not examined whether the difference between right- and left-hand performance is the same for brain-damaged and normal children, nor whether performance on these measures differentiates between right- and left-hemisphere brain damage. In addition, results from exploratory factor analytic studies typically find that measures obtained from both hands, or from both sides of the body, load on the same factor (Goldstein & Shelley, 1972; Royce, Yeudall, & Bock 1976; Swiercinsky & Hallenbeck, 1975; Swiercinsky, 1979). While shared method variance could account for these findings, the results of these studies do not demonstrate definitively the discriminant validity of sensorimotor measures.

In order to examine the discriminant validity of sensorimotor measures in a modified Halstead-Reitan Neuropsychological Battery, Francis et al. (1988) used confirmatory factor analysis, which is a good statistical procedure for controlling for the effects of shared method variance. Four tactile and four motor measures (for both the right-and left-hand) were administered to a group of 888 children (predominantly learning-disabled and with no evidence of frank neurological damage). In addition, five measures of verbal and visual-spatial constructive skills were also included in the analysis in order to increase the power to test for discriminant validity. Four models (one a null model) of sensorimotor functioning were proposed. The first model (the null model) proposed that all eight tactile tests measured a tactile skills factor and the eight motor tests measured a motor skills factor. The second model allowed for both right- and left-hand tactile and motor skills factors. The third model proposed in this study specified that the tactile and motor skills factors could be identified as either simple or complex skills. The final factor allowed for right- and left-hand and simple and complex tactile and motor skills factors. In addition, each model had a verbal and visual-spatial factor. The results indicated that the model of simple and complex tactile and motor factors fit the data better than a model of right- and left-handed factors. This finding was supported in the cross-validation sample. Francis et al. (1988) concluded that there was no evidence for the discriminant validity of sensorimotor measures in children without evidence of brain damage. They argued that further factor analytic studies of neuropsychological measures need not include measures of right- and left-hand performance (a composite measure of performance being preferred).

Francis et al. (1992) continued this line of investigation by examining the underlying constructs of the motor and psychomotor measures (Finger Tapping, Grip Strength, Grooved Pegboard, Mazes, and Holes) and tests of visual-spatial abilities. These latter measures were included because some motor measures have a visual-spatial component (e.g., Grooved Pegboard Test) and measures of visual-spatial ability usually require a motor response (e.g., WISC Object Assembly and Block Design subtests). In all, data was obtained on twelve measures from 722 children (predominantly learning disabled and with no known neurological involvement). Unlike Francis et al. (1988), who examined children between the ages of 9- and 14-years, this study examined children between the ages of 9- and 12-years. A null model suggesting the presence of one-factor was compared with a three, four, and five factor model. The factors within each of these models were selected using an index variable and then allowing all other factor loadings and correlations to be estimated. The three-factor model (Model 3) specified the presence of a Simple Motor Factor (indexed by Grip Strength), a Motor Steadiness Factor (indexed by the Holes Test), and a Complex Visual-Spatial Relations Factor (indexed by the WISC Block Design Subtest). The four-factor model (Model 4) added a Speeded Motor-Sequencing Factor, which was indexed by the WISC Coding Subtest, and the five-factor model (Model 5) separated the Motor Steadiness Factor from Models 3 and 4 into a Simple-Spatial-Motor Factor (indexed by the Target Test) and a Motor Steadiness Factor (indexed by the Holes Test). The five-factor model was also modified to produce a model labelled Model 5A by Francis et al. (1992). This model restricted factor loadings in Model 5 to zero if they had a non-significant t-value (in this case less than 1.7) and allowed Finger Tapping to load on the factor of Motor Steadiness. Results from confirmatory factor analysis indicated that the five-factor model provided the best global fit for the data. Thus, factors of (1) Simple Motor Skill, (2) Complex Visual-Spatial Relations, (3) Simple Spatial-Motor Operations, (4) Motor Steadiness, and (5) Speeded Motor Sequencing were identified as underlying the measures used in this study. The authors also noted that these factors seemed to represent a hierarchical arrangement of skills in this area. This arrangement would proceed from the factor of Simple Motor Skill, through the Motor Steadiness, Simple Spatial-Motor Operations, and Complex Visual-Spatial Relations Factors to the Speeded Motor Sequencing Factor. Further investigation of the possibility that abilities might progress in this manner was recommended.

Davidson (1992) extended research investigating the content of the

Halstead-Reitan Neuropsychological Battery by examining the verbal measures included in this battery. The measures used in this study included measures from the Halstead-Reitan Neuropsychological Battery (Reitan & Davison, 1974), as well as the Peabody Picture Vocabulary Test (PPVT; Dunn, 1965), the Auditory Closure Test (Kass, 1964), the Verbal Fluency Test, the Sentence Memory Test (Benton, 1965), and four subtests from the Verbal component of the WISC (Wechsler, 1949; Information, Similarities, Vocabulary, and Comprehension). Data for these measures was obtained from 884 children (predominantly learning disabled with no explicit neurological damage) aged between 9- and 14-years. Eight models were compared. The first model (the null or baseline model) proposed a simple general verbal factor. The second model proposed the verbal factors as identified by Swiercinsky (Swiercinsky & Howard, 1982), and included a verbal information processing factor (where verbal reasoning requires judgement and the forming of relationships between information), a verbal short-term memory factor, and a language use factor represented by variables requiring reading, writing, and speech production. The third model was derived from the work of Royce and his associates (Aftanas & Royce, 1969; Royce 1973; Royce et al., 1976). Two factors, verbal comprehension and verbal long-term memory, were proposed. Lezak's model of intellectual functioning (Lezak, 1976, 1983) was used as the fourth model in Davidson's (1992) study. This model specified the existence of four factors: verbal receptive, verbal expressive, verbal memory and learning, and verbal cognitive processing. The fifth model proposed a solution similar to that outlined by Thurstone (1938; Thurstone & Thurstone, 1941). Three verbal factors (verbal fluency, verbal memory, and verbal comprehension) were proposed in this model. The sixth model investigated in this study was developed so that the second and fifth models were nested in a "parent" model (Davidson, 1992, p. 71) and the seventh model was developed from the fifth model to allow for the testing of an additional factor (Verbal Reasoning). The final model postulated by Davidson (1992) was a three factor model which hypothesized the existence of a General Verbal Factor and two correlated factors, Acoustic and Semantic Processing skills.

The results of confirmatory factor analysis indicated that the last model proposed by Davidson provided the best overall fit to the data of the models suggested. Thus, the verbal measures of the modified Halstead-Reitan Neuropsychological Battery used in this study are best described as being representative of a General Verbal Factor (on which all measures load), an Acoustic Processing Factor and a Semantic Processing Factor. The General Verbal Factor is uncorrelated with the other two factors, whereas they are correlated with each other. Davidson (1992) noted, however, that this model could still be improved upon as less than half of the t-values associated with the General Verbal Factor were significant and three (out of four) indices for the Semantic Processing Factor were significant. Davidson (1992) argued that the Semantic Processing Factor might in fact be serving as a General Verbal Factor.

In summary, research examining the underlying theoretical factor structure of a modified Halsted-Reitan Neuropsychological Test Battery for children has identified five factors relating to motor and visual-spatial functions (Francis et al., 1992) and three factors related to language and auditory-perceptual abilities (Davidson, 1992). Examination of the five motor and visual-spatial factors suggests that they are hierarchically arranged, moving from simple to complex motor and visual-spatial abilities, in the following manner: (1) Simple Motor; (2) Motor Steadiness; (3) Simple Spatial Motor; (4) Complex Visual Spatial; and (5) Speeded Motor Sequencing. A hierarchy suggests that a more complex skill requires the adequate development and usage of a simpler skill before it can be performed adequately. In addition, this particular hierarchy suggests that psychomotor and visual-spatial skills proceed from rote, concrete abilities to those requiring processing of increasingly novel and complex information.

Examination of the auditory-verbal and language measures in the modified Halstead-Reitan Neuropsychological Battery for children has identified two factors that appear to be representative of different modes of information processing, subsumed under a factor of General Verbal ability. This would appear to be consistent with research in the area of language and reading development (e.g., Downing & Leong, 1982; Franklin & Barten, 1988; Gibson & Levin, 1975; Stanovich, 1980, 1990) that suggests that language processing consists of two general modes of operation. The first involves visual-perceptual abilities and phonological processing, while the second is represented by syntactic and semantic processing skills. In light of the NLD model presented above, these types of skills can also be viewed as involving the processing of novel and complex information (such as auditory analysis skills), or as skills that are primarily rote in nature (such as those involving word definitions and recall of information). Thus, although language does not necessarily develop in a hierarchical fashion, the factors identified by Davidson (1992) support the presence of two modes of language processing, subsumed under a factor of general verbal ability. In addition, closer examination of the factors identified by Davidson (1992) reveals that they can be distinguished on the basis of task complexity and novelty. Tasks loading on the Semantic Processing Factor are felt to represent those that are more rote or routine in nature than those loading on the Acoustic Processing Factor, which are more representative of novel, complex tasks.

## Purpose of the Present Study and Hypotheses

The purpose of the present study was to further examine the factors identified by Francis et al. (1992) and Davidson (1992) in order to continue investigations into the construct validity of a modified Halstead-Reitan Neuropsychological Battery as used with children. Continued investigation of these factors will help to further the knowledge of brain-behavior relationships, which will ultimately result in better diagnosis and treatment planning for children seen for neuropsychological assessment. The NLD model proposed by Rourke (1982, 1987, 1988b, 1989) provides a good paradigm within which to examine these factors. In addition, the two subtypes of learning disabled children (Group R-S and Group A) identified by earlier research (Rourke & Finlayson, 1978; Rourke & Strang, 1978; Strang & Rourke, 1983) appear to be ideal for testing the relationships among the factors identified by Francis et al. (1992) and Davidson (1992). The nature of these factors was examined in a series of three studies. The hypotheses generated for each study were based on theoretical considerations (Goldberg & Costa, 1981; Rourke, 1982, 1987, 1988b, 1989) and on previous findings from the literature investigating the NLD syndrome (e.g., Casey & Rourke, 1991; Casey et al., 1991; Harnadek & Rourke, 1992, 1994; Rourke, 1991).

Study 1. The purpose of this study was to examine the discriminant validity of the motor, psychomotor, visual-spatial, and auditory-language factors in two groups of learning-disabled children (Groups R-S and A). It was expected, based on results from Harnadek and Rourke (1992, 1994), that the motor and visual-spatial factors (and, in particular, the Simple Spatial-Motor and Complex Visual-Spatial Relations Factors) would be particularly salient to the discrimination of these two groups of learning disabled children.

Study 2. The potential hierarchy suggested in the motor, psychomotor, and visual-spatial factors identified by Francis et al. (1992) was examined in the second study. The underlying correlational structure of these factors was expected to conform to a simplex model in both groups (Guttman, 1954; Jöreskog, 1970). This model is one in which adjacent means are more highly correlated than distal means and is a necessary manifestation of hierarchically ordered variables (Humphreys, 1960, 1985; Nunnally, 1978). In addition, Group A children were expected to show increasingly poorer performance (reflected in lower T-scores), relative to both normative levels and themselves, as the demands for information processing of novel, complex, and/or meaningful material increased. In other words, while performance on measures reflected by the Simple Motor Factor was expected to be near normal levels (Rourke & Strang, 1978), a decline in the level of performance of Group A children was expected as the complexity of the factors increased. Group R-S children, on the other hand, were not expected to exhibit difficulties (relative to norms or to their own level of performance on previous factors) on any factor other than the Speeded Motor Sequencing Factor (given their difficulties with symbolic processing).

Study 3. The final study examined the factors identified by Davidson (1992) in order to determine whether they represented different verbal processing skills.

Group R-S children were expected to perform at below average levels for the General Verbal Factor, whereas Group A children were expected to perform within average limits. Of more interest, however, was the relationship between the Semantic Processing and Acoustic Processing Factors exhibited by these two groups. As measures loading on the Semantic Processing Factor were felt to represent the more rote aspects of psycholinguistic skills, Group A children were expected to exhibit average to superior skills for this factor, given their proclivity for rote information processing. Group R-S children were expected to exhibit lower levels of performance than Group A children, although not necessarily impaired (relative to norms), given that their neuropsychological deficits are verbal in nature. On the other hand, the Acoustic Processing Factor is composed of measures that were felt to emphasize the processing of novel, complex, and/or meaningful information. As such, Group A children were expected to show a decrease in their performance, relative to that observed on the Semantic Processing Factor. Group R-S children were also expected to show a decline in their level of performance when compared to the Semantic Processing Factor. In addition, Group R-S children were expected to show the largest discrepancy between their performance on Semantic and Acoustic Processing Factors, due to their known difficulties with acoustic language processing.

# CHAPTER II

# METHOD

## Subjects

Subjects were selected from an archival database of over 5000 children who had received a comprehensive neuropsychological examination. The complete battery of neuropsychological measures was administered in a standardized manner by trained technicians. The children were referred for assessment because of a learning, perceptual, or other type of behavioral handicap to which it was believed that cerebral dysfunction might be a contributing factor.

In order to be consistent with subject selection made for the confirmatory factor analytic studies (particularly Francis et al., 1992), the subjects selected for this study were in the age range of 9- to 12- years old. In addition, they were right-handed, and their Wechsler Intelligence Scale for Children (WISC; Wechsler, 1949) Full Scale I.Q. fell within the normal range (i.e., between 86 and 114). All subjects had attended school regularly from the age of six years. Subjects also met the following exclusionary criteria: (1) they were not judged as being in need of psychiatric treatment for an emotional disorder; (2) they did not have defective hearing (i.e., there was no greater than 25 decibel hearing loss with either ear within the frequency range of 500 to 4000 Hz); (3) there was no evidence of a visual defect; (4) they were not considered "culturally deprived"; and (5) English was their mother tongue. This information was obtained from their social and medical histories and fulfilled the generally accepted criteria for "learning disabilities" as used in Rourke's laboratory (Rourke, 1975, 1976b, 1978, 1981, 1985).

From the subjects who met the above selection criteria, 122 were chosen for inclusion in this study, based on their pattern of performance on the Wide Range Achievement Test (WRAT; Jastak & Jastak, 1965). Verbal-Performance IQ discrepancies, and patterns of neuropsychological strengths and weaknesses, were not used as selection criteria, given that the dependent variables in this study were composed of measures representing these areas. Initially attempts were made to select subjects based on the same criteria used by Rourke and Finlayson (1978), Rourke and Strang (1978) and Strang and Rourke (1983). However, this resulted in a fairly small sample size (n=60). A larger sample size was felt to be more appropriate, given the types of statistical analyses to be conducted [e.g., multivariate analyses and investigation into the possible existence of a simplex model (see below)]. General "rules of thumb" for conducting multivariate analyses suggest that a minimum of 10 subjects per variable is appropriate, with a higher subject to variable ratio (e.g., 20 to 1) being preferred (Tabachnick & Fidell, 1989). Subject selection criterion was changed from differences between grade-equivalent scores to a difference of at least 10 points between the standard score on the Arithmetic subtest and the standard scores on the Reading and Spelling subtests of the WRAT. This modified criterion was still felt to represent adequately those children exhibiting differential patterns of reading and spelling performance relative to their arithmetic performance (see Table 1 for subject selection criteria).

Group R-S children had Reading and Spelling standard scores at least 10 points below their Arithmetic standard score. Group A was composed of children whose WRAT Reading and Spelling standard score exceeded their Arithmetic standard score by at least 10 points.

The two groups were matched for age, Full Scale IQ on the WISC, and WRAT Arithmetic performance. Results of t-tests indicated that the two groups did not differ from one another with respect to age [t (61) = -0.11, p<.91], Full Scale IQ [t (61) = 0.03, p<.98], or WRAT Arithmetic performance, as measured by standard scores, [t (61) = 1.54, p<.13].

## Measures

The WRAT Reading, Spelling, and Arithmetic subtests (Jastak & Jastak, 1965) are widely used measures of academic achievement and, therefore, will not be described in great detail. Suffice it to say that the Reading subtest is an oral word-reading test, the Spelling subtest requires the child to spell words to dictation, and the Arithmetic subtest consists of various types of progressively more difficult mechanical mathematical problems (Rourke, Bakker, Fisk, & Strang, 1983; Rourke, Fisk, & Strang, 1986).

Table 1

Descriptive Statistics for Subject Selection Criteria

| | Group ($n$ = 61 in each) | |
|---|---|---|
| | R-S | A |
| Age (in years)[1] | | |
| M (SD) | 10.80 (1.06) | 10.82 (1.06) |
| WISC Full Scale I.Q.[1] | | |
| M (SD) | 99.49 (7.40) | 99.46 (6.92) |
| WRAT Reading[2] (Standard Score) | | |
| M (SD) | 73.10 (5.17) | 110.62 (9.00) |
| WRAT Spelling[2] (Standard Score) | | |
| M (SD) | 71.89 (4.94) | 103.11 (7.17) |
| WRAT Arithmetic[1] (Standard Score) | | |
| M (SD) | 87.08 (4.33) | 85.93 (3.87) |
| WRAT Reading[2] (Percentile) | | |
| M (SD) | 4.30 (2.56) | 72.62 (17.07) |
| WRAT Spelling[2] (Percentile) | | |
| M (SD) | 3.72 (2.45) | 56.93 (16.00) |
| WRAT Arithmetic[1] (Percentile) | | |
| M (SD) | 20.20 (7.36) | 18.20 (6.69) |

[1] No significant differences between the two groups

[2] Group 3 > Group 2 ($p < .0001$)

For the purposes of Studies 1, 2, and 3, the following measures from the modified Halstead-Reitan Neuropsychological Battery for older children were utilized:

1. Finger Tapping Test (Reitan & Davison, 1974)
2. Grip Strength - Dynamometer (Reitan & Davison, 1974)
3. Grooved Pegboard Test (Kløve, 1963; Knights & Moule, 1968; Rourke, Yanni, MacDonald, & Young, 1973)
4. Graduated Holes Test (Kløve, 1963; Knights & Moule, 1968)
5. Mazes Test (Kløve, 1963; Knights & Moule, 1968)
6. Trail Making Test, Part A (Reitan & Davison, 1974; Rourke & Finlayson, 1975)
7. Target Test (Reitan & Davison, 1974)
8. Tactual Performance Test (Reitan & Davison, 1974)
9. Halstead-Wepman Aphasia Screening Test (Reitan & Davison, 1974)
10. Auditory Closure (Kass, 1964)
11. Sentence Memory Test (Benton, 1965)
12. Speech-Sounds Perception Test (Reitan & Davison, 1974)
13. Verbal Fluency Test (Rourke et al., 1983; Rourke, Fisk et al., 1986)
14. Peabody Picture Vocabulary Test (Dunn, 1965)
15. WISC Comprehension (Wechsler, 1949)
16. WISC Information (Wechsler, 1949)
17. WISC Similarities (Wechsler, 1949)

18. WISC Vocabulary (Wechsler, 1949)
19. WISC Object Assembly (Wechsler, 1949)
20. WISC Block Design (Wechsler, 1949)
21. WISC Picture Completion (Wechsler, 1949)
22. WISC Coding (Wechsler, 1949).

These measures are widely used in child clinical neuropsychological assessment and details for test administration and scoring are provided in Rourke, Fisk, et al. (1986).

## Methodological Issues

Prior to any statistical analyses, composite factor scores were obtained for each subject on each factor. These composite factor scores were used in the analyses for each study. Initially, standardized test scores based on normative data (Knights & Norwood, 1980) were obtained. Each subject's raw score on the dependent measures was transformed into a T-score, with a mean of 50 and a standard deviation of 10. The T-scores were adjusted so that higher performance was represented in one direction (above 50) and lower performance in the opposite direction (below 50).

A composite factor score was derived for each factor by calculating an average T-score from the measures composing each factor. Right- (RH) and left-hand (LH) T-scores for the Finger Tapping Test, Grip Strength Test, Grooved Pegboard Test, Holes Test, and Mazes Test were combined to form one score (the average of both hands), as it is clear that there is little support for the discriminant validity of right- versus left-hand performance (Francis et al., 1988), and also because they were combined in the original confirmatory factor analytic study (Francis et al., 1992).

For all studies presented below, the dependent variables were grouped in two manners. First, they were classified according to the variables loading on the factors identified by Francis et al. (1992) and Davidson (1992). The factors and corresponding measures are presented in Table 2. This type of classification was referred to as **statistical selection**, as all variables that were included in the original confirmatory factor analytic studies were used to describe the factors. Although this manner of classification allowed for factor composition as determined by the initial factor analytic studies, several variables were found to identify more than one factor (e.g., Finger Tapping loads on both the Simple Motor and Motor Steadiness Factors). For this reason, the dependent variables were also classified in another manner referred to as **clinical selection**. Only those variables represented by an asterix in Table 2 were used to describe the factors in this method of grouping. These variables were chosen as they were felt to be the best clinical representatives of the underlying factors identified by Francis et al. (1992) and Davidson (1992).

The General Verbal Factor identified by Davidson (1992), which is composed of all variables that load on the Semantic and Acoustic Processing Factors, was excluded from the majority of analyses in this study and,

Table 2

Factors of neuropsychological functioning and associated measures

| Factors | Measures |
|---|---|
| Simple Motor | Finger Tapping (Right & Left) *<br>Grip Strength (Right & Left) * |
| Motor Steadiness | Mazes Test (Right & Left - Contact Time) *<br>Graduated Holes Test (Right & Left - Contact Time) *<br>Grooved Pegboard (Right & Left)<br>Finger Tapping (Right & Left) |
| Simple Spatial-Motor | Target Test *<br>WISC Object Assembly<br>Mazes Test (Right & Left - Contact Time)<br>Trail Making Test (Part A) |
| Complex Visual-Spatial Relations | WISC Object Assembly *<br>WISC Block Design *<br>WISC Picture Completion<br>Grooved Pegboard (Right & Left)<br>Tactual Performance Test (Total Time) |
| Speeded Motor Sequencing | WISC Coding *<br>Mazes Test (Right & Left - Contact Time)<br>Trail Making Test (Part A) *<br>WISC Object Assembly<br>Tactual Performance Test (Total Time)<br>Grooved Pegboard Test (Right & Left) |
| Acoustic Processing | Auditory Closure *<br>Sentence Memory *<br>Speech-Sounds Perception Test<br>Verbal Fluency |
| Semantic Processing | Aphasia Screening Test (Total aphasic errors)<br>WISC Vocabulary *<br>WISC Comprehension<br>WISC Information<br>WISC Similarities<br>Peabody Picture Vocabulary Test * |

therefore, is not presented in Table 2.

In addition, as an exploratory measure, the total number of errors made on the Category Test (Reitan & Davison, 1974) was added to the variables composing the Complex Visual-Spatial Relations Factor. Although the Category Test was not included in the initial confirmatory factor analytic study examining motor, psychomotor, and visual-spatial measures (Francis et al., 1992) it was felt that it might be a representative variable of cognitive abilities falling in this domain. While abilities required by the Category Test probably represent more than one of the factors identified by Francis et al. (1992), the Complex Visual-Spatial Relations Factor was felt to be the most appropriate factor on which to place this measure. The Category Test was, therefore, included in the statistical analyses in order to determine whether its addition would improve the discriminant and predictive validity of the Complex Visual-Spatial Relations Factor.

Finally, analyses involving the language factors were conducted on the data both with and without the Aphasia Screening Test. This was because Davidson (1992) had originally used the total number of errors committed on this test, rather than the number of aphasic errors. The total number of errors committed on the Aphasia Screening Test is not entirely reflective of language abilities (as dysgraphic and dyspraxic errors are also included). The number of **aphasic** errors (which would be a more appropriate measure) made by children selected for the present study could not be converted to $\underline{T}$-scores, due to normative data indicating that, for one age group, the standard deviation was zero. However, as Davidson (1992) had included the Aphasia Screening Test in his confirmatory factor analytic investigation of auditory-verbal and language measures, it was included in this study (using the total number of errors). As the total number of errors on this measure consists of language and other errors, analyses were also conducted excluding the Aphasia Screening Test from the Semantic Processing Factor.

The means and standard deviations for all the dependent variables are presented in Table 3. Table 4 contains the means and standard deviations for the five motor, psychomotor, and visual-spatial factors and the two language factors under investigation.

## Statistical Analyses

All of the analyses presented below were conducted twice: once for the statistical selection of the factors and once for the clinical selection criteria. Statistical significance for all analyses was evaluated at the .05 probability level.

Study 1. In order to evaluate which of the factors (with the exception of the General Verbal Factor), identified in previous research (Francis et al., 1992; Davidson, 1992), best discriminated between Groups R-S and A children, a stepwise discriminant function analysis was performed. The goal of discriminant function is to predict group membership on the basis of a variety of predictor variables. Scores for each factor were employed as predictors.

Table 3

Means and standard deviations for all dependent variables

| Variable | Group R-S M | Group R-S SD | Group A M | Group A SD |
|---|---|---|---|---|
| Finger Tapping (average of right and left hand scores) | 33.23 | 4.42 | 34.57 | 6.51 |
| Grip Strength (average of right and left hand scores) | 15.39 | 5.30 | 16.13 | 4.20 |
| Grooved Pegboard Test (average of right and left hand time) | 78.63 | 13.69 | 81.64 | 18.73 |
| Holes Test (average of right and left hand contact time) | 25.66 | 12.24 | 20.09 | 11.41 |
| Mazes Test (average of right and left hand contact time) | 4.76 | 3.52 | 3.99 | 5.24 |
| Target Test (total number correct) | 16.65 | 2.21 | 16.09 | 2.72 |
| Trail Making Test - Part A (time to completion) | 21.56 | 8.72 | 22.08 | 9.25 |
| Tactual Performance Test (total time for all three trials) | 6.75 | 3.48 | 9.58 | 6.26 |
| Aphasia Screening Test (total number of errors) | 12.62 | 2.92 | 5.84 | 2.98 |
| Auditory Closure Test (total number correct) | 10.84 | 4.32 | 15.16 | 3.77 |
| Sentence Memory (total number of sentences repeated) | 12.48 | 2.61 | 13.79 | 2.54 |
| Speech Sounds Perception Test (total number correct) | 19.30 | 4.41 | 25.90 | 2.32 |
| Verbal Fluency Test (average number of correct words over two trials) | 6.24 | 2.49 | 8.43 | 3.24 |
| Peabody Picture Vocabulary Test IQ (standard score) | 95.93 | 12.79 | 103.90 | 11.35 |

Table 3 (continued)

Means and standard deviations for all dependent variables

| Variable | Group R-S M | Group R-S SD | Group A M | Group A SD |
|---|---|---|---|---|
| WISC Comprehension (scaled score) | 9.00 | 2.22 | 9.79 | 2.46 |
| WISC Information (scaled score) | 7.39 | 1.44 | 8.98 | 2.02 |
| WISC Similarities (scaled score) | 10.48 | 1.95 | 11.48 | 2.53 |
| WISC Vocabulary (scaled score) | 9.39 | 1.99 | 10.31 | 2.10 |
| WISC Object Assembly (scaled score) | 11.26 | 2.56 | 10.49 | 2.62 |
| WISC Block Design (scaled score) | 11.28 | 2.73 | 10.12 | 2.55 |
| WISC Picture Completion (scaled score) | 10.82 | 2.70 | 10.43 | 2.76 |
| WISC Coding (scaled score) | 10.03 | 2.74 | 9.75 | 2.77 |
| Category Test (total number of errors) | 50.34 | 16.67 | 50.18 | 17.26 |

**NOTE:** The Grooved Pegboard, Holes, Mazes and Trail Making Test scores are in seconds, while the Tactual Performance Test score is in minutes.

Table 4

Means and standard deviations of the neuropsychological factors

| Factor | Group R-S | | Group A | |
|---|---|---|---|---|
| | M | SD | M | SD |
| Simple Motor (same for both clinical and statistical selection) | 50.97 | 6.61 | 52.50 | 7.50 |
| Motor Steadiness | | | | |
| Clinical Selection | 47.13 | 12.50 | 51.97 | 12.57 |
| Statistical Selection | 47.44 | 7.85 | 49.63 | 10.53 |
| Simple Spatial-Motor | | | | |
| Clinical Selection | 46.83 | 9.36 | 43.84 | 11.62 |
| Statistical Selection | 46.85 | 6.40 | 47.87 | 7.80 |
| Complex Visual-Spatial Relations | | | | |
| Clinical Selection | 54.23 | 7.48 | 51.01 | 7.23 |
| Statistical Selection | 52.74 | 5.47 | 50.48 | 6.69 |
| Complex Visual-Spatial Relations (including Category Test) | | | | |
| Clinical Selection | 52.94 | 6.37 | 50.77 | 6.00 |
| Statistical Selection | 52.40 | 5.15 | 50.45 | 6.01 |
| Speeded Motor Sequencing | | | | |
| Clinical Selection | 48.09 | 8.42 | 47.02 | 8.43 |
| Statistical Selection | 51.26 | 4.23 | 49.10 | 3.75 |

Table 4 (cont'd)

Means and standard deviations of the neuropsychological factors

| Factor | Group R-S M | Group R-S SD | Group A M | Group A SD |
|---|---|---|---|---|
| Semantic Processing | | | | |
| Clinical Selection | 47.63 | 6.56 | 51.82 | 6.55 |
| Statistical Selection | 46.97 | 4.37 | 50.89 | 5.46 |
| Semantic Processing (including Aphasia Screening Test) | | | | |
| Statistical Selection only | 42.41 | 4.05 | 49.83 | 5.13 |
| Acoustic Processing | | | | |
| Clinical Selection | 36.81 | 8.83 | 44.49 | 6.90 |
| Statistical Selection | 33.94 | 7.62 | 46.74 | 6.41 |

**NOTE:** All scores are T-scores.

In order to test the more specific hypothesis that the Simple Spatial-Motor and Complex Visual-Spatial Relations Factors were the best factors for predicting group membership, a logistic regression analysis was conducted. This type of regression analysis is equivalent to linear regression analysis (Tabachnick & Fidell, 1989), with the exception that the dependent variable (groups in this case) has undergone a logarithmic transformation (Norŭsis, 1985). This is done because the variable is dichotomous in nature. In **linear** regression analyses, dependent variables are continuous in nature. Linear (and logistic) regression analyses attempt to relate a dependent variable to a set of independent variables and develop an equation that summarizes the relationship between these two variables (Tabachnick & Fidell, 1989).

Regression analyses were conducted using composite scores for the seven factors as predictors. The Simple Spatial-Motor and Complex Visual-Spatial Relations Factors were entered into the equations first, with subsequent analyses being conducted in order to determine whether additional factors improved the "goodness of fit" of the prediction equation (Morrison, 1976; Tabachnick & Fidell, 1989).

Study 2. In order to examine the possibility of the hierarchical arrangement of the motor, psychomotor, and visual-spatial factors, two procedures were followed. First, the correlation matrix of these five factors was examined (for both groups) in order to determine whether it formed a simplex structure (Guttman, 1954; Jöreskog, 1970). This structure is one in which the adjacent measures are more highly correlated than distal measures (e.g., the Simple Motor Factor will correlate more highly with the Motor Steadiness Factor than with the Speeded Motor Sequencing Factor) and is necessary for the type of hierarchical model under investigation. If a simplex structure is evident, then correlations should become smaller as the factors are more "distally related" (J. Hawkins, personal communication, July 1993).

The second component of this study involved the application of a one-way multivariate analysis of variance (MANOVA) procedure (SAS Institute, 1986) in order to examine trends and differences between the means of the five factors. Profile analysis was also conducted. Profile analysis is an application of MANOVA whereby several dependent measures are measured on the same scale. As the factor scores for each subject were presented as T-scores, this procedure is possible as it requires that variables be measured in "commensurate" or comparable units in order for interpretation to be meaningful (Harris, 1975; Morrison, 1976). Profile analysis directly assesses "patterns" of group test performance by separating differences among groups and differences among variables. In doing this, profile analysis addresses three issues: parallelism (shape), levels (elevation), and flatness (Harris, 1975; Morrison, 1976).

The test of parallelism is the primary question of interest and determines whether or not the group profiles exhibit the same pattern or shape. If they do not, testing the elevation and flatness of a profile is somewhat meaningless and irrelevant (Harris, 1975; Morrison, 1976) because answers about a profiles elevation and flatness will depend on which subset of measures or groups are considered (Francis, Espy, Rourke, & Fletcher, 1991). Parallelism tests the slope of each line segment (between adjacent means) for each group and involves a multivariate analysis. It is similar to testing the interaction of rows and columns seen in analysis of variance techniques (ANOVAs; Morrison, 1976). If the profiles are parallel or have the same shape, then the issues of elevation (levels) and flatness can be addressed. The profile elevation (or levels) test involves a between groups comparison on a single variable (the group grand mean for the set of measures). In order to assess the flatness of the profile, the average performance on each measure (ignoring the group component) is obtained. Mean differences between adjacent pairs are then tested. While profile analysis is a relatively new technique in the area of neuropsychology, it has been applied successfully (Francis et al., 1991; Stewart, 1992) and is a conceptually simple technique that allows for direct examination of differences in performance patterns.

Study 3. In order to determine whether there were group differences on the General Verbal Factor, a t-test was performed. Profile analytic techniques were used to examine the performance of both groups of subjects on the Semantic and Acoustic Processing Factors.

# CHAPTER III

# RESULTS

The major analyses investigating hypotheses about the factors identified by confirmatory factor analytic studies (Davidson, 1992; Francis et al., 1992) are presented. The data were analyzed using the Statistical Analysis System developed by the SAS Institute Inc. (1985), the Statistical Package for the Social Sciences-X (SPSS$^{X}$; Norŭsis, 1985), or LISREL (Jöreskog & Sörbom, 1986).

All analyses were conducted on the factors determined by both statistical and clinical selection criteria. Results obtained from both assessments are presented. In addition, results are presented for all analyses that included the Category Test on the Complex Visual-Spatial Relations factor and the Aphasia Screening Test on the Semantic Processing factor.

## Study 1

Investigation of the hypotheses for Study 1 was conducted by using (a) stepwise discriminant function analyses to determine which factors best predicted group membership and (b) logistic regression analyses to determine the predictive accuracy of the Simple Spatial-Motor and Complex Visual-Spatial Relations factors.

### A. Discriminant Function Analyses

In order to determine which of the seven factors under investigation would be the most useful in classifying Groups R-S and A children, a stepwise discriminant function analysis was conducted. Analyses maximized Wilks' Lambda. Of the original 122 subjects, 92 (approximately 75%) were randomly selected to be used in the initial analysis with the remaining 30 (approximately 25%) reserved for cross-validation.

### Clinical selection criteria

Analysis of the factors determined by clinical selection criteria (without the Category Test) resulted in a significant discriminant function, [$\chi^2$ (7, N = 92) = 35.97, p = .0000]. All seven of the factors were retained in the canonical discriminant function equation. The overall classification rate was 77.17% for the original sample. Cross-validation of the obtained function using the holdout sample resulted in a shrinking of the overall classification rate to 66.67%.

The classification rates for both the original and the validation sample are presented in Table 5. As can be seen from this table, there is a relatively high rate of misclassifications for the original sample. The misclassification rate is even greater for the validation sample.

Table 6 presents the loading matrix of correlations between the predictor variables and the discriminant function, along with the unstandardized discriminant function coefficients. From this table it can be seen that four factors (Acoustic Processing, Semantic Processing, Complex Visual-Spatial

Table 5

Discriminant classification results and cross-validation: Clinical selection of the factors

| Actual Group | N | Predicted Group<br>R-S | <br>A | Overall Accuracy |
|---|---|---|---|---|
| **Original Sample:** | | | | |
| R-S | 46 | 35<br>(76.1%) | 11<br>(23.9%) | |
| A | 46 | 10<br>(21.7%) | 36<br>(78.3%) | 77.17% |
| **Validation Sample:** | | | | |
| R-S | 15 | 9<br>(60.0%) | 6<br>(40.0%) | |
| A | 15 | 4<br>(26.7%) | 11<br>(73.3%) | 66.67% |

Table 6

Correlations and unstandardized discriminant function coefficients: Clinical selection of the factors

| Predictor Variables | Correlation of predictor variables with discriminant function | Unstandardized discriminant function coefficients |
|---|---|---|
| Simple Motor | 0.18 | 0.030 |
| Motor Steadiness | **0.31** | 0.031 |
| Simple Spatial-Motor | -0.26 | -0.027 |
| Complex Visual-Spatial Relations | **-0.33** | -0.059 |
| Speeded Motor Sequencing | -0.12 | -0.034 |
| Acoustic Processing | **0.74** | 0.088 |
| Semantic Processing | **0.39** | 0.035 |
| Constant | | -2.352 |

Relations, and Motor Steadiness) are the best discriminating variables ($r$ = .74, .39, -.33, and .31, respectively).

When the Category Test was added to the Complex Visual-Spatial Relations factor, the resulting discriminant function was also significant [$\chi^2$ (4, $N$ = 92) = 30.16, $p$ = .0000]. However, only four factors were retained in the equation (Motor Steadiness, Simple Spatial-Motor, Acoustic Processing, and Semantic Processing). Increases in the number of factors beyond these four failed to increase the discriminating power of the equation significantly ($F$ < 1.00). The overall classification rate was 71.74% for the original sample. Classification of the two groups of learning-disabled children was worse in the cross-validation sample (60%).

The classification rates for both the original and the validation sample are presented in Table 7. As can be seen from this table, there is a relatively high rate of misclassifications for the original sample and this rate is even greater for the validation sample (particularly for Group 2).

Table 8 contains the loading matrix of the correlations between the factors and the discriminant function, and the unstandardized discriminant function coefficients. Examination of this table reveals that the Acoustic Processing ($r$ = .84), Semantic Processing ($r$ = .44), and Motor Steadiness ($r$ = .34) factors are the best discriminators between the two groups.

In general, results of discriminant function analysis using clinical selection criteria indicate that the variables which best discriminate between the

Table 7

Discriminant classification results and cross-validation: Clinical selection of the factors (including Category Test)

| Actual Group | N | Predicted Group<br>R-S | <br>A | Overall Accuracy |
|---|---|---|---|---|
| **Original Sample:** | | | | |
| R-S | 46 | 33<br>(71.7%) | 13<br>(28.3%) | |
| A | 46 | 13<br>(28.3%) | 33<br>(71.7%) | 71.74% |
| **Validation Sample:** | | | | |
| R-S | 15 | 6<br>(40.0%) | 9<br>(60.0%) | |
| A | 15 | 3<br>(20.0%) | 12<br>(80.0%) | 60.00% |

Table 8

Correlations and unstandardized discriminant function coefficients: Clinical selection of the factors (including Category Test)

| Predictor Variables | Correlation of predictor variables with discriminant function | Unstandardized discriminant function coefficients |
|---|---|---|
| Simple Motor | 0.01 | * |
| Motor Steadiness | **0.34** | 0.026 |
| Simple Spatial-Motor | -0.29 | -0.041 |
| Complex Visual-Spatial Relations | -0.06 | * |
| Speeded Motor Sequencing | 0.04 | * |
| Acoustic Processing | **0.84** | 0.099 |
| Semantic Processing | **0.44** | 0.037 |
| Constant | | -5.222 |

* These factors were not included in the discriminant function

two groups are the two language factors and the Motor Steadiness Factor. However, there is a lack of consistency in the classification scheme, as evidenced by the large differences in classification rates between the original and validation samples. In addition, the inclusion of the Category Test does not appear to add to the discriminatory power of the Complex Visual-Spatial Relations factor.

Statistical selection criteria

Analysis of the factors determined by statistical selection criteria (without the Category Test or the Aphasia Screening Test) resulted in a significant discriminant function [$\chi^2$ (6, $\underline{N}$ = 92) = 68.89, $\underline{p}$ = .0000]. All factors, with the exception of the Simple Motor Factor, were retained in the equation. The discriminant function correctly classified 84.78% of the original sample and 83.33% of the validation sample, indicating a high degree of consistency in the classification scheme (see Table 9).

Table 10 contains the loading matrix of the correlations between the factors and the discriminant function. The unstandardized discriminant function coefficients are also presented. From this table it is seen that only the Acoustic Processing and Semantic Processing factors correlate substantially with the discriminant function ($\underline{r}$ = .81 and .34, respectively). Thus, the language factors appear to be the best discriminating variables in this analysis.

When the Category Test was added to the variables composing the factors, a significant discriminant function was obtained [$\chi^2$ (6, $\underline{N}$ = 92) = 66.44,

Table 9

Discriminant classification results and cross-validation: Statistical selection of the factors

| | | Predicted Group | | |
|---|---|---|---|---|
| Actual Group | N | R-S | A | Overall Accuracy |
| **Original Sample:** | | | | |
| R-S | 46 | 38<br>(82.6%) | 8<br>(17.4%) | |
| A | 46 | 6<br>(13.0%) | 40<br>(87.0%) | 84.78% |
| **Validation Sample:** | | | | |
| R-S | 15 | 12<br>(80.0%) | 3<br>(20.0%) | |
| A | 15 | 2<br>(13.3%) | 13<br>(86.7%) | 83.33% |

Table 10

Correlations and unstandardized discriminant function coefficients: Statistical selection of the factors

| Predictor Variables | Correlation of predictor variables with discriminant function | Unstandardized discriminant function coefficients |
|---|---|---|
| Simple Motor | 0.10 | * |
| Motor Steadiness | 0.12 | 0.091 |
| Simple Spatial-Motor | 0.07 | -0.068 |
| Complex Visual-Spatial Relations | -0.19 | -0.100 |
| Speeded Motor Sequencing | -0.19 | -0.053 |
| Acoustic Processing | **0.81** | 0.115 |
| Semantic Processing | **0.34** | 0.036 |
| Constant | | 0.243 |

* This factor was not included in the discriminant function

$\underline{p}$ = .0000]. This function received loadings from all of the factors except the Simple Motor factor and correctly classified 85.87% of the original sample and 83.33% of the validation sample (see Table 11). This indicates a high degree of consistency in the classification scheme.

The correlations between the factors and the discriminant function, and the unstandardized discriminant function coefficients for this analysis, are presented in Table 12. Examination of the table reveals that the Acoustic Processing factor ($\underline{r}$ = .84), the Semantic Processing factor ($\underline{r}$ = .35), and the Speeded Motor Sequencing factor ($\underline{r}$ = -.30) are the best discriminating variables in this analysis.

The total number of errors made on the Aphasia Screening Test was added to the Semantic Processing factor in order to determine whether this would affect the classification rate of the factors. The resulting discriminant function using the seven factors as predictors was significant [$\chi^2$ (6, $\underline{N}$ = 92) = 60.69, $\underline{p}$ = .0000]. Similar to previous findings using the statistical selection criteria, all factors (except the Simple Motor factor) were included in the discriminant function. Of the original sample, 82.61% were correctly classified and the classification rate improved slightly in the validation sample (83.33%). Table 13 presents the classification rates for both samples.

Examination of Table 14 (the loading pattern matrix and unstandardized discriminant function coefficients) reveals that the Semantic Processing factor ($\underline{r}$ = .75), the Acoustic Processing factor ($\underline{r}$ = .53), and the Speeded Motor

Table 11

Discriminant classification results and cross-validation: Statistical selection of the factors (including Category Test)

| | | Predicted Group | | |
|---|---|---|---|---|
| Actual Group | N | R-S | A | Overall Accuracy |
| **Original Sample:** | | | | |
| R-S | 46 | 38<br>(82.6%) | 8<br>(17.4%) | |
| A | 46 | 5<br>(10.9%) | 41<br>(89.1%) | 85.87% |
| **Validation Sample:** | | | | |
| R-S | 15 | 12<br>(80.0%) | 3<br>(20.0%) | |
| A | 15 | 2<br>(13.3%) | 13<br>(86.7%) | 83.33% |

Table 12

Correlations and unstandardized discriminant function coefficients: Statistical selection of the factors (including Category Test)

| Predictor Variables | Correlation of predictor variables with discriminant function | Unstandardized discriminant function coefficients |
|---|---|---|
| Simple Motor | 0.08 | * |
| Motor Steadiness | 0.13 | 0.080 |
| Simple Spatial-Motor | 0.07 | -0.068 |
| Complex Visual-Spatial Relations | -0.17 | -0.082 |
| Speeded Motor Sequencing | **-0.30** | -0.071 |
| Acoustic Processing | **0.84** | 0.116 |
| Semantic Processing | **0.35** | 0.038 |
| Constant | | 0.679 |

* This factor was not included in the discriminant function

Table 13

Discriminant classification results and cross-validation: Statistical selection of the factors (including Aphasia Screening Test)

| | | Predicted Group | | |
|---|---|---|---|---|
| Actual Group | N | R-S | A | Overall Accuracy |
| **Original Sample:** | | | | |
| R-S | 46 | 38<br>(82.6%) | 8<br>(17.4%) | |
| A | 46 | 8<br>(17.4%) | 38<br>(82.6%) | 82.61% |
| **Validation Sample:** | | | | |
| R-S | 15 | 12<br>(80.0%) | 3<br>(20.0%) | |
| A | 15 | 2<br>(13.3%) | 13<br>(86.7%) | 83.33% |

Table 14

Correlations and unstandardized discriminant function coefficients: Statistical selection of the factors (including Aphasia Screening Test)

| Predictor Variables | Correlation of predictor variables with discriminant function | Unstandardized discriminant function coefficients |
|---|---|---|
| Simple Motor | 0.24 | * |
| Motor Steadiness | 0.13 | 0.088 |
| Simple Spatial-Motor | 0.08 | -0.058 |
| Complex Visual-Spatial Relations | -0.21 | -0.072 |
| Speeded Motor Sequencing | **-0.32** | -0.092 |
| Acoustic Processing | **0.53** | 0.040 |
| Semantic Processing | **0.75** | 0.158 |
| Constant | | -1.971 |

* This factor was not included in the discriminant function

Sequencing factor ($r$ = -.32) were the best discriminators in this analysis.

The final discriminant function was calculated for the statistically determined factors, including both the Category Test and the Aphasia Screening Test. This function was significant [$\chi^2$ (6, $N$ = 92) = 58.99, $p$ = .0000]. This function included all factors except the Simple Motor factor and correctly classified 81.52% of the original sample. The classification rate increased slightly to 83.33% in the validation sample (see Table 15).

The correlation coefficients between the factors and the discriminant function, and the unstandardized discriminant function coefficients, are presented in Table 16. From this table it is observed that the Semantic Processing factor, the Acoustic Processing factor, and the Speeded Motor Sequencing factor were, once again, the best discriminating factors between the groups ($r$ = .77, .54, -.33, respectively).

In general, discriminant functions obtained from the factors that were derived using statistical selection criteria indicate that the two language factors and the Speeded Motor Sequencing factor are the best discriminating factors between the two groups. Classification rates are good and there is a high degree of consistency within the classification scheme (as evidenced by the similar classification rates observed between the original and the validation sample). Little difference was observed in the overall classification rate when the Category Test and the Aphasia Screening Test were added to the variables constituting the factors. Any differences observed affected the classification

Table 15

Discriminant classification results and cross-validation: Statistical selection of the factors (including Category Test and Aphasia Screening Test)

|  |  | Predicted Group |  |  |
|---|---|---|---|---|
| Actual Group | N | R-S | A | Overall Accuracy |
| **Original Sample:** |  |  |  |  |
| R-S | 46 | 38<br>(82.6%) | 8<br>(17.4%) |  |
| A | 46 | 9<br>(19.6%) | 37<br>(80.4%) | 81.52% |
| **Validation Sample:** |  |  |  |  |
| R-S | 15 | 12<br>(80.0%) | 3<br>(20.0%) |  |
| A | 15 | 2<br>(13.3%) | 13<br>(86.7%) | 83.33% |

Table 16

Correlations and unstandaroized discriminant function coefficients: Statistical selection of the factors (including Category Test and Aphasia Screening Test)

| Predictor Variables | Correlation of predictor variables with discriminant function | Unstandardized discriminant function coefficients |
|---|---|---|
| Simple Motor | 0.23 | * |
| Motor Steadiness | 0.14 | 0.076 |
| Simple Spatial-Motor | 0.08 | -0.057 |
| Complex Visual-Spatial Relations | -0.18 | -0.052 |
| Speeded Motor Sequencing | **-0.33** | -0.110 |
| Acoustic Processing | **0.54** | 0.039 |
| Semantic Processing | **0.77** | 0.163 |
| Constant | | -1.787 |

* This factor was not included in the discriminant function

rate of Group A children. The addition of the Aphasia Screening Test to the Semantic Processing Factor resulted in this factor being the best discriminating variable between the groups. When the Aphasia Screening Test was omitted, the Acoustic Processing factor was the best discriminator. In general, however, the results of discriminant factor analysis suggested that the Category and Aphasia Screening Test do not add any significant discriminatory power to the factors of neuropsychological functioning.

## B. Logistic Regression Analyses

In order to examine the more specific hypothesis that the Simple Spatial-Motor and Complex Visual-Spatial Relations factors would be the most salient to the discrimination of the two groups of learning-disabled children, logistic regression analyses were conducted through SPSS$^{X}$. Logistic regression was also used to determine the best predictors of group membership.

### Clinical selection criteria

The first logistic regression was calculated on the factors selected according to clinical criteria. As it was hypothesized that the Simple Spatial-Motor and Complex Visual-Spatial Relations factors would be the best predictors of group membership, these factors were entered into the equation first. Results indicated that these two factors alone could predict 59.02% of Group R-S children and 57.38% of Group A children accurately. However, the results also indicated that this restricted model differed significantly from a "perfect" model that would describe the data well [$\chi^2$ (119, $\underline{N}$ = 122) = 162.337,

$p$ = .0051]. For this reason, other variables were allowed to enter the prediction equation, based on the likelihood-ratio test. The Simple Spatial-Motor and Complex Visual-Spatial Relations factors were constrained to remain in the analysis.

The best logistic regression model obtained under these conditions was one that included the Simple Spatial-Motor factor, the Complex Visual-Spatial Relations factor, the Motor Steadiness factor, and the Acoustic Processing factor. This model did not differ from a "perfect" model [$\chi^2$ (117, $N$ = 122) = 130.225, $p$ = .1902) and fit the data well. However, the overall level of correct classification was 72.13% (68.85% for Group R-S children and 75.41% for Group A children). In addition, the Simple Spatial-Motor factor was not a significant contributing variable to the prediction equation [Wald (1) = 1.4398, $p$ = .2302]. Results are presented in Table 17.

The analysis was re-run with no constraints as to how (or which) variables entered the equation. This resulted in an equation containing just the Complex Visual-Spatial Relations and Acoustic Processing factors that correctly predicted only 68.03% of all the subjects (67.21% of Group R-S and 68.85% of Group A). Both factors were significant contributors to the prediction equation. This model did not differ significantly from the "perfect" model [$\chi^2$ (119, $N$ = 122) = 135.257, $p$ = .1464] and provided a reasonable "fit" to the data. Results are also presented in Table 17.

When the Category Test was added to the Complex Visual-Spatial

Table 17

Logistic Regression analysis results for the neuropsychological factors selected according to clinical criteria

**Constrained Entry**

| Variable | Beta | Standard Error | Wald | df | p |
|---|---|---|---|---|---|
| Complex Visual-Spatial Relations | -.0814 | .0319 | 6.53 | 1 | .0106 |
| Simple Spatial-Motor | -.0244 | .0203 | 1.44 | 1 | .2302 |
| Motor Steadiness | .0349 | .0176 | 3.95 | 1 | .0468 |
| Acoustic Processing | .1336 | .0307 | 18.90 | 1 | .0000 |
| Constant | -1.799 | | | | |

**Unconstrained Entry**

| Variable | Beta | Standard Error | Wald | df | p |
|---|---|---|---|---|---|
| Complex Visual-Spatial Relations | -.0795 | .0299 | 7.07 | 1 | .0078 |
| Acoustic Processing | .1362 | .0302 | 20.27 | 1 | .0000 |
| Constant | -1.363 | | | | |

Relations factor, logistic regression analyses revealed that this factor and the Simple Spatial-Motor factor could correctly predict 55.74% of Group R-S and 60.66% of Group A children. This equation, however, did not fit the data well [$\chi^2$ (119, $\underline{N}$ = 122) = 163.951, $\underline{p}$ = .004]. As such, the remaining variables were allowed to enter the equation, based on the likelihood-ratio test.

The best fitting logistic regression equation (see Table 18) included the Complex Visual-Spatial Relations, the Simple Spatial-Motor, Motor Steadiness, and Acoustic Processing factors. This equation correctly classified 65.57% of Group R-S children and 73.77% of Group A children and represented a good fit to the data [$\chi^2$ (117, $\underline{N}$ = 122) = 133.029, $\underline{p}$ = .1476]. However, the Simple Spatial-Motor and Motor Steadiness Factors did not contribute significantly to the model [Wald (1) = 1.9875, $\underline{p}$ = .1586 and Wald (1) = 3.80, $\underline{p}$ = .0513, respectively]. The analysis was then re-run with no constraints on the variables.

The results of this analysis (see Table 18) indicated that the best prediction equation included the Complex Visual-Spatial Relations and Acoustic Processing factors. This model fit the data reasonably well [$\chi^2$ (119, $\underline{N}$ = 122) = 138.337, $\underline{p}$ = .1086]. However, the overall classification rate was only 67.21% (67.21% of Group R-S and 67.21% of Group A children were correctly classified).

Results from logistic regression analyses for the factors (selected according to clinical criteria) indicate that, in general, the Complex Visual-

Table 18

Logistic Regression analysis results for the neuropsychological factors selected according to clinical criteria (including Category Test)

**Constrained Entry**

| Variable | Beta | Standard Error | Wald | df | p |
|---|---|---|---|---|---|
| Complex Visual-Spatial Relations | -.0729 | .0361 | 4.08 | 1 | .0434 |
| Simple Spatial-Motor | -.0279 | .0198 | 1.99 | 1 | .1586 |
| Motor Steadiness | .0335 | .0172 | 3.80 | 1 | .0513 |
| Acoustic Processing | .1294 | .0302 | 18.36 | 1 | .0000 |
| Constant | -1.904 | | | | |

**Unconstrained Entry**

| Variable | Beta | Standard Error | Wald | df | p |
|---|---|---|---|---|---|
| Complex Visual-Spatial Relations | -.0718 | .0341 | 4.43 | 1 | .0353 |
| Acoustic Processing | .1311 | .0295 | 19.68 | 1 | .0000 |
| Constant | -1.613 | | | | |

Spatial Relations and Acoustic Processing factors are the best predictors of group membership. The Motor Steadiness factor was a good predictor only under conditions where the model for group membership was constrained to include both the Complex Visual-Spatial Relations and Simple Spatial-Motor factors. When all factors were free to enter (or be removed from) the equation, the Motor Steadiness factor did not contribute significantly to the regression equation. However, the overall classification rates based on the equations using these factors are somewhat low and, as a result, a large number of cases are misclassified. The addition of the Category Test did not appear to affect the prediction and classification rates significantly.

Statistical selection criteria

The Simple Spatial-Motor and Complex Visual-Spatial Relations factors, selected according to statistical criteria, could correctly predict 57.38% of Group R-S and 62.30% of Group A children. The logistic regression equation differed significantly from the perfect model [$\chi^2$ (119, $\underline{N}$ = 122) = 162.064, $\underline{p}$ = .0053]. The remaining variables were then entered into the analysis using the likelihood-ratio method.

The best fitting logistic regression model under these conditions consisted of the Simple Spatial-Motor, Complex Visual-Spatial Relations, Motor Steadiness, and Acoustic Processing factors. This model fit the data well [$\chi^2$ (117, $\underline{N}$ = 122) = 76.810, $\underline{p}$ = .9985] and the four factors contributed significantly to the equation. The most contributory were the Acoustic

Processing and Complex Visual-Spatial Relations factors. This model correctly classified 83.61% of both Group R-S and Group A children (an overall classification rate of 83.61%). Table 19 presents the results of this analysis. The results of this analysis were identical to those obtained when all variables were allowed to enter (and be removed) from the equation freely (i.e., no constraints on the variables).

When the Category Test was added to the Complex Visual-Spatial Relations factor, this factor along with the Simple Spatial-Motor factor, could correctly predict the membership of 55.74% of Group R-S and 59.02% of Group A. This regression model did not fit the data well [$\chi^2$ (119, $\underline{N}$ = 122) = 162.91, $\underline{p}$ = .0047], and the remaining variables were entered into the analysis.

The best fitting regression equation obtained from this analysis (see Table 20 for results) included the Simple Spatial-Motor, Complex Visual-Spatial Relations, Motor Steadiness, and Acoustic Processing factors and fit the data well [$\chi^2$ (117, $\underline{N}$ = 122) = 79.072, $\underline{p}$ = .9972]. This model could correctly classify 85.25% and 81.97% of Group R-S and A children, respectively. All of the factors, with the exception of the Simple Spatial-Motor factor [Wald (1) = 3.3481, $\underline{p}$ = .0673], were significant contributors to the equation. For this reason, the analysis was then conducted with no constraints on the data.

The results of this analysis (see Table 20) indicated that the best fitting regression model included the Complex Visual-Spatial Relations, Motor Steadiness, and Acoustic Processing factors. This model fit the data well

Table 19

Logistic Regression analysis results for the neuropsychological factors selected according to statistical criteria

**Constrained Entry**

| Variable | Beta | Standard Error | Wald | df | p |
|---|---|---|---|---|---|
| Complex Visual-Spatial Relations | -.2955 | .0792 | 13.94 | 1 | .0002 |
| Simple Spatial-Motor | -.1650 | .0811 | 4.14 | 1 | .0418 |
| Motor Steadiness | .2342 | .0778 | 9.05 | 1 | .0026 |
| Acoustic Processing | .3015 | .0557 | 30.03 | 1 | .0000 |
| Constant | -.6366 | | | | |

**Unconstrained Entry**

| Variable | Beta | Standard Error | Wald | df | p |
|---|---|---|---|---|---|
| Complex Visual-Spatial Relations | -.2955 | .0792 | 13.94 | 1 | .0002 |
| Simple Spatial-Motor | -.1650 | .0811 | 4.14 | 1 | .0418 |
| Motor Steadiness | .2342 | .0778 | 9.05 | 1 | .0026 |
| Acoustic Processing | .3015 | .0557 | 30.03 | 1 | .0000 |
| Constant | -.6366 | | | | |

Table 20

Logistic Regression analysis results for the neuropsychological factors selected according to statistical criteria (including Category Test)

**Constrained Entry**

| Variable | Beta | Standard Error | Wald | df | p |
|---|---|---|---|---|---|
| Complex Visual-Spatial Relations | -.2804 | .0779 | 12.94 | 1 | .0003 |
| Simple Spatial-Motor | -.1439 | .0786 | 3.35 | 1 | .0673 |
| Motor Steadiness | .1961 | .0702 | 7.80 | 1 | .0052 |
| Acoustic Processing | .3030 | .0054 | 29.92 | 1 | .0000 |
| Constant | -.5393 | | | | |

**Unconstrained Entry**

| Variable | Beta | Standard Error | Wald | df | p |
|---|---|---|---|---|---|
| Complex Visual-Spatial Relations | -.2306 | .0699 | 10.89 | 1 | .001 |
| Motor Steadiness | .0917 | .0383 | 5.73 | 1 | .0167 |
| Acoustic Processing | .2903 | .0525 | 30.60 | 1 | .0000 |
| Constant | -4.337 | | | | |

[$\chi^2$ (118, N = 122) = 82.674, p = .9944] and correctly classified 83.61% of Group R-S and 80.33% of Group A children correctly. All variables contributed significantly to the regression equation.

In the next analysis, the Aphasia Screening Test was added to the Semantic Processing factor. The Simple Spatial-Motor and Complex Visual-Spatial Relations factors classified 57.38% of Group R-S and 62.30% of Group A children correctly. The regression model did not fit the data well [$\chi^2$ (119, N = 122) = 162.064, p = .0053] and the remaining variables were entered into the analysis.

The best fitting regression model obtained from this analysis (see Table 21) indicated that the Simple Spatial-Motor, Complex Visual-Spatial Relations, Motor Steadiness, Acoustic Processing, and Semantic Processing factors were the best predictors. These variables all contributed significantly to the equation. This model fit the data well [$\chi^2$ (116, N = 122) = 61.684, p = 1.000] and correctly classified 85.25% of Group R-S children and 88.52% of Group A children. The same results were obtained when all variables were allowed to enter (and be removed from) the equation freely.

The final logistic regression equation was calculated using the factors (determined by statistical selection criteria) as predictors and included both the Category and Aphasia Screening Tests. Under these conditions, the Simple Spatial-Motor and Complex Visual-Spatial Relations factors alone could correctly classify 55.74% and 59.02% of Groups R-S and A children,

Table 21

Logistic Regression analysis results for the neuropsychological factors selected according to statistical criteria (including Aphasia ScreeningTest)

**Constrained Entry**

| Variable | Beta | Standard Error | Wald | df | p |
|---|---|---|---|---|---|
| Complex Visual-Spatial Relations | -.3277 | .0949 | 11.56 | 1 | .0007 |
| Simple Spatial-Motor | -.2020 | .0955 | 4.47 | 1 | .0345 |
| Motor Steadiness | .2777 | .0931 | 8.91 | 1 | .0028 |
| Acoustic Processing | .2629 | .0634 | 17.20 | 1 | .0000 |
| Semantic Processing | .2830 | .0835 | 11.48 | 1 | .0007 |
| Constant | -10.86 | | | | |

**Unconstrained Entry**

| Variable | Beta | Standard Error | Wald | df | p |
|---|---|---|---|---|---|
| Complex Visual-Spatial Relations | -.3277 | .0949 | 11.56 | 1 | .0007 |
| Simple Spatial-Motor | -.2020 | .0955 | 4.47 | 1 | .0345 |
| Motor Steadiness | .2777 | .0931 | 8.91 | 1 | .0028 |
| Acoustic Processing | .2629 | .0634 | 17.20 | 1 | .0000 |
| Semantic Processing | .2830 | .0835 | 11.48 | 1 | .0007 |
| Constant | -10.86 | | | | |

respectively. This model, however, did not fit the data well [$\chi^2$ (119, N = 122) = 162.910, p = .0047]. The remaining variables were then entered into the analysis, using the likelihood-ratio test.

The results of this analysis (see Table 22) revealed that the best fitting regression model included the Simple Spatial-Motor, Complex Visual-Spatial Relations, Motor Steadiness, Acoustic Processing, and Semantic Processing factors [$\chi^2$ (116, N = 122) = 63.261, p = 1.000]. All factors, with the exception of the Simple Spatial-Motor factor [Wald (1) = 3.79, p = .0516], were significant contributors to the model and 85.25% of Group R-S and 88.52% of Group A children were correctly classified using this regression model. As the Simple Spatial-Motor factor was not a significant contributing variable to the equation, the analyses were then conducted with no constraints on the data.

Results obtained from this analysis (see Table 22) revealed that the best fitting regression model included the Complex Visual-Spatial Relations, Motor Steadiness, Acoustic Processing, and Semantic Processing factors [$\chi^2$ (117, N=122) = 67.466, p = 0.999]. This model correctly classified 88.52% of both groups of learning-disabled children.

The results of logistic regression analyses using the factors selected according to statistical criteria indicated that, in general, the Complex Visual-Spatial Relations, Motor Steadiness, Acoustic Processing, and the Simple Spatial-Motor factors were the best predictors of group membership. Closer examination reveals that the Acoustic Processing and Complex Visual-Spatial

Table 22

Logistic Regression analysis results for the neuropsychological factors selected according to statistical criteria (including Category and Aphasia Screening Tests)

**Constrained Entry**

| Variablo | Beta | Standard Error | Wald | df | p |
|---|---|---|---|---|---|
| Complex Visual-Spatial Relations | -.3135 | .0935 | 11.25 | 1 | .0008 |
| Simple Spatial-Motor | -.1843 | .0947 | 3.79 | 1 | .0516 |
| Motor Steadiness | .2407 | .0843 | 8.14 | 1 | .0043 |
| Acoustic Processing | .2647 | .0638 | 17.21 | 1 | .0000 |
| Semantic Processing | .2846 | .0834 | 11.66 | 1 | .0006 |
| Constant | -10.59 | | | | |

**Unconstrained Entry**

| Variable | Beta | Standard Error | Wald | df | p |
|---|---|---|---|---|---|
| Complex Visual-Spatial Relations | -.2378 | .0771 | 9.52 | 1 | .0020 |
| Motor Steadiness | .1014 | .0395 | 6.58 | 1 | .0103 |
| Acoustic Processing | .2419 | .0582 | 17.30 | 1 | .0000 |
| Semantic Processing | .2670 | .0799 | 11.18 | 1 | .0008 |
| Constant | -14.75 | | | | |

Relations factors are the two best factors for predicting group membership. The addition of the Category Test to the Complex Visual-Spatial Relations factor tended to eliminate the contributing factor of Simple Spatial-Motor abilities. When the Aphasia Screening Test was added to the Semantic Processing factor, this factor contributed significantly to the regression equations. This was not the case when the Aphasia Screening Test was omitted from those variables that defined the Semantic Processing factor.

### Summary of results for Study 1

The results obtained from discriminant function and logistic regression analyses partially supported the hypotheses proposed. Although the motor and psychomotor factors (and, in particular, the Simple Spatial-Motor and Complex Visual-Spatial Relations factors) were not the best discriminators between, or predictors of, the two groups of learning-disabled children, they contributed to the best discriminant and regression equations. When only these two factors were included in regression equations, the overall classification rate tended to be around 58%. The best **single** predictor and discriminating factor was the Acoustic Processing factor.

The best discriminant function equations combined the Acoustic Processing factor with the Semantic Processing factor and either the Motor Steadiness factor (under clinical selection criteria) or the Speeded Motor Sequencing factor (under statistical selection criteria). The Complex Visual-

Spatial Relations factor also contributed when the factors were selected according to clinical criteria and when the Category Test was excluded from the analyses.

The best logistic regression equations combined the Acoustic Processing factor with the Complex Visual-Spatial Relations factor (under both clinical and statistical selection criteria), and also with the Motor Steadiness and Simple Spatial-Motor factors (under statistical selection criteria only). The Semantic Processing factor contributed to the logistic regression equations only when the Aphasia Screening Test was a component of this factor.

Thus, there appears to be partial support for the hypothesis that those factors representing the primary neuropsychological deficits of Group A children and assets of Groups R-S children (i.e., those tapping psychomotor and motor skill) best discriminate and predict the performance of these two groups. However, factors tapping language ability (as reflected primarily by the Acoustic Processing factor) were the most significant factors in both discriminant function and logistic regression equations. These factors represent those skills underlying the primary neuropsychological deficits of Group R-S children and assets of Group A children.. Therefore, a combination of factors assessing the primary neuropsychological assets and deficits of both groups of children appears to provide the best discrimination and prediction of their performance.

While the addition of the Category Test contributed little to the overall discrimination or prediction of the groups, the Aphasia Screening Test added to the strength of the prediction ability of the Semantic Processing factor. In fact, the Semantic Processing factor only contributed to logistic regression equations when the Aphasia Screening Test was added to those variables defining the factor.

The classification rates of the factors and the "fit" of discriminant and regression equations were best when factors were selected according to statistical criteria rather than when they were chosen according to clinical criteria (a reduced number of variables). However, slightly different patterns of results were obtained from clinical and statistical selection criteria. Although the Acoustic Processing factor remained the single best discriminator and predictor under both selection criteria, other factors contributed to the equations differentially depending on which selection criteria were used.

### Study 2

Examination of the hypotheses for Study 2 consisted of: (a) investigating whether the data conformed to a simplex model; (b) comparison of the two groups on the five neuropsychological factors [through multivariate analysis of variance (MANOVA) and Profile Analytic techniques]; and (c) comparison of each group individually on the five neuropsychological factors.

In the appendices and figures related to Study 2, Factor 1 refers to the Simple Motor factor, Factor 2 is the Motor Steadiness factor, Factor 3 is the Simple Spatial-Motor factor, Factor 4 is the Complex Visual-Spatial Relations factor, and Factor 5 refers to the Speeded Motor Sequencing factor.

### A. Investigating the Simplex Model

Data which is hierarchical in nature should have, as its structure, a simplex model. A simplex model is one in which the correlations between "neighbouring" variables are higher than those between more distally related variables. If the data conforms to a simplex model, then the data can be said to exhibit a hierarchy of complexity, with each variable building on the one immediately preceding it (Guttman, 1954; Humphreys, 1960, 1985). Analysis of the simplex model was conducted through LISREL (Jöreskog & Sörbom, 1986) using both the correlation and covariance matrices of the data.

The correlation matrices obtained for the five factors for the sample as a whole, Group R-S, and Group A are presented in Appendices A through C, respectively. Matrices for both clinical and statistical selection criteria are presented.

#### Clinical and statistical selection criteria

Results obtained from this analyses indicated that the data for the five factors failed to pass the tests of admissibility. As such, results could not be interpreted. Examination of the correlation matrices for Group A (the group in which the hierarchy was hypothesized to be most apparent) indicated that the Speeded Motor Sequencing factor (Factor 5) had low correlations with the Simple Spatial-Motor factor (Factor 3). In addition, the Simple Spatial-Motor factor tended to have higher correlations with the Complex Visual-Spatial

Relations factor (Factor 4) than the Complex Visual-Spatial Relations factor had with the Speeded Motor Sequencing factor. The only exception to this was under statistical selection criteria (without the Category Test). However, it was felt that combining the Simple Spatial-Motor factor with the Complex Visual-Spatial Relations factor to form a general Visual-Spatial Abilities factor might make some sense and was worth exploring as a potential for an alternative hierarchical arrangement. This combination also appeared to make some theoretical sense and so the Simple Spatial-Motor and Complex Visual-Spatial Relations factors were combined and the presence of a possible simplex model was investigated. The correlation matrices using the combined factor in place of the Simple Spatial-Motor and Complex Visual-Spatial Relations factors are presented in Appendices D through F.

The results were then re-run combining the Simple Spatial-Motor and Complex Visual-Spatial Relations factors. Although visual examination of the correlation matrices suggested that a simplex model might fit the data, the data failed to pass tests of admissibility. This was the case despite different attempts to constrain the data statistically.

For this reason, multivariate techniques (including profile analysis) were then applied to the data obtained from the sample as a whole and then to each individual group.

## B. Group comparisons on the neuropsychological factors

In order to examine group differences in performance across the five factors, the data were analyzed using MANOVA and profile analysis. Given that there are only two groups under investigation, the MANOVA is, in fact, a Hotelling's $T^2$ test.

Clinical selection criteria

The mean T-score performance of Group R-S and Group A children on the five neuropsychological factors is presented in Figure 3. Figure 4 presents the same data but with the Category Test added to the Complex Visual-Spatial Relations factor.

Examination of both Figures 3 and 4 reveals that the level of performance of the two groups across the five neuropsychological factors is remarkably similar. However, Group A performs better than Group R-S on the first two factors, and then performs at a lower level on the remaining three factors. The performance of both groups falls within average limits for all five factors.

Table 23 presents the multivariate and univariate analyses of variance conducted on the five motor, psychomotor, and visual-spatial factors selected according to clinical criteria, both with and without the addition of the Category Test to the Complex Visual-Spatial Relations factor.

A MANOVA (Hotelling's $T^2$) across the five motor, psychomotor, and visual-spatial factors (without the inclusion of the Category Test) was significant [$F$ (5,116) = 3.744, $p$ = .0035]. Examination of group differences for each variable revealed significant differences between the groups for the Motor

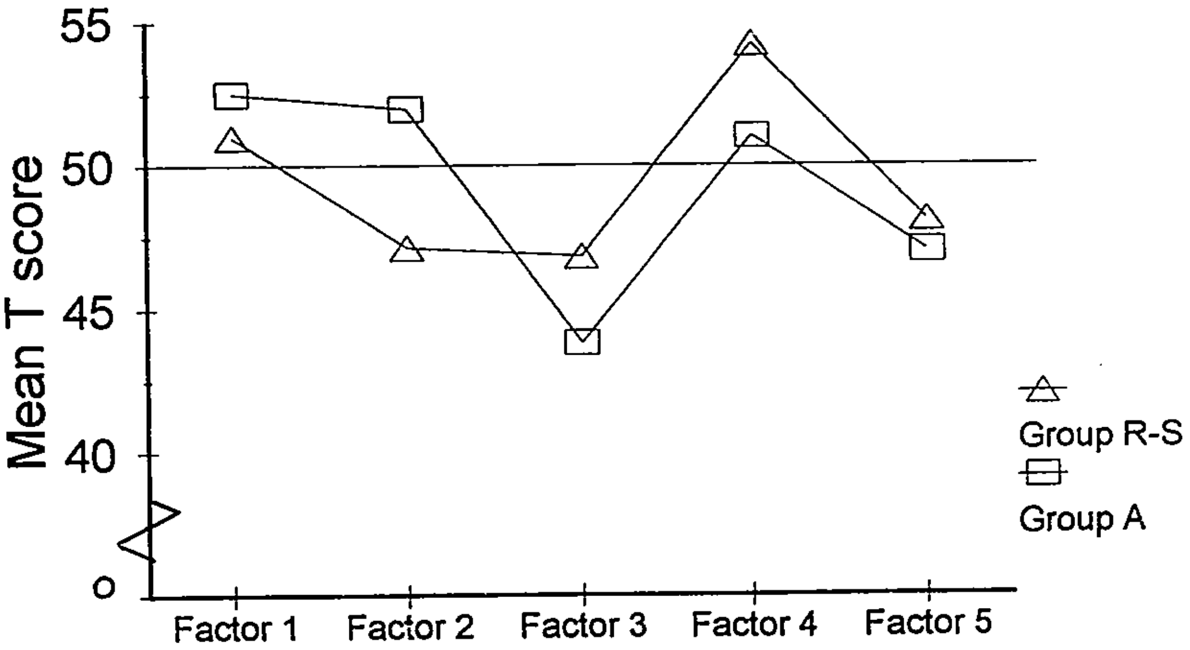


Figure 3. Mean T scores for motor and visual-spatial factors (clinical selection).

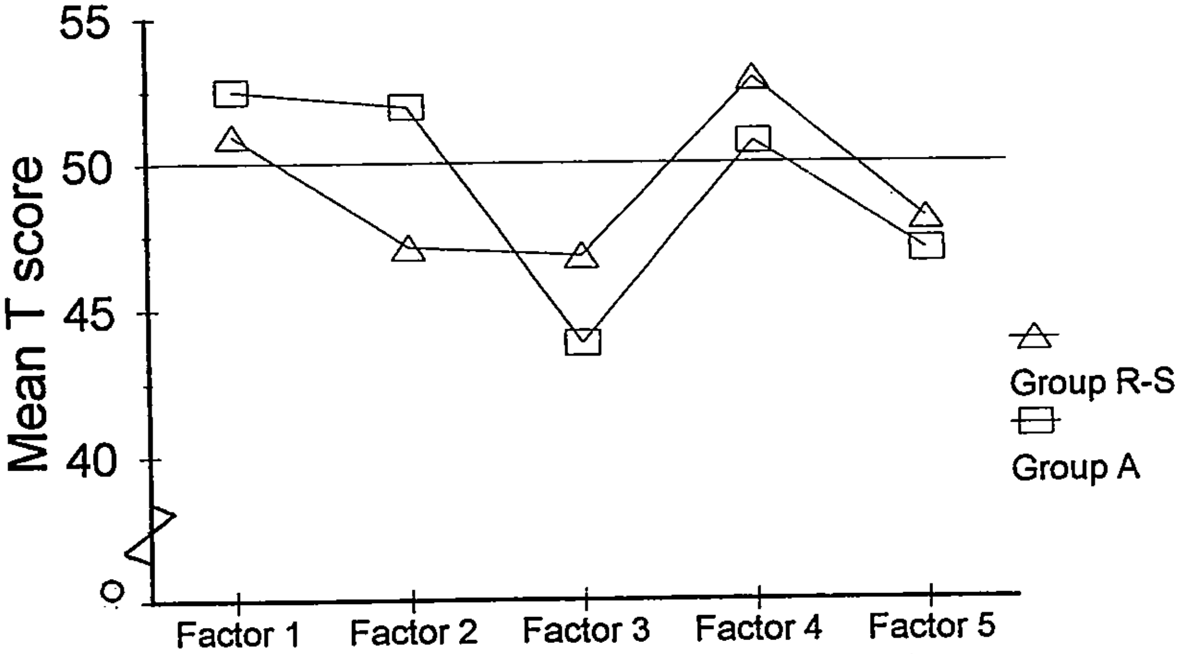


Figure 4. Mean T scores for motor and visual-spatial factors including Category Test (clinical selection).

Table 23

Summary of MANOVA and ANOVA results for motor and visual-spatial factors selected according to clinical criteria

| Variable | F value | p | Direction of significant effect ($p < .05$) |
|---|---|---|---|
| MANOVA (Hotelling-Lawley Trace) | 3.744 | .0035 | |
| Simple Motor (F1) | 1.42 | .2362 | n.s. |
| Motor Steadiness (F2) | 4.55 | .0350 | A > R-S |
| Simple Spatial-Motor (F3) | 2.45 | .1200 | n.s. |
| Complex Visual-Spatial Relations (F4) | 5.86 | .0170 | R-S > A |
| Speeded Motor Sequencing (F5) | .50 | .4831 | n.s. |

**Addition of Category Test to Complex Visual-Spatial Relations (F4)**

| Variable | F value | p | Direction of significant effect ($p < .05$) |
|---|---|---|---|
| MANOVA (Hotelling-Lawley Trace) | 3.278 | .0083 | |
| Simple Motor (F1) | 1.42 | .2362 | n.s. |
| Motor Steadiness (F2) | 4.55 | .0350 | A > R-S |
| Simple Spatial-Motor (F3) | 2.45 | .1200 | n.s. |
| Complex Visual-Spatial Relations (F4) | 3.75 | .0550 | n.s. |
| Speeded Motor Sequencing (F5) | .50 | .4831 | n.s. |

Steadiness factor [F (1,120) = 4.55, p = .035] and for the Complex Visual-Spatial Relations factor [F (1,120) = 5.86, p = .017]. Group A children performed at higher levels than Group R-S children on the former factor, whereas they performed at lower levels to Group R-S children on the latter one.

The addition of the Category Test to the Complex Visual-Spatial Relations factor resulted in an overall significant difference between the two groups [F (5,116) = 3.278, p = .0083]. When individual variables were analyzed, significant differences were observed only on the Motor Steadiness factor [F (1,120) = 4.55, p = .035], with Group A children performing in a superior manner to Group R-S children.

Profile analysis on the five measures (without the Category Test) indicated that the profiles deviated significantly from parallelism [F (4,117) = 4.328, p = .003]. When scores were averaged over groups, variables were found to deviate significantly from flatness with significant differences observed only between the Simple Spatial-Motor and Complex Visual-Spatial Relations factors [F (1,120) = 8.042, p = .005]. The levels test indicated that there was no difference between the overall performance of the two groups when the scores were averaged across all variables [F (1,120) < 1]. Similar findings were obtained when the Category Test was added to the analysis.

Follow-up examination of the performance of these two groups on these factors was conducted by two MANOVA's that modeled a repeated-measures design. The factors were entered as the repeated-measures and analyses were conducted separately for each group. The overall test for differences between the variables for Group R-S (without the inclusion of the Category Test) was significant [F (4,57) = 8.608, p < .001] and differences were observed between the Simple Spatial-Motor and Complex Visual-Spatial Relations factors, and Complex Visual-Spatial Relations and Speeded Motor Sequencing factors [F (1,60) = 11.060, p = .002, and F (1,60) = 21.545, p < .001, respectively]. The addition of the Category Test to the Complex Visual-Spatial Relations factor did not change the pattern (or significance level) of these results.

The second repeated-measures MANOVA (without the inclusion of the Category Test) was conducted on Group A children. The overall test for differences between the variables was significant [F (4,57) = 15.941, p < .001] and differences were observed between the Motor Steadiness and Simple Spatial-Motor factors, the Simple Spatial-Motor and Complex Visual-Spatial Relations factors, and Complex Visual-Spatial Relations and Speeded Motor Sequencing factors [F (1,60) = 10.24, p = .002, F (1,60) = 13.906, p = .000, F (1,60) = 6.824, p =.011, respectively]. Again, the addition of the Category Test did not alter the pattern of results obtained from this analysis.

The results of these two repeated measures MANOVAs indicated that both Group R-S and A children performed significantly better on measures underlying the Complex Visual-Spatial Relations factor than on those representing the Simple Spatial-Motor factor. In addition, their performance on the Speeded Motor Sequencing factor was worse than on the Complex Visual-Spatial Relations factor. Group A children's performance on the Simple Spatial-Motor factor differed significantly from (i.e., was lower than) their performance on the Motor Steadiness factor, suggesting that the Simple Spatial-Motor factor was more difficult for these children than the Motor Steadiness factor.

Investigation into the possibility of the data conforming to a simplex model had also included examination of a combined Simple Spatial-Motor and Complex Visual-Spatial Relations factor (Visual-Spatial Ability). For this reason, group comparisons were also conducted using four factors (Simple Motor, Motor Steadiness, Visual-Spatial Ability, and Speeded Motor Sequencing). The performance of the two groups is graphically presented in Figures 5 and 6 (without and with the inclusion of the Category Test). Examination of both figures reveals that Group A children's performance tends to decrease across the factors, whereas Group R-S children's performance decreases from the Simple Motor to the Motor Steadiness factor, then increases for the combined factor of Visual-Spatial ability. Their performance on the Speeded Motor Sequencing factor then decreases from that observed on the combined factor.

Table 24 presents the multivariate and univariate analyses of variance conducted on the four motor, psychomotor, and visual-spatial factors selected according to clinical criteria (with the combined Visual-Spatial Ability factor), both without and with the addition of the Category Test to the combined factor.

A MANOVA conducted on the two groups (without the inclusion of the

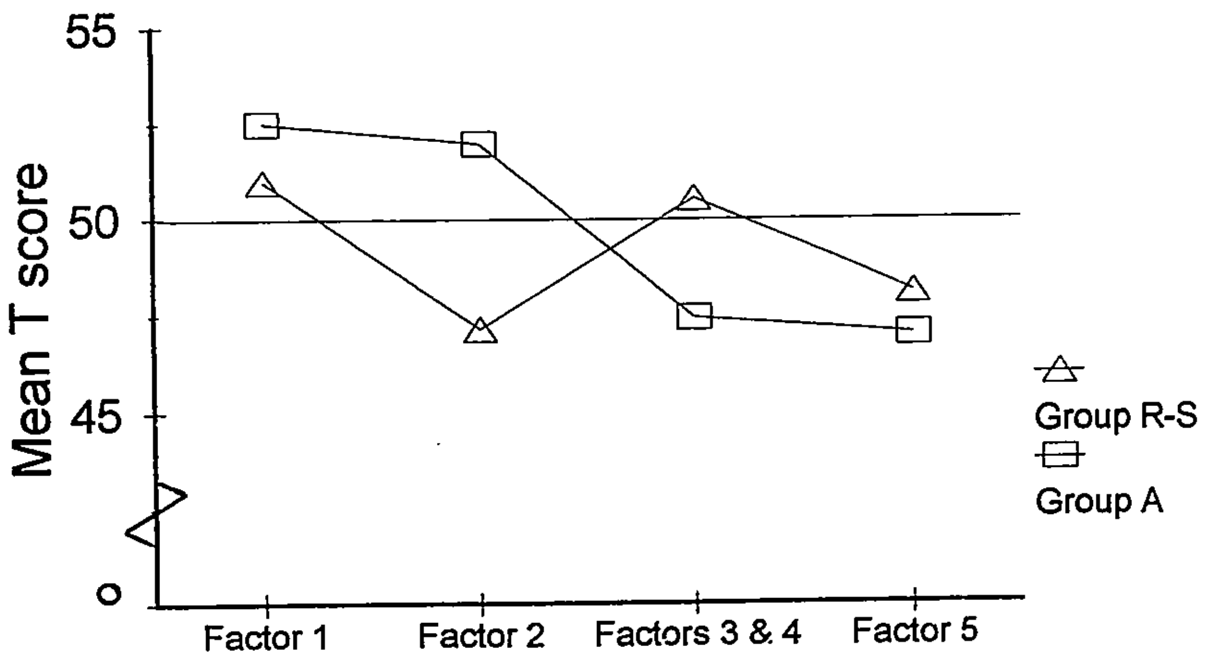


**Figure 5. Mean T scores for motor and visual-spatial factors (clinical selection).**

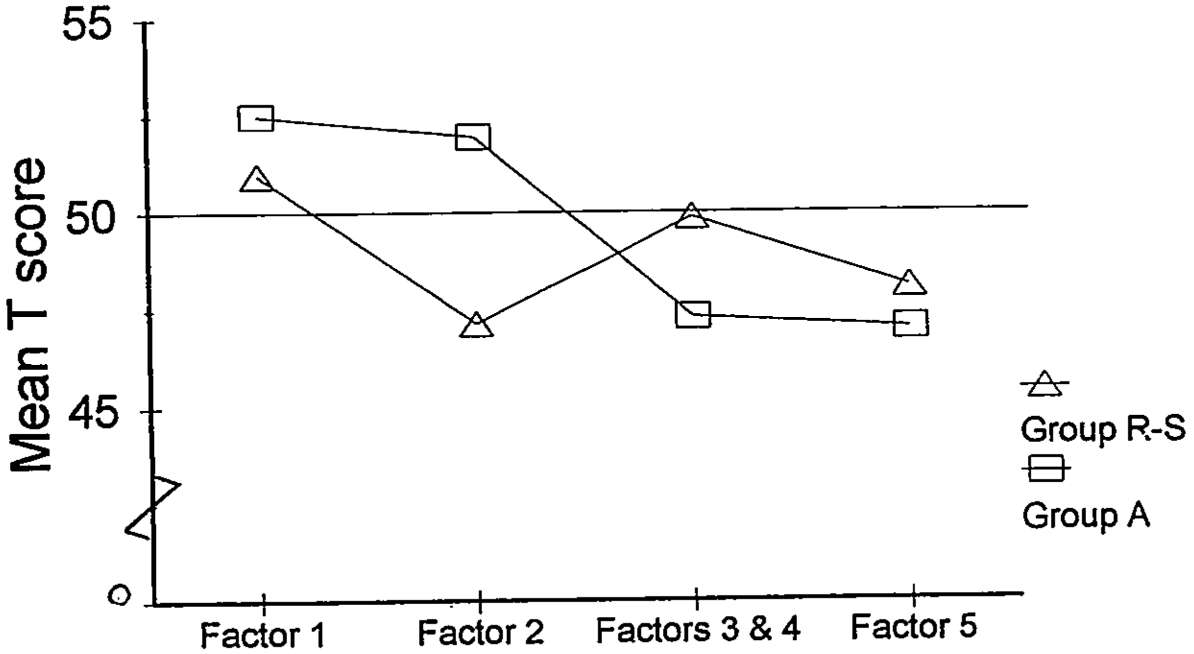


**Figure 6.** Mean T scores for motor and visual-spatial factors including Category Test (clinical selection).

Table 24

Summary of MANOVA and ANOVA results for motor and visual-spatial factors selected according to clinical criteria (combined Simple Spatial-Motor and Complex Visual-Spatial Relations factors)

| Variable | F value | p | Direction of significant effect ($p < .05$) |
|---|---|---|---|
| MANOVA (Hotelling-Lawley Trace) | 4.29 | .0028 | |
| Simple Motor (F1) | 1.42 | .2362 | n.s. |
| Motor Steadiness (F2) | 4.55 | .0350 | A > R-S |
| Visual Spatial Ability (F3 & F4) | 5.82 | .0174 | R-S > A |
| Speeded Motor Sequencing (F5) | .50 | .4831 | n.s. |

**Addition of Category Test to Visual-Spatial Ability (F3 & F4)**

| Variable | F value | p | Direction of significant effect ($p < .05$) |
|---|---|---|---|
| MANOVA (Hotelling-Lawley Trace) | 3.87 | .0055 | |
| Simple Motor (F1) | 1.42 | .2362 | n.s. |
| Motor Steadiness (F2) | 4.55 | .0350 | A > R-S |
| Visual Spatial Ability (F3 & F4) | 4.64 | .0333 | R-S > A |
| Speeded Motor Sequencing (F5) | .50 | .4831 | n.s. |

Category Test) across these four factors was significant [$F$ (4,117) = 4.287, $p$ = .0028]. Significant differences between the two groups were observed on the Motor Steadiness factor and the Visual-Spatial Ability factor [$F$ (1,120) = 4.55, $p$ = .035, and $F$ (1,120) = 5.82, $p$ = .0174]. Group A children again performed in a superior manner to Group R-S children on the Motor Steadiness factor but in an inferior manner to Group R-S children on the combined factor of Visual-Spatial Ability.

Profile analysis (without including the Category Test) indicated that the profiles differed significantly from parallelism [$F$ (3,118) = 5.493, $p$ = .001]. When scores were averaged over groups, variables were found to differ significantly from flatness, with significant effects observed only on the Motor Steadiness - Visual-Spatial Ability factors [$F$ (1,120) = 10.899, $p$ = .001]. There were no overall differences between the groups when scores were averaged across all variables [$F$ (1,120) < 1].

Examination of the performance of Group R-S children across these four factors (without the Category Test) revealed an overall significant difference among the variables [$F$ (3,58) = 4.367, $p$ = .009]. Significant differences were observed between the combined Visual-Spatial Ability factor and the Speeded Motor Sequencing factor [$F$ (1,60) = 10.06, $p$ = .002], with Group R-S children performing at a lower level on the latter factor.

Differences among the four neuropsychological factors (excluding the Category Test) were also observed for Group A children [$F$ (3,58) = 12.125, $p$ =

.000]. Significant differences were observed between the Motor Steadiness factor and the combined Visual-Spatial Ability factor [$F$ (1,60) = 8.936, $p$ = .004]. Group A children performed at lower levels on the Visual-Spatial Ability factor when compared to the Motor Steadiness factor.

The results of these analyses suggested that Group R-S children exhibited lower levels of performance (relative to themselves) on the Speeded Motor Sequencing factor. No significant differences were observed between the other variables, indicating a stability in the performance of Group R-S children. On the other hand, Group A children perform worse on tasks requiring visual-spatial abilities than on those tasks requiring only motor and psychomotor skills.

The Category Test was also added to the combined factor of Visual-Spatial Ability and group differences were again examined. The results obtained from these analyses were identical to those obtained when the Category Test was excluded from the analysis.

### Summary of group comparisons on the motor, psychomotor, and visual-spatial factors selected according to clinical criteria

The results of these analyses indicate that, under clinical selection criteria, the two groups differ primarily on the Motor Steadiness factor and the Complex Visual-Spatial Relations factor. Interestingly, Group A children perform in a superior manner, relative to Group R-S children, on the Motor Steadiness factor. When the Category Test was added to the Complex Visual-

Spatial Relations factor, significant group differences were observed only on the Motor Steadiness factor. In general, the two groups of children perform at similar levels on all five factors. Group A children tend to perform somewhat better than Group R-S children on the Simple Motor and Motor Steadiness factors, but are inferior to Group R-S children on those factors requiring Simple Spatial-Motor, Complex Visual-Spatial Relations, and Speeded Motor Sequencing abilities (those factors requiring more integration of abilities).

While the presence of a hierarchy of complexity could not be established through examination of the simplex model, profile analytic and repeated measures MANOVA techniques suggest that, when the two visual-spatial factors are combined to form one general Visual-Spatial Ability factor, there was partial support for the hypothesis of a hierarchy of abilities. Group A children performed at lower levels as the factors become more complex in nature. Significant differences between the Motor Steadiness factor and the combined Visual-Spatial Ability factor were observed, indicating lower performance on tasks requiring integration of motor and visual-spatial abilities when compared to tasks involving simple motor and psychomotor skills. In contrast, Group R-S children did not show this pattern of performance. They did exhibit greater difficulty on the Speeded Motor Sequencing factor when compared to their performance on the combined Visual Spatial Ability factor. This suggests greater difficulty on measures where processing of symbolic information is a component of task requirements.

Statistical selection criteria

Group comparisons were also conducted across the five factors selected according to statistical criteria. The mean T-scores of the two groups across the five factors selected in this manner are presented in Figures 7 and 8. Figure 8 represents the five factors with the addition of the Category Test on the Complex Visual-Spatial Relations factor. Examination of both figures reveals that the two groups are performing at similar levels across all five factors. However, Group A children perform somewhat better than Group R-S on the first three factors and lower than Group R-S on the last two. The performance of both groups falls within average limits on all factors.

The results of multivariate and univariate analyses of variance conducted on the five factors selected according to statistical criteria (both without and with the addition of the Category Test) are presented in Table 25.

The MANOVA conducted on the two groups (without the Category Test) across these five factors was significant [$F$ (5,116) = 4.316, $p$ = .0012]. Significant differences between the two groups were observed on the Complex Visual-Spatial Relations and Speeded Motor Sequencing factors [$F$ (1,120) = 4.18, $p$ = .043; $F$ (1,120) = 8.89, $p$ = .0035, respectively], with Group A performing at lower levels than Group R-S on both factors. When the Category Test was added to the Complex Visual-Spatial Relations factor the overall MANOVA was significant [$F$ (5,116) = 3.98, $p$ = .0023]. Significant differences between the two groups were no longer evident on the Complex Visual-Spatial

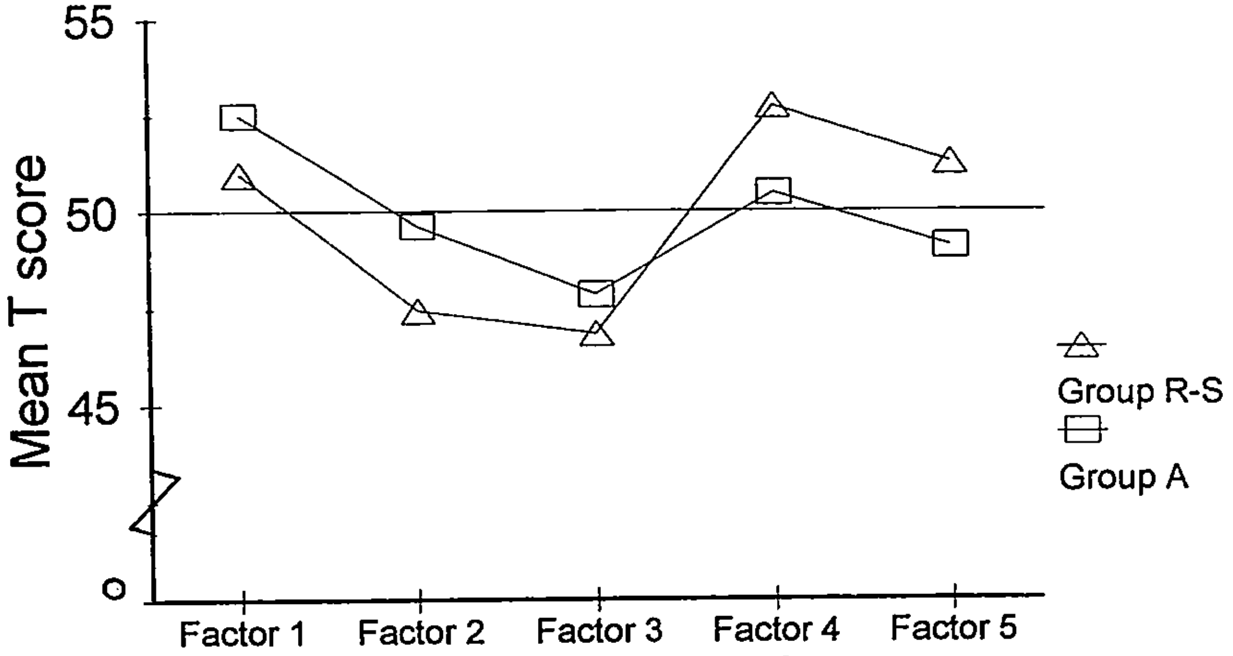


Figure 7. Mean T scores for motor and visual-spatial factors (statistical selection).

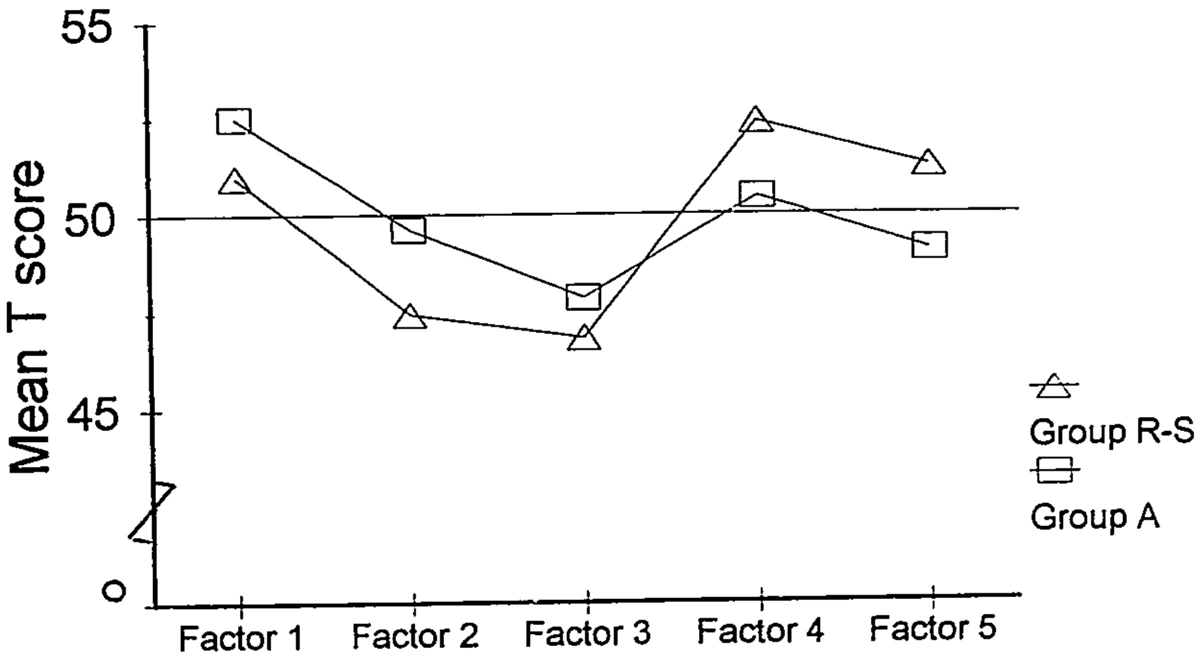


**Figure 8. Mean T scores for motor and visual-spatial factors including Category Test (statistical selection).**

Table 25

Summary of MANOVA and ANOVA results for motor and visual-spatial factors selected according to statistical criteria

| Variable | F value | p | Direction of significant effect ($p < .05$) |
|---|---|---|---|
| MANOVA (Hotelling-Lawley Trace) | 4.32 | .0012 | |
| Simple Motor (F1) | 1.42 | .2362 | n.s. |
| Motor Steadiness (F2) | 1.69 | .1956 | n.s. |
| Simple Spatial-Motor (F3) | .62 | .0430 | n.s. |
| Complex Visual-Spatial Relations (F4) | 4.18 | .0430 | R-S > A |
| Speeded Motor Sequencing (F5) | 8.89 | .0035 | R-S > A |

**Addition of Category Test to Complex Visual-Spatial Relations (F4)**

| Variable | F value | p | Direction of significant effect ($p < .05$) |
|---|---|---|---|
| MANOVA (Hotelling-Lawley Trace) | 3.98 | .0023 | |
| Simple Motor (F1) | 1.42 | .2362 | n.s. |
| Motor Steadiness (F2) | 1.69 | .1956 | n.s. |
| Simple Spatial-Motor (F3) | .62 | .4308 | n.s. |
| Complex Visual-Spatial Relations (F4) | 3.69 | .0572 | n.s. |
| Speeded Motor Sequencing (F5) | 8.89 | .0035 | R-S > A. |

Relations factor [F (1,120) = 3.69, p = .0572], but were evident on the Speeded Motor Sequencing factor [F (1,120) = 8.89, p = .0035], with Group A performing at lower levels than Group R-S.

Profile analysis on the five neuropsychological factors revealed that the profiles differed significantly from parallelism [F (4,117) = 3.679. p = .007]. In addition, the two groups did not differ from each other when scores were averaged over variables [F (1,120) < 1.00]. When scores were averaged over groups, differences were observed on the Simple Spatial-Motor - Complex Visual-Spatial Relations comparison [F (1,120) = 6.04, p = .015]. The addition of the Category Test to the Complex Visual-Spatial Relations factor revealed identical results.

The two groups were then examined independently. There was an overall effect for differences among the factors for Group R-S children [F (4,57) = 13.449, p = .000], with significant differences observed between the Motor Steadiness and Simple Spatial-Motor factors [F (1,60) = 14.58, p = .000], the Simple Spatial-Motor and Complex Visual-Spatial Relations factors [F (1,60) = 23.608, p = .000], and the Complex Visual-Spatial Relations and Speeded Motor Sequencing factors [F (1,60) = 5.535, p = .022]. Group R-S performs at a lower level on the Simple Spatial-Motor factor than on the Motor Steadiness factor, then shows an improvement on the Complex Visual-Spatial Relations factor, and finally exhibits a decrease in their level of performance for the Speeded Motor Sequencing factor.

When the Category Test was added to the Complex Visual-Spatial Relations factor, significant differences were only observed between the Motor Steadiness and Simple Spatial-Motor factors [F (1,60) = 12.754, p = .001] and the Simple Spatial-Motor and Complex Visual-Spatial Relations factors [F (1,60) = 26.393, p = .000]. Thus, Group R-S children exhibit similar levels of performance on the last two factors when the Category Test is allowed to contribute to the Complex Visual-Spatial Relations factor.

Examination of Group A children also revealed an overall significant effect for differences among the variables [F (4,57) = 8.564, p = .000]. Significant differences were observed between the Simple Motor and Motor Steadiness factors [F (1,60) = 17.537, p = .000] and the Simple Spatial-Motor and Complex Visual-Spatial Relations factors [F (1,60) = 4.08, p = .048]. A trend towards a significant difference between the Complex Visual-Spatial Relations and Speeded Motor Sequencing factors was also observed [F (1,60) = 3.903, p = .053]. Group A children exhibit a decline in their performance across the first two factors, with no difference between the second and third, then an increase in their performance level between the Simple Spatial-Motor and Complex Visual-Spatial Relations factors. The addition of the Category Test to the Complex Visual-Spatial Relations factor did not alter the results obtained from this analysis.

The performance of the two groups was then examined for the condition where the Simple Spatial-Motor and Complex Visual-Spatial Relations factors were combined to form a general Visual-Spatial Ability factor. Figures 9 and 10 (excluding and including the Category Test, respectively) illustrate that Group R-S children exhibit a decline in their performance level between the Simple Motor and Motor Steadiness factors and then gradually improve across the remaining two factors. In contrast, Group A children show a decline from the Simple Motor to the Motor Steadiness factor and then perform at a relatively unchanged level across the remaining two factors. Group A children perform at higher levels than Group R-S on the first two factors and at lower levels on the last two. Both groups, however, are performing within normal limits across all four factors.

The results of multivariate and univariate analyses of variance for the groups across the four factors (both without and with the Category Test) added to the combined Visual-Spatial Ability factor) are presented in Table 26.

The MANOVA conducted on the two groups without the addition of the Category Test yielded an overall significant effect for differences between the two groups [$F$ (4,117) = 5.315, $p$ = .0006]. When individual variables were examined, significant differences were observed only on the Speeded Motor Sequencing factor [$F$ (1,120) = 8.89, $p$ = .0035], with Group A performing at lower levels to Group R-S. The addition of the Category Test to the combined factor yielded similar results.

Profile analysis of the two groups on these four factors revealed that the profiles differed from parallelism [$F$ (3,118) = 3.858, $p$ = .011]. When the

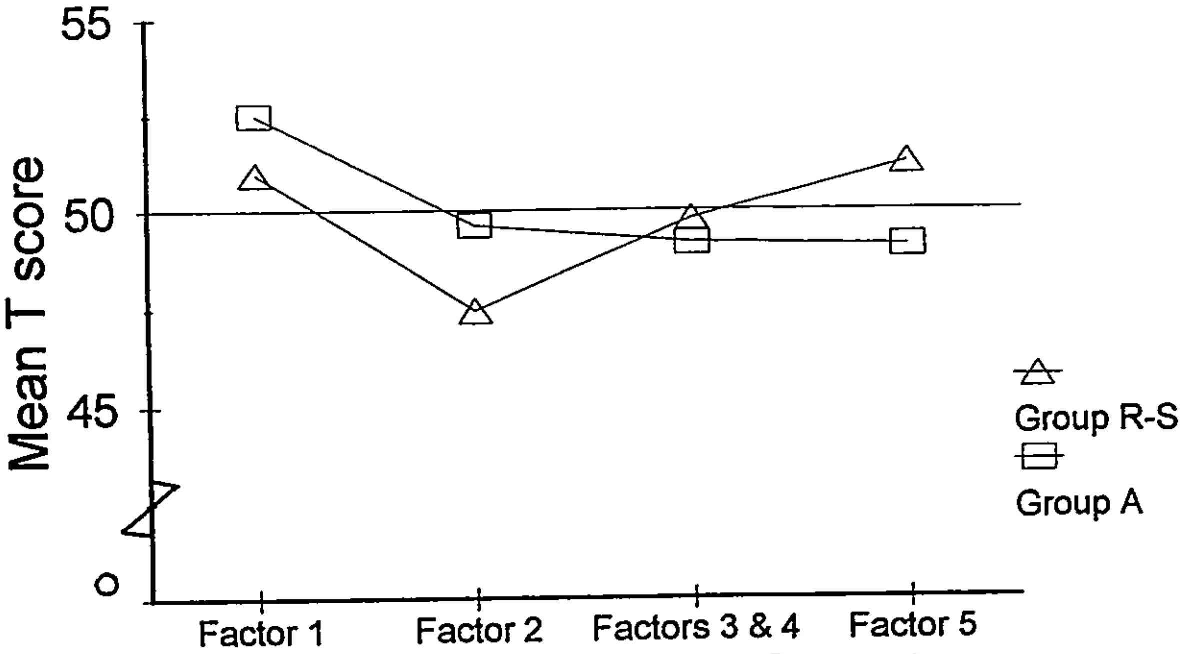


**Figure 9.** **Mean T scores for motor and visual-spatial factors (statistical selection).**

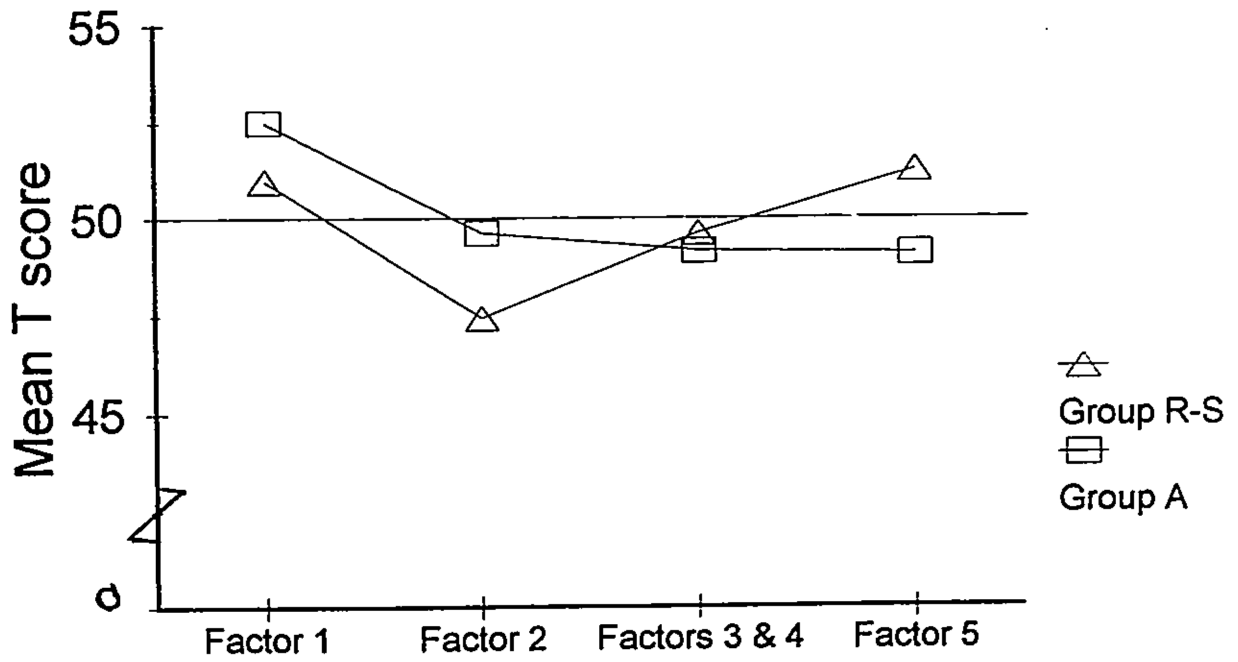


Figure 10. Mean T scores for motor and visual-spatial factors including Category Test (statistical selection).

Table 26

Summary of MANOVA and ANOVA results for motor and visual-spatial factors selected according to statistical criteria (combined Simple Spatial-Motor and Complex Visual-Spatial Relations factors)

| Variable | F value | p | Direction of significant effect ($p < .05$) |
|---|---|---|---|
| MANOVA (Hotelling-Lawley Trace) | 5.32 | .0006 | |
| Simple Motor (F1) | 1.42 | .2362 | n.s. |
| Motor Steadiness (F2) | 1.69 | .1956 | n.s. |
| Visual Spatial Ability (F3 & F4) | .39 | .5360 | n.s. |
| Speeded Motor Sequencing (F5) | 8.89 | .0035 | R-S > A |

**Addition of Category Test to Visual-Spatial Ability (F3 & F4)**

| Variable | F value | p | Direction of significant effect ($p < .05$) |
|---|---|---|---|
| MANOVA (Hotelling-Lawley Trace) | 4.95 | .0010 | |
| Simple Motor (F1) | 1.42 | .2362 | n.s. |
| Motor Steadiness (F2) | 1.69 | .1956 | n.s. |
| Visual Spatial Ability (F3 & F4) | .23 | .6880 | n.s. |
| Speeded Motor Sequencing (F5) | 8.89 | .0035 | R-S > A |

scores were averaged across groups, deviations from flatness were observed between the Motor Steadiness and the Visual-Spatial Ability factor [F (1,120) = 9.284, p = .003]. When the scores were averaged across variables, no significant differences were observed between the two groups. The addition of the Category Test did not alter these results.

The two groups were then examined independently. There was a significant effect for overall differences among the variables for Group R-S children [F (3,58) = 5.276, p = .003], with significant differences observed between the Motor Steadiness and the Visual-Spatial Ability factors [F (1,60) = 13.562, F = .000]. When the Category Test was added to the combined factor, significant differences were also observed between the Visual-Spatial Ability and Speeded Motor Sequencing factors [F (1,60) = 4.961, p = .03]. The results of this analysis suggest that Group R-S children appear to improve their performance on measures requiring more complex or novel information processing, such as those underlying the Visual-Spatial Ability and Speeded Motor Sequencing factors, when compared to measures requiring simple motor and psychomotor skills.

There was also a significant overall effect for differences among the variables for Group A children [F (3,58) = 6.226, p = .001]. Significant differences were only observed between the Simple Motor and Motor Steadiness factors [F (1,60) = 17.84, p = .000]. Similar results were obtained for the analysis including the Category Test. These results indicate that Group

A children perform at a higher level on the Simple Motor factor than on the remaining factors.

Summary of group comparisons on the motor, psychomotor, and visual-spatial factors selected according to statistical criteria

The results of analyses in this area indicate that the two groups, although performing at similar levels, do have different patterns of performance. Group R-S and A children differ from each other primarily on the Speeded Motor Sequencing factor. Differences between the two groups were also observed on the Complex Visual-Spatial Relations factor when the Category Test was not included. The two groups have different patterns of performance with Group R-S performing at a lower level than Group A on the Simple Motor and Motor Steadiness factors but better than Group A on the Complex Visual-Spatial Relations, the Speeded Motor Sequencing, and the combined factor of Visual-Spatial Ability.

It also appears that some sort of "hierarchical" organization is present under conditions where the Simple Spatial-Motor and Complex Visual-Spatial Relations factors are combined. The performance of Group A children is lower on the Motor Steadiness factor than on the Simple Motor factor; however, they neither improve nor worsen on the remaining factors. Group R-S children, on the other hand, show a non-significant decrease in their performance between the Simple Motor and Motor Steadiness factors but then steadily improve over the remaining factors. This pattern of performance is less obvious when all five factors are included in the analysis.

### Summary of results for Study 2

In general, the results of analyses conducted in this study provide partial support for the hypotheses. Although the existence of a simplex model within the data could not be determined, additional analyses suggested that there might be some evidence for the presence of a hierarchy of motor, psychomotor, and visual-spatial skills, particularly when the factors were selected using clinical criteria and the two factors of Simple Spatial-Motor and Complex Visual-Spatial Relations were combined to form a general Visual-Spatial Ability factor. When the factors were selected using statistical criteria, the evidence for this hierarchy was not as strong. It is clear, however, that Group R-S and A children perform in different manners on the five factors of motor, psychomotor, and visual-spatial ability.

## Study 3

Investigations into the hypotheses presented for Study 3 consisted of: (a) a *t*-test on the General Verbal factor; (b) examination of group differences through multivariate techniques, including profile analysis, on the Acoustic and Semantic Processing factors.

### A. General Verbal factor

As the General Verbal factor is a linear combination of both the Acoustic and Semantic Processing factors, it could not be included in the overall analysis of the language factors. As such, t-tests were conducted on the General Verbal factor under both clinical and statistical selection criteria, both with and without the inclusion of the Aphasia Screening Test. Results obtained from all t-tests indicated that Group A children performed significantly better ($p < .001$ for all analyses) than Group R-S children. Group means and t-test values for each analysis are presented in Table 27.

B. Group comparisons on the language factors

Clinical selection criteria

Figure 11 presents the mean T-scores of the groups on the Acoustic and Semantic Processing factors selected according to clinical criteria. From this figure it can be seen that Group R-S performs at lower levels than Group A on both factors. Although both groups are performing within average limits on the Semantic Processing factor, Group R-S performs well below average on the Acoustic Processing factor. The performance of Group A on this factor is lower than their performance on the Semantic Processing factor, although still within average limits.

Results of multivariate and univariate analyses conducted on these two factors is contained in Table 28. There was a significant overall effect for differences between the groups [$F$ (2,119) = 16.077, $p$ = .0001]. Analysis of both variables revealed significant group differences on both the Semantic [$F$ (1,120) = 12.45, $p$ = .0006] and the Acoustic [$F$ (1,120) = 28.66, $p$ = .0001]

Table 27

Group means and t-test results for General Verbal factor

| | M | SD | t | p |
|---|---|---|---|---|
| **Clinical Selection** | | | | |
| Group R-S | 26.23 | 15.48 | | |
| Group A | 54.51 | 10.63 | -11.76 | .0001 |
| **Clinical Selection + Aphasia Screening Test** | | | | |
| Group R-S | 22.94 | 9.14 | | |
| Group A | 49.51 | 7.88 | -17.20 | .0001 |
| **Statistical Selection** | | | | |
| Group R-S | 41.18 | 4.85 | | |
| Group A | 49.04 | 4.50 | -9.29 | .0001 |
| **Statistical Selection + Aphasia Screening Test** | | | | |
| Group R-S | 39.02 | 4.62 | | |
| Group A | 48.59 | 4.46 | -11.64 | .0001 |

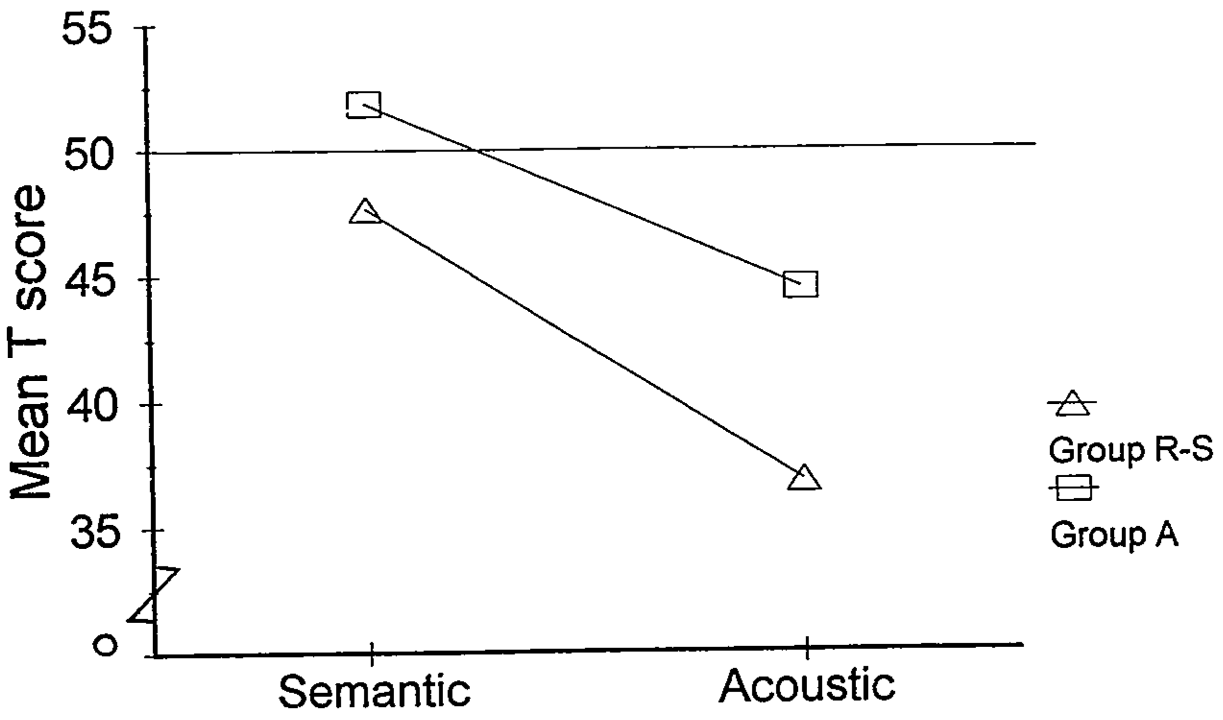


Figure 11. Mean T scores for language factors (clinical selection).

Table 28

Summary of MANOVA and ANOVA results for language factors selected according to clinical criteria

| Variable | F value | p | Direction of significant effect ($p < .05$) |
|---|---|---|---|
| MANOVA<br>(Hotelling-Lawley Trace) | 16.08 | .0001 | |
| Semantic Processing | 12.45 | .0006 | A > R-S |
| Acoustic Processing | 28.66 | .0001 | A > R-S |

Processing factors. Group A performed significantly better than Group R-S on both factors.

Profile analysis revealed that there was an overall difference between the two groups when scores were averaged across variables [$F$ (1,120) = 31.03, $p$ = .000]. In addition, the profiles differed significantly from flatness, when scores were averaged over groups [$F$ (1,120) = 5.1, $p$ = .026].

In general, the results obtained for the language factors under clinical selection criteria indicate that Group A performs significantly better than Group R-S on both the Semantic and Acoustic Processing factors. In addition, both groups perform more poorly on the Acoustic Processing factor, when compared to the Semantic Processing factor.

Statistical selection criteria

Figures 12 and 13 present the mean $T$-scores for both groups on the Semantic and Acoustic Processing variables. Figure 13 includes the Aphasia Screening Test on the Semantic Processing factor. Examination of both figures indicates that Group A children perform at higher levels to Group R-S children on both language factors. In addition, while both groups perform within average limits on the Semantic Processing factor, Group R-S children perform well below average on the Acoustic Processing factor. Group A children perform within low average limits on this factor.

Multivariate and univariate analyses of variance results are presented in Table 29 for both analyses (without and with the Aphasia Screening Test).

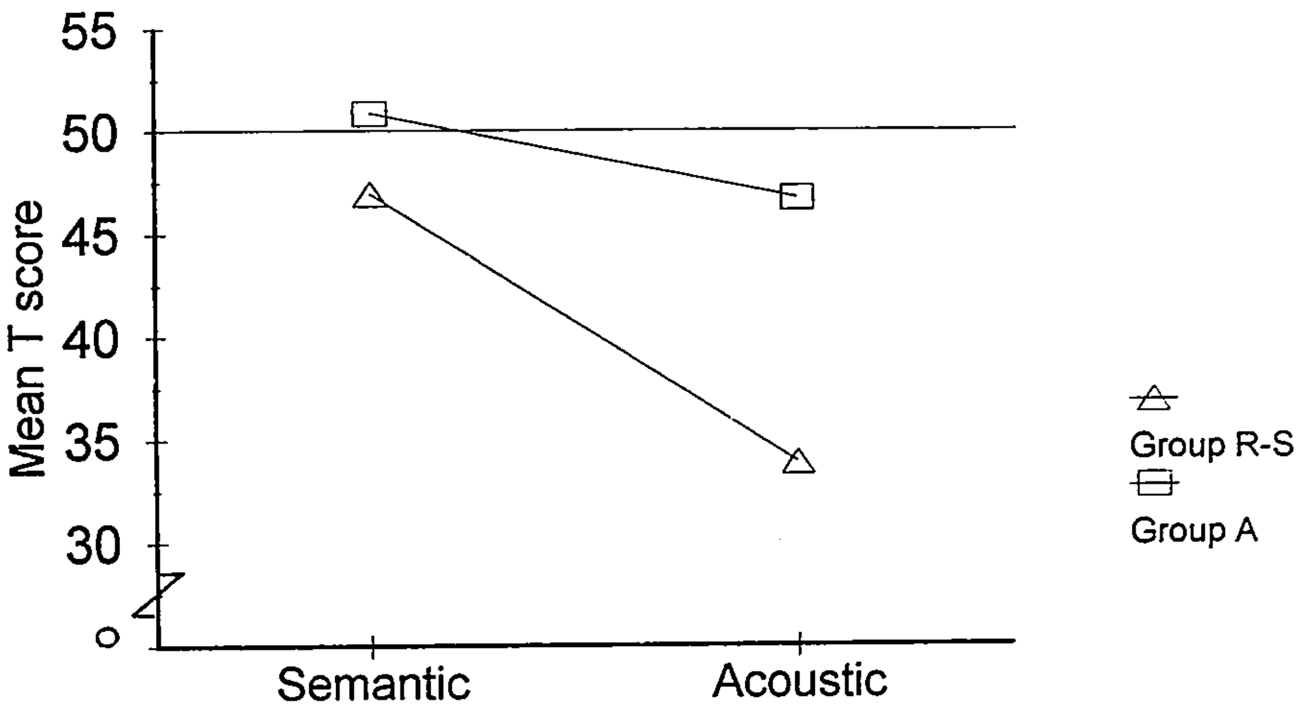


Figure 12. Mean T scores for language factors (statistical selection).

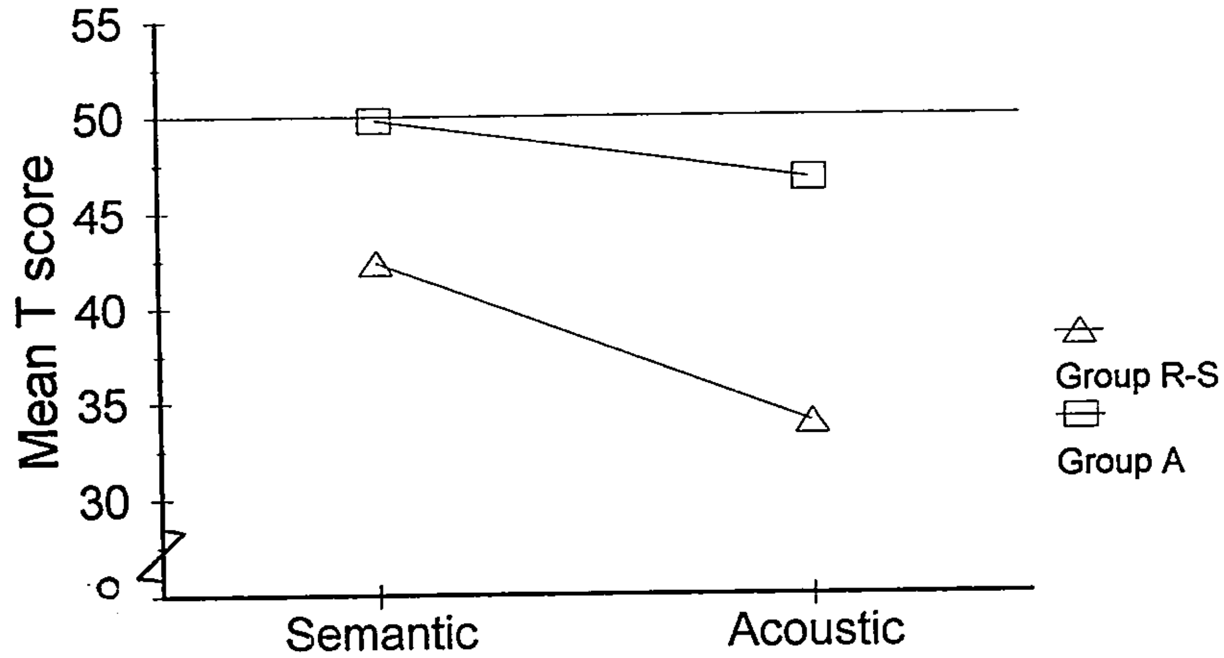


Figure 13. Mean T scores for language factors including Aphasia Screening Test (statistical selection).

Table 29

Summary of MANOVA and ANOVA results for language factors selected according to statistical criteria

| Variable | F value | p | Direction of significant effect ($p < .05$) |
|---|---|---|---|
| MANOVA (Hotelling-Lawley Trace) | 51.56 | .0001 | |
| Semantic Processing | 19.21 | .0001 | A > R-S |
| Acoustic Processing | 100.74 | .0001 | A > R-S |

**Addition of Aphasia Screening Test to Semantic Processing Factor**

| Variable | F value | p | Direction of significant effect ($p < .05$) |
|---|---|---|---|
| MANOVA (Hotelling-Lawley Trace) | 67.59 | .0001 | |
| Semantic Processing | 78.55 | .0001 | A > R-S |
| Acoustic Processing | 100.74 | .0001 | A > R-S |

Results when the Aphasia Screening Test was not included revealed a significant overall effect for group differences [$F$ (2,119) = 51.56, $p$ = .0001]. Analysis of the two factors revealed significant group differences on both the Semantic [$F$ (1,120) = 19.21, $p$ = .0001] and the Acoustic [$F$(1,120) = 100.74, $p$ = .0001] Processing factors. Group A children performed significantly better than Group R-S children on both factors. Identical results were obtained when the Aphasia Screening Test was added to the Semantic Processing factor.

Profile analysis results (on the data without the Aphasia Screening Test) indicated that there was a significant overall difference between the level of performance of the two groups when scores were averaged across the factors [$F$ (1,120) = 92.29, $p$ = .000], with Group A performing at higher levels than Group R-S. When the scores were averaged for each variable, results indicated that there was a significant difference between the Semantic and Acoustic Processing factors [$F$ (1,120) = 43.08, $p$ = .000], with better performance being observed on the Semantic Processing factor. A similar pattern of performance was observed when the Aphasia Screening Test was added to the Semantic Processing factor.

Results of analyses conducted on the language factors selected according to statistical criteria mirror those obtained when the factors were selected according to clinical criteria. Group A performs significantly better than Group R-S on both language factors and both groups perform more poorly on the Acoustic Processing factor, when compared to the Semantic Processing factor. In addition, the magnitude of the difference between the two groups is greater for the Acoustic Processing factor than the Semantic Processing.

### Summary of results for Study 3

The results of analyses conducted on the language factors strongly support the hypotheses proposed for Study 3. Group A children perform at higher levels than Group R-S children on the General Verbal factor, and the Semantic and Acoustic Processing factors. In addition, both groups perform more poorly on the Acoustic Processing factor, when compared to the Semantic Processing factor, with Group R-S performing at lower levels compared to Group A.

## Summary of Results

The hypotheses concerning the prediction of group membership and ability of the factors to discriminate between the two groups of learning-disabled children were partially supported by the results of Study 1. The motor and psychomotor factors were not solely the best discriminators between or predictors of the two groups of learning-disabled children. The best single predictor and discriminating factor was the Acoustic Processing factor. However, the best discriminant function equations combined the Acoustic Processing factor with the Semantic Processing factor and either the Motor Steadiness or the Speeded Motor Sequencing factor. The Complex Visual-

Spatial Relations factor also contributed to discriminant function equations under clinical selection criteria.

The best logistic regression equations combined the Acoustic Processing factor with the Complex Visual-Spatial Relations factor (under both clinical and statistical selection criteria), and also with the Motor Steadiness and Simple Spatial-Motor factors (under statistical selection criteria only). The Semantic Processing factor contributed to the logistic regression equations only when the Aphasia Screening Test was a component of this factor.

Thus, there appears to be partial support for the hypothesis that neuropsychological functions representing the primary deficits of Group A children and the primary assets of Group R-S children (as measured by factors tapping psychomotor and motor skill) best discriminate and predict the performance of these two groups of learning-disabled children. In general, however, it was factors tapping language ability (as reflected by the Acoustic Processing factor) which were the most significant in predicting performance of an individual and discriminating between the two groups. These factors represent measures underlying the primary neuropsychological assets of Group A children and the primary neuropsychological deficits of Group R-S children.

While the addition of the Category Test contributed little to the overall discrimination or prediction of the groups, the Aphasia Screening Test added to the strength of the prediction ability of the Semantic Processing factor. In addition, the classification rates of the factors and the "fit" of regression equations were best when factors were selected according to statistical criteria rather than when they were chosen according to clinical criteria (a reduced number of variables).

The existence of a hierarchy of motor, psychomotor, and visual-spatial abilities could not be fully established (Study 2). The data did not support the presence of a simplex model, which would have provided the strongest support for evidence of a hierarchy. There did, however, appear to be weak support for the existence of a hierarchy, particularly when the Simple Spatial Motor and Complex Visual-Spatial Relations factors were combined, and when the factors were selected according to clinical criteria. In addition, the results obtained indicated that Group R-S and A children perform in different manners on the five neuropsychological factors representing motor, psychomotor, and visual-spatial ability.

Results obtained for Study 3 strongly support the hypotheses as presented. It is clear that Group R-S children perform significantly lower than Group A children on language and auditory-verbal measures. In addition, while both groups perform at lower levels on the Acoustic Processing factor, when compared to the Semantic Processing factor, Group R-S has greater difficulty than Group A on measures underlying this factor of cognitive ability.

### Results using a sample size of 60

All analyses presented above were conducted for the sample of 122 children (n=61 per group), given the general "rules of thumb" that apply for conducting multivariate statistics suggesting that there should be a minimum of 100 subjects, or a subject-variable ratio of at least ten to one (Tabachnik & Fidell, 1989). However, the analyses (with the exception of the examination of the simplex model) were also conducted using the original sample of 60 subjects (n=30 per group) in order to determine whether similar results would be obtained using a more restricted subject selection criteria and because that sample was selected using the same criteria as in the original studies of these subtypes of learning-disabled children (Rourke & Finlayson, 1978; Rourke & Strang, 1978; Strang & Rourke, 1983). While the results obtained were generally identical to those presented above, some differences were observed. These are presented below.

In general, the results obtained from discriminant function analyses of the smaller sample size mirrored those obtained using the larger sample size. The Acoustic Processing factor remained the best single variable that discriminated between the two groups and the best discriminant function equations included this factor along with the Complex Visual-Spatial Relations, Motor Steadiness, Simple Spatial-Motor, and Semantic Processing variables (depending on whether the Category and Aphasia Screening Tests were used in factor definitions). However, the overall classification rates obtained under both clinical and statistical selection criteria were much higher using the smaller sample size than those obtained from the original sample.

Results from logistic regression analyses conducted on the smaller sample were also similar to those found from analyses using the original sample size, particularly under statistical selection criteria. Using clinical selection criteria, however, it was observed that the Motor Steadiness factor was dropped from the logistic regression equations with the Acoustic Processing and Complex Visual-Spatial Relations factors being retained. Once again, under both selection criteria conditions, the overall classification rates were higher in the analyses using the smaller sample size.

Examination of the existence of a potential hierarchy within the motor, psychomotor, and visual-spatial factors was conducted only through MANOVA's and Profile Analysis. In general, the results obtained from the smaller sample were identical to those obtained from the larger sample. However, some differences were observed between the findings obtained for both samples under statistical selection criteria. Independent examination of the two groups revealed that both Groups R-S and A performed better on the Complex Visual-Spatial Relations factor when compared to their performance on the Simple Spatial Motor factor. Although this result was also obtained from the larger sample size, results from analyses of the larger sample had also revealed differences between the Motor Steadiness and Simple Spatial-Motor factors and the Complex Visual-Spatial Relations and the Speeded Motor Sequencing factors for Group R-S. Group A had been observed to perform at lower levels on the Motor Steadiness factor when compared to the Simple Motor factor.

These differences were not observed in analyses using the smaller sample size. Results obtained for both sample sizes when the Simple-Spatial Motor and Complex Visual-Spatial Relations factors were combined were identical. In general, the results obtained from the smaller sample indicated that there was some evidence for a potential hierarchy of cognitive abilities when the two factors were combined to form a general Visual-Spatial Ability factor. The existence of the hierarchy was not as evident when all five factors were included in the analyses.

Analyses investigating the language factors yielded identical results to those observed in the original sample size. Group A children performed at higher levels than Group R-S children on both the Semantic and Acoustic Processing factors and both groups performance on the Acoustic Processing factor was lower than on the Semantic Processing factor (with Group R-S exhibiting the largest decline). The magnitude of the differences between the two groups was greatest for the Acoustic Processing factor (similar to observations made for the larger sample size). At this point it was felt that a graphic illustration of the distribution of the scores obtained by both groups on these factors would highlight their pattern of performance.

Figures 14 and 15 present the performance of both groups on the Semantic and Acoustic Processing factors using clinical selection criteria and Figures 16 and 17 present the same information using statistical selection criteria. Examination of these four figures indicates that there is a greater

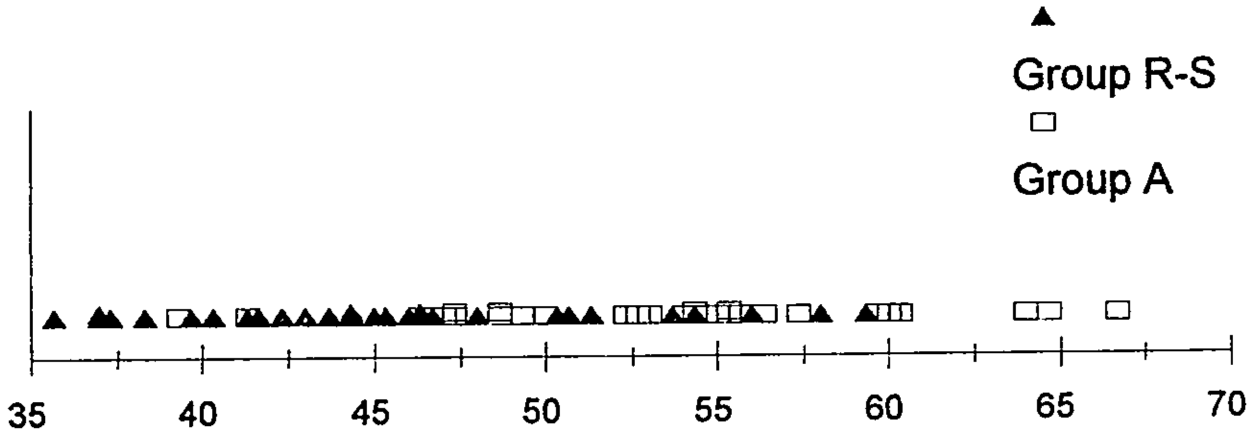


Figure 14. Distribution of T-scores obtained on the Semantic Processing Factor (clinical selection).

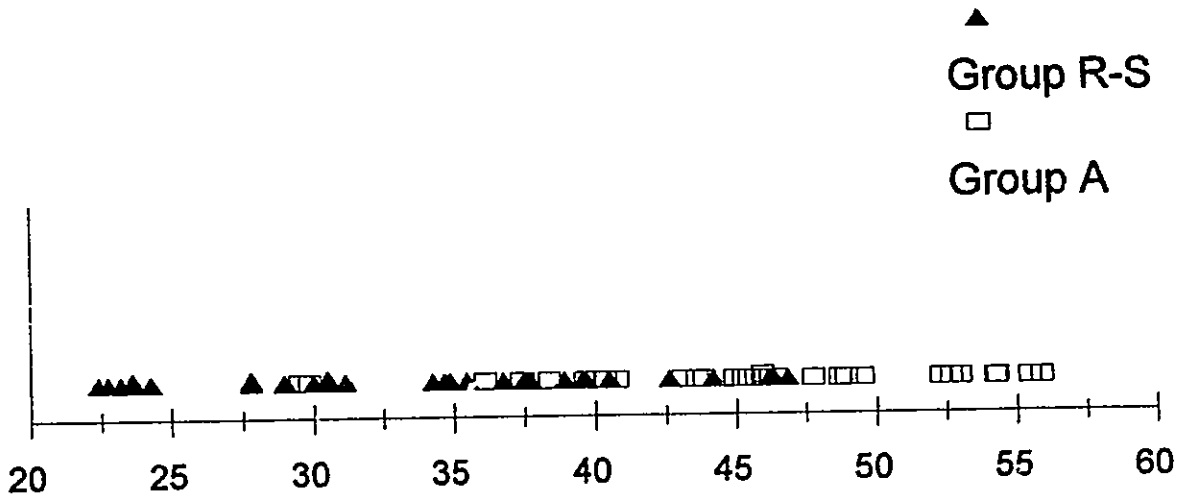


Figure 15. Distribution of T-scores obtained on the Acoustic Processing Factor (clinical selection).

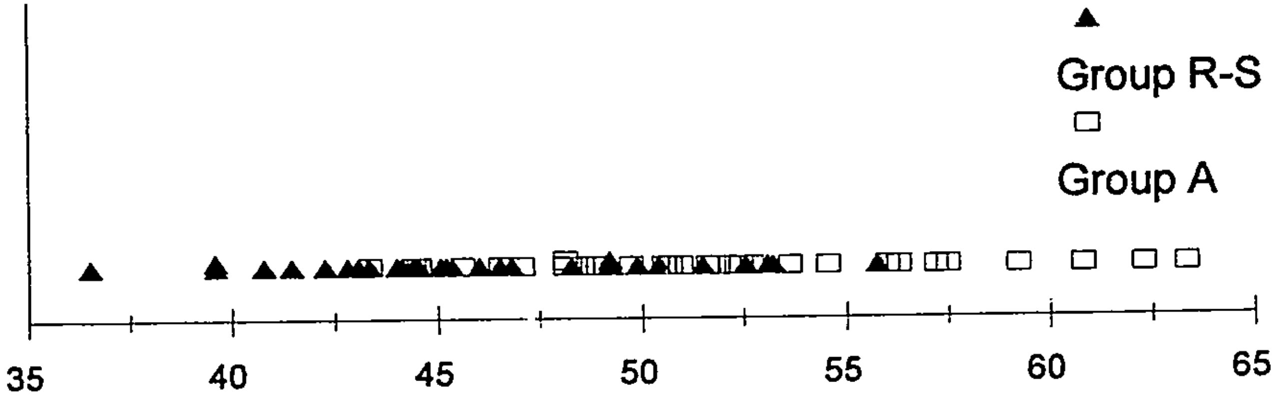


Figure 16. Distribution of T-scores obtained on the Semantic Processing Factor (statistical selection).

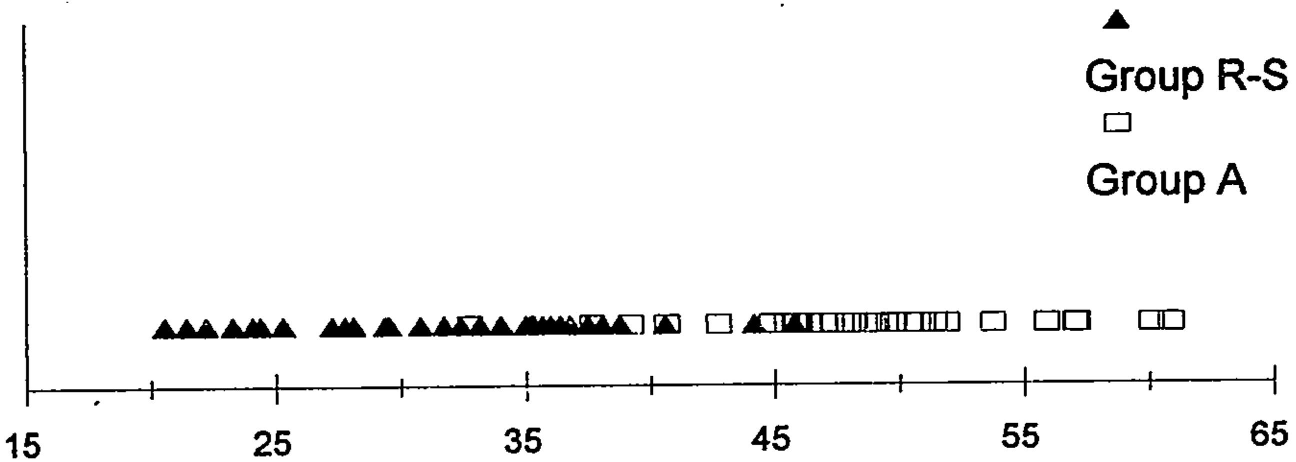


**Figure 17. Distribution of T-scores obtained on the Acoustic Processing Factor (statistical selection).**

amount of overlap between the two groups on the Semantic Processing factor (under both clinical and statistical selection criteria) and less overlap on the Acoustic Processing factor. The groups are best discriminated on the Acoustic Processing factor when statistical selection criteria are employed.

In summary, it is clear that higher classification rates are obtained from discriminant function and logistic regression analyses when using more restricted subject selection criteria. This is not surprising given that, in the smaller sample size, the two groups are originally more discrete. The results obtained from the smaller sample for all three studies tended to mirror those obtained from the larger sample.

# CHAPTER IV

# DISCUSSION

The purpose of this study was to further examine factors of neuropsychological functioning identified in previous research (Davidson, 1992; Francis et al., 1992) in order to continue investigations into the construct validity of a modified Halstead-Reitan Neuropsychological Battery (HRNB) as used with children. Five factors of motor, psychomotor, and visual-spatial abilities and three factors of auditory-language functions were examined in a series of three studies aimed at investigating: (1) their discriminant and predictive validity; (2) the possible existence of a hierarchy within the motor, psychomotor, and visual-spatial factors; and (3) the nature of the language factors. Two groups of learning-disabled children identified by earlier research (Rourke & Finlayson, 1978; Rourke & Strang, 1978; Strang & Rourke, 1983) were used as subjects.

In general, the findings of the present study provided partial support for the hypotheses presented for the first two studies. Full support was found for hypotheses pertaining to the third study. In the following sections, results obtained from each of the three studies are discussed. In addition, implications and directions for future research in this area are also presented. Prior to discussing the results and their implications, however, limitations of the present study and other general issues will be presented.

## Limitations of the Present Study and other General Issues

This series of studies utilized learning-disabled children who ranged in age from 9- to 12-years. As such, the generalizability of the results is limited to this age range. Although similar constructs of cognitive ability would be expected for older (and younger children), the nature of the underlying constructs of cognitive ability (reflected in the HRNB for Children) has yet to be fully determined for these age groups. As such, the predictive validity and the manner in which they describe the arrangement of cognitive abilities in these age groups may differ from those observed in this study. This would appear to be particularly true for younger children as some "higher order" cognitive abilities are still emerging and developing. As further factor analytic studies are conducted using both older and younger children, more comprehensive research into the nature of factors of cognitive ability underlying of the HRNB for Children can be carried out.

Another limitation of this series of studies is reflected by the lack of a control group. The inclusion of a group of children with no history of learning disabilities or neurological insult would have helped to identify more clearly the progression, and nature, of the cognitive abilities under investigation. Although it is expected that normal children would perform at a similar level on all factors examined (that is, around a T-score of 50), the inclusion of a group of non-clinical children would be useful for comparison purposes. In addition, including this type of group in the first study would have been consistent with methods employed by Harnadek and Rourke (1992, 1994). These investigators used a control group of non-clinical children (normal readers) in their investigation of the discriminant validity of the NLD syndrome. This allowed for examination of variables that would discriminate groups of clinically identified children from their non-clinical peers. If a similar group of non-clinical children had been included in the present study, factors of cognitive ability that distinguished the two groups of learning-disabled children from their normal peers could also have been identified.

In general, results obtained from this study can not be used to interpret contributions from **individual** neuropsychological tests with respect to predictive validity issues, the existence of a potential hierarchy, or their role in language functioning. This is because scores obtained from various individual tests were combined to form factor scores reflecting underlying neuropsychological constructs identified by confirmatory factor analytic studies.

Although combinations of individual test scores series of studies were used in this study, the contribution of the Category Test to the motor, psychomotor, and visual-spatial factors with respect to predictive validity issues and its role in the existence of a potential hierarchy was also examined. In general, the addition of the Category Test to the Complex Visual-Spatial Relations factor did not improve the "fit" of discriminant function and logistic regression equations. In addition, results obtained from investigations into the possible existence of a hierarchy were not as clear when the Category Test was added to the Complex Visual-Spatial Relations factor.

The Category Test is felt to be a test of nonverbal problem-solving ability and, as such, requires a number of different cognitive abilities for its successful completion. The choice to place the Category Test on the Complex Visual-Spatial Relations factor was based on clinical judgement that this factor was the most representative of the skills underlying the Category Test. However, the results obtained suggest that the Category Test does not contribute to the discriminant and predictive validity of Complex Visual-Spatial Relations factor. The addition of the Category Test to the Complex Visual-Spatial Relations factor also does not appear to extend the understanding of that factors role in the potential hierarchy of cognitive abilities.

The observation that the addition of the Category Test to the Complex Visual-Spatial Relations factor failed to contribute significantly to the results obtained can be explained in several ways. As the Category Test requires a number of cognitive abilities for its successful completion, it is likely representative of more than one of the factors of cognitive ability included in this study and, therefore, should be a component of each factor that it appears to represent. Alternatively, it may define a single factor of problem solving ability that represents the "next step" in the hierarchy of cognitive functions. In that case, examination of a hierarchy that includes a factor defined by the Category Test would be appropriate. Finally, the age range of the subjects used in this study is somewhat limited (9- to 12-years old). As most of these subjects are still functioning in the stage of concrete operations (Piaget, 1954), the Category Test may not be measuring the same abilities across subjects and may be tapping abilities other than mental flexibility and abstraction (such as matching skill). This suggests that the influences of the stage of cognitive development need to be controlled for when examining measures of "higher-order" cognitive function. Further confirmatory factor analytic studies should include the Category Test in both younger and older subject samples. Once these studies have been completed, a re-examination of the potential existence of a hierarchy of abilities can be conducted with the inclusion of the Category Test.

The Aphasia Screening Test appeared to contribute significantly to the predictive validity of the Semantic Processing factor (as determined through logistic regression analyses). Although the total number of errors committed on this task (rather than the total number of aphasic errors) was included in the analyses, it was clear that the Semantic Processing factor became a good predictor of group membership only when the Aphasia Screening Test contributed to the definition of the factor. Closer examination revealed that Group R-S children made more errors on the Aphasia Screening Test than did Group A children. Examination of the type of errors made by these two groups of learning-disabled children indicated that Group R-S children made more language related errors (i.e., dyslexic, dysnomic, and spelling errors) than Group A children. However, conclusions regarding the contribution of the

Aphasia Screening Test to an understanding of the language factors are limited by the fact that the total number of errors made on this test (which includes errors that are not purely language related) was included in this study. Although it was not possible to include just the language related errors in the present study (due to limitations in the normative sample distribution used to calculate T-scores), further analyses using the mean and standard deviation of the selected sample in order to determine T-scores might further the understanding of the contribution of the Aphasia Screening Test.

Although the purpose of the present study was to continue examinations of the underlying constructs of the modified HRNB for Children, comparison of the performance of Groups R-S and A children with that of the groups used in the original series of studies (Rourke & Finlayson, 1978; Rourke & Strang, 1978; Strang & Rourke, 1983) was felt to be instructive with respect to providing information regarding the overall patterns of performance exhibited by these two groups. In the original series of studies, individual tests were used as dependent variables. Therefore, a comparison of the performance of those two groups of learning-disabled children with the two groups used in the present series was conducted on selected individual tests.

Figure 18 presents the performance of Groups R-S and A children from both the original series of studies and the present study (n=122) on selected representative variables (for explanation of the abbreviations used in this figure, see Appendix G). Portions of this figure (i.e., the performance of the two

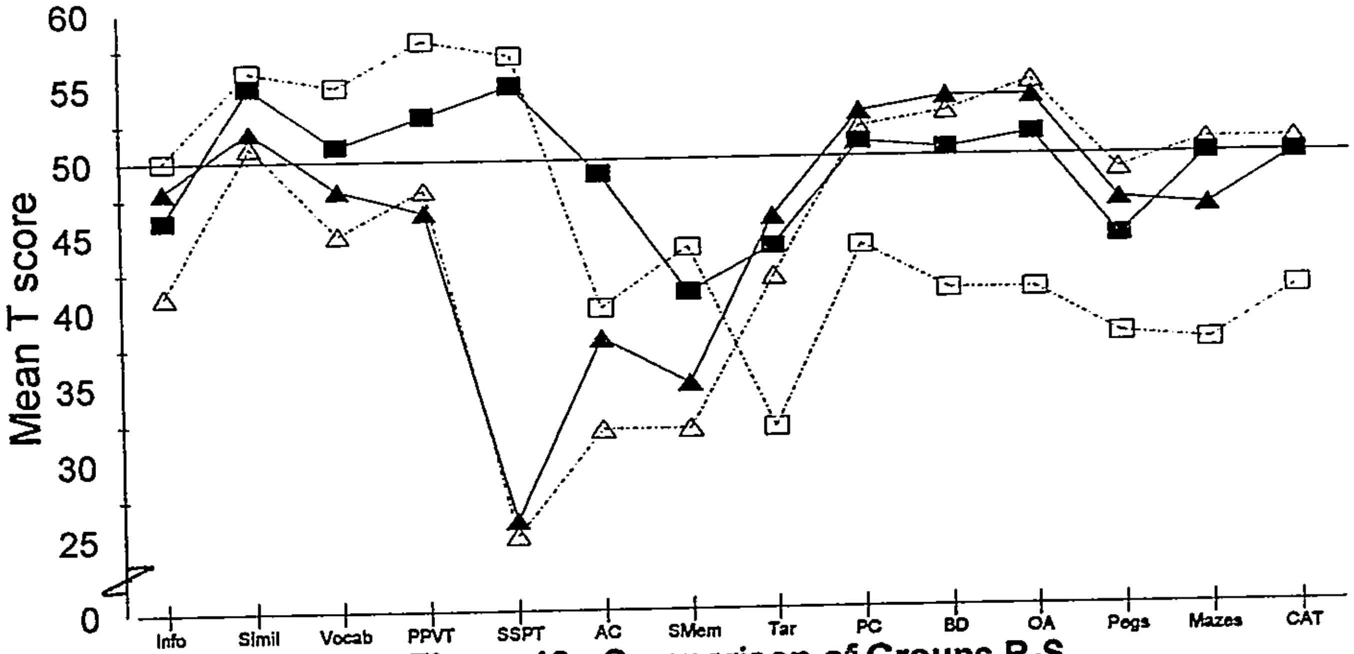


Figure 18. Comparison of Groups R-S and A on selected measures from the present and original study series.

original subtypes of children) are adapted from one presented by Strang and Rourke (1985b; p. 175) and Rourke (1989; p.28). It should be noted that measures from the Tactual Performance Test are not included in this figure. This is because it was not possible to calculate a T-score representing the total amount taken to complete this task from information presented in the original series of studies.

From this figure it can be seen that Group R-S children from both series of studies performed in a remarkably similar manner. They tended to exhibit higher levels of performance on tasks of visual-perceptual-organizational ability and psychomotor ability than on those of language and auditory-verbal skill. Comparison of the performance of both Group A subtypes, however, revealed that although they performed in a similar manner on measures of language and auditory-verbal ability, Group A children from the present study performed at a higher level on measures of visual-perceptual-organizational functions than that observed for Group A children from the original series. In addition, comparison of the two subtypes of children from the present series revealed that Group R-S children performed at lower levels on measures of language and auditory-verbal ability when compared to measures of visual-perceptual-organizational and psychomotor functioning, whereas Group A children tended to have a fairly consistent level of performance across all measures administered.

In general, the performance of Group R-S children in the present study was consistent with what would be expected from the original series and reflects difficulties with abilities thought to be subserved primarily by systems within the left cerebral hemisphere. The performance of Group A children in the present study, however, was not entirely consistent with that observed in the original series of studies, particularly on measures of visual-perceptual-organizational ability. Group A children in the present series of studies tended to perform at higher levels on these measures than that observed in the original series of studies, perhaps reflecting the more relaxed subject selection criteria or the age differences between the two samples. It should be noted, however, that although it does not appear that the two groups of children are performing at significantly different levels on measures of motor, psychomotor, and visual-spatial abilities, Group A children generally performed at lower levels than Group R-S children on these measures. This would be consistent with findings obtained by Ozols and Rourke (1988, 1991) in their investigation of the neuropsychological performance of younger (aged 7- and 8-years) Group R-S and A children.

While Group A children from both samples experience difficulties in arithmetic, the Group A children selected for the present study may be experiencing difficulties for reasons other than those exhibited by the original Group A children (given that the selection criteria had to be relaxed in order to increase the sample size). Arithmetic difficulties typically observed by Group A children reflect poor visual-spatial abilities, visual detail errors (e.g., misreading the mathematical sign), procedural errors (e.g., misapplying mathematical rules), failure to shift psychological set (continuing to apply one rule when another rule is requested), graphomotor difficulties, judgment and reasoning errors (e.g., attempting questions clearly beyond their current level of capability), and/or memory difficulties (Strang & Rourke, 1985b). Other factors that can lead to poor arithmetic performance, however, include anxiety, a tendency to avoid unfamiliar questions and operations, and reading difficulties. Although not expressly examined in the present study, it may be that some Group A children selected for inclusion in this study received low scores on the WRAT Arithmetic test due to difficulties other than those typically observed in these children. This, in turn, would imply that some Group A children in the present study may not be exhibiting patterns of neuropsychological functioning similar to those observed in the original Group A sample.

Alternatively, differences in the performance between the two groups of Group A children may be attributable to the age differences between the two samples. The original sample used children ranging in age from 9- to 14-years, whereas only 9- to 12-year old children were used in the present sample. Examination of the mean ages of the children in both studies revealed that the children in the present study were, on average, one year to one year, three-months, younger than the children in the original series of studies. The NLD syndrome is known to manifest most clearly over the course of development (Casey et al., 1991). As the primary neuropsychological deficits (those representing visual-perceptual-organizational, psychomotor coordination, and complex tactile perceptual skill) of Group A (NLD) children are those that result in increasingly greater disparity between groups of learning-disabled children over the course of development (Casey et al., 1991), it may well be that the mean performance of children selected for the present study on measures of motor, psychomotor, and visual-perceptual-organizational abilities is better than that observed in the previous studies simply because the Group A children are younger than those in the original sample.

Measures of simple tactile-perceptual skills were not specifically included in this study and, therefore, their role in the discrimination and prediction of the two groups, as well as how they might be arranged in the potential hierarchy of cognitive skills can not be addressed. However, one dependent measure included in the present investigation {the Tactual Performance Test (TPT)}, does require these abilities. An *a posteriori* examination of the data revealed that Group A children performed worse than Group R-S children on this test (which loaded on the Complex Visual-Spatial Relations and Speeded Motor Sequencing factors). Although abilities underlying the TPT include those representative of primary neuropsychological deficits of Group A children and primary assets of Group R-S children (with respect to tactile-perceptual abilities), the two factors on which the test loaded were not the best discriminators between or predictors of the groups of learning-disabled children (although they contributed to some of the discriminant function and logistic regression equations). This was of interest because results of the first study (see below) found that factors representing other primary neuropsychological assets and deficits of these two groups of children (i.e., motor and psychomotor skills, and auditory perceptual abilities) were the best discriminators and predictors of the groups. In addition, the TPT was one of the four tests identified by Harnadek and Rourke (1992, 1994) as being the best discriminators between groups of children with NLD, children with reading and spelling disabilities (Group R-S) and a group of nonclinical children. Further examination of the TPT, its underlying cognitive abilities, and its relationship to other measures of basic tactile-perceptual skills, would be beneficial in determining the role that tactile-perceptual abilities play in the discrimination and prediction of these two groups of learning-disabled children.

The final general issue regarding the results obtained from this series of studies relates to the differential findings for clinical and statistical selection criteria. Different patterns of findings were obtained in the first two studies, depending on the selection criteria employed. These will be discussed in the presentation of the results for the study to which they pertain.

## Review of Hypotheses and Findings

### Study 1

The results obtained for Study 1 from both discriminant function and logistic regression analyses partially supported the hypotheses presented. The Complex Visual-Spatial Relations and the Simple Spatial-Motor factor were hypothesized to be the best discriminators between and predictors of group membership. Results obtained from both discriminant function and logistic regression analyses revealed that they were not the **best** discriminators between, or predictors of, the two groups of learning-disabled children. However, motor and psychomotor factors were significant contributors to the best discriminant and regression equations. The Acoustic Processing factor was the best single predictor and discriminating factor. The Semantic Processing factor was found to contribute to discriminant function equations but only to logistic regression equations when the Aphasia Screening Test was added. This indicates that although this factor contributes significantly to the discrimination of the groups, its contribution to the prediction of group membership is less clear. In general, it appears that there was some support for the hypothesis that factors measuring primary neuropsychological skills (as measured by factors tapping motor and psychomotor skills) would best discriminate between and predict the performance of these two groups of learning-disabled children. However, language abilities, as represented primarily by the Acoustic Processing factor, were the best overall predictor variable. This particular factor clearly represents the primary and verbal neuropsychological assets of Group A children as well as the primary neuropsychological deficit of Group R-S children. Thus, it appears that the two groups of learning-disabled children can be discriminated between based on measures that reflect primary neuropsychological abilities or deficits. In addition, it is performance on factors of measures representing these primary skills that result in the best prediction equations for these two groups of children.

Specific hypotheses for this study were generated from results obtained by Harnadek and Rourke (1992, 1994). Although the current study was essentially a replication of their investigation, several important differences between the two investigations likely contributed to the discrepant findings. In the present study, children were selected only on the basis of the patterns of academic achievement. Harnadek and Rourke utilized both patterns of academic achievement and patterns of neuropsychological functioning in order to select subjects who were considered to exhibit nonverbal learning disabilities (NLD). Children with NLD exhibit the same pattern of academic achievement as Group A children. However, the subject selection criteria used to identify NLD children in the Harnadek and Rourke investigation (1992, 1994) included their performance on motor, psychomotor, and visual-spatial measures. These selection criteria were employed as the purpose of Harnadek and Rourke's (1992, 1994) investigation was to determine the principal distinguishing features of the NLD syndrome. The results of that study indicated that neuropsychological measures reflective of primary neuropsychological deficits (i.e., deficits in visual-perceptual-organizational, psychomotor coordination, and complex tactile perceptual skill) were the most discriminative variables.

In the present study, Group A children were selected solely on the basis of their pattern of performance on the WRAT. The results obtained indicated that measures reflective of both primary and verbal neuropsychological assets (i.e., auditory perception and phonemic analysis) were the most discriminative (e.g., the Acoustic Processing factor); however, the classification rates were best once measures assessing these skills were combined with those reflecting primary neuropsychological deficits. Thus, it appears that a combination of the primary neuropsychological deficits (i.e., psychomotor and visual-perceptual-organizational) and the primary and verbal neuropsychological assets of Group A children yields the best discriminant and predictive equations when they are selected only on the basis of their pattern of academic achievement. Measures underlying these factors also represent the primary neuropsychological assets and deficits of Group R-S children. The obtained results argue that clinical criteria used for diagnostic purposes need to include measures that are representative of both the neuropsychological assets and deficits of these groups of learning-disabled children.

Another important difference between Harnadek and Rourke's (1992, 1994) investigation and the present study is that single test measures were utilized in the former study, whereas combinations of variables were used in this study. Of the four variables identified by Harnadek and Rourke (1992, 1994) as being the most representative of the NLD syndrome, only three were used in the present study. In addition, two of these three variables loaded on more than one factor of neuropsychological functioning. The two factors selected (Simple Spatial-Motor and Complex Visual-Spatial Relations) were felt to be the best representatives of primary neuropsychological difficulties, as reflected by the variables identified by Harnadek and Rourke (1992, 1994). However, using other combinations of the psychomotor factors might have resulted in higher classification rates than obtained by the Simple Spatial-Motor and Complex Visual-Spatial Relations factors alone.

Post-hoc examination of the discriminant validity of only the five motor and psychomotor factors revealed that the Complex Visual-Spatial Relations factor was the best single predictor. This factor was combined with the Motor Steadiness factor in the best discriminant function equations. However, when this was re-examined using the smaller sample size (n=60), the Complex Visual-Spatial Relations factor and the Simple Spatial-Motor factor were the best discriminators. This indicates that those factors felt to be most representative of primary neuropsychological deficits within the NLD model are the best discriminators between Group A and Group R-S children when only motor, psychomotor, and visual-spatial abilities are considered. This was particularly true under conditions where subject selection criteria was more restrictive, and thus more representative of the original groups of children.

Closer examination of the discriminant and logistic regression equations obtained from this study revealed a slightly different pattern of results when clinical selection criteria were used for factor definition when compared to statistical selection criteria. When statistical selection criteria were used to define the factors, classification rates were higher than when clinical selection criteria were employed. Examination of the means and standard deviations of the factors obtained under both conditions revealed that, under statistical selection criteria there was less variance around the mean (i.e., lower standard deviations). As such, the two groups were more distinct on each factor and there was less overlap between the groups on factors which distinguished them from one another. This allowed for better classification rates.

In addition, more variables were used in the determination of the factors using statistical selection criteria. As a result, the better classification rates obtained under this condition argue that using a more comprehensive approach to assessment will result in more accurate prediction of group membership and differentiation from other subtypes of learning-disabled children, as more complete information is obtained on each individual.

Under clinical selection criteria, the best discriminant functions combined the Acoustic and Semantic Processing factors with the Motor Steadiness and Complex Visual-Spatial Relations factors. When statistical criteria were used to define the factors, the best discriminating variables were the Acoustic and Semantic Processing factors combined with the Speeded Motor Sequencing factor. It appears that when factors are defined in a "pure" sense (clinical selection criteria), they share very little variance with each other. However, as more information is used in order to define the factors, the amount of shared variance increases. The Speeded Motor Sequencing factor has the most shared variance with the remaining five motor factors under statistical selection criteria, as it has only one unique variable. The nature of stepwise discriminant function is to classify variables on the basis of their correlations with the discriminant function and the amount of independent variance. When variance is shared amongst predictor variables, it is assigned to the variable that has the highest correlation with the discriminant function (Fletcher, Rice, & Ray, 1978; Tabachnick & Fidell, 1989). Following the two language factors, the Speeded Motor Sequencing factor had the highest correlations with the discriminant functions obtained under statistical selection criteria. Once this factor was entered into the equation, the remaining factors lacked sufficient unique variance to satisfy entry requirements to the discriminant function. It is clear that under clinical selection criteria (where there was less shared variance) other factors had enough predictive utility and unique variance to be included in discriminant function equations.

Results obtained from logistic regression analyses were also slightly different under both clinical and statistical selection criteria. The best factors for predicting group membership under both conditions were the Acoustic Processing and Complex Visual-Spatial factors. However, under statistical selection criteria, the best regression equations also consisted of the Motor Steadiness and Simple Spatial-Motor factors, with the Semantic Processing factor contributing only when the Aphasia Screening Test was a component of that factor. Thus, it appears that as more information is available, more factors of cognitive ability are available to be used in the prediction equation. However, the addition of the motor and psychomotor factors to logistic regression equations under statistical selection criteria can also be attributed to the increased amount of shared variance amongst the predictor variables.

Results obtained from discriminant function and logistic regression analyses using the smaller sample size were virtually identical to those for the larger sample. However, overall classification rates were higher. This is not surprising given that the two groups were selected using more restrictive criteria and that their performance on the dependent variables (predictors) was more disparate than observed in the larger sample.

In general, results obtained from both discriminant function and logistic regression analyses indicate that clinicians and researchers should be aware that subtypes of learning-disabled children can be distinguished from one another in somewhat different manners, depending upon the amount of test data available. Although language abilities remain the best predictors regardless of the amount of data available (i.e., clinical or statistical selection), factors representing the primary neuropsychological deficits of Group A children and primary neuropsychological assets of Group R-S children (i.e., complex psychomotor and visual-perceptual abilities) also contribute to the discrimination and prediction of the groups. When more information is available (such as under statistical selection criteria) higher overall rates of successful classification are obtained. As such, both clinicians and researchers should attempt to gain as much information as possible from a neuropsychological assessment in order to increase the probability that correct group classification and diagnoses will be made.

## Study 2

Results obtained from investigations into the potential existence of a hierarchical organization of the motor, psychomotor, and visual-spatial factors, identified by Francis et al. (1992), provided partial support for the hypotheses presented. This was the case regardless of which sample size was examined. The existence of a simplex model within the data could not be established, although results obtained from later analyses suggested that some sort of hierarchy might be present in the data. It was felt that the presence of a simplex model would have provided the greatest evidence for a hierarchical arrangement of these factors. A simplex model assumes a linear relationship between adjoining variables. Given that a simplex model could not be established under either clinical or statistical selection criteria (or when the Simple Spatial-Motor and Complex Visual-Spatial Relations factors were combined), it appears that the relationship between the five factors under investigation does not progress in a linear fashion. Cognitive abilities do not appear to progress in a manner consistent with the idea that successful mastery of one skill is necessary in order to complete a skill considered more difficult. It is more likely that cognitive abilities are multiply determined rather than determined in a linear fashion. In other words, performance on tasks underlying the Complex Visual-Spatial Relations factor, for example, may depend on a combination of skills, including those that are not tapped directly by performance on the Simple Spatial-Motor factor (the one preceding it in the proposed hierarchy).

Earlier research (e.g., Guttman, 1954; Jöreskog, 1970) investigating the presence of simplex models within tests of cognitive abilities focused on individual areas of cognitive functioning (i.e., verbal ability, numerical ability). However, in this study at least two areas of cognitive ability (motor skills and visual-perceptual abilities) were examined. Guttman (1954) has proposed that when more than one area of cognitive functioning is under investigation, their interrelationships might be **circular**, rather than linear, in nature. The possibility that this may be the case with these five factors of cognitive ability deserves investigation, particularly as the Speeded Motor Sequencing factor was highly correlated with most of the factors (at least when clinical selection criteria were employed).

Results obtained from multivariate analyses of the pattern of performance exhibited by the two groups on these factors of ability provided partial support to the hypotheses as proposed. This was particularly true under conditions where the Simple Spatial-Motor and Complex Visual-Spatial Relations factors were combined to form a factor of Visual-Spatial Ability.

Both groups of children performed within average limits on all five factors regardless of the factor selection criteria. In addition, both groups performed at lowest levels (when compared to their performance on other factors) on the Simple Spatial-Motor factor. Group differences were observed on the Motor Steadiness factor (under clinical selection only) and on the Speeded Motor Sequencing factor (under statistical selection only). Group A performed in a superior manner to Group R-S on the former factor and in an inferior manner on the latter. As the Motor Steadiness factor represents measures of both simple and complex psychomotor ability, the performance of Group A would be somewhat consistent with the tenets of the NLD model which indicate that simple motor skills are a primary neuropsychological asset of this group. In addition, the performance of the two groups on the Speeded Motor Sequencing factor is consistent with the NLD model in that skills required by measures underlying this factor (such as processing of novel information, visual perception and attention, and visual memory) represent areas of neuropsychological deficit for Group A children but are neuropsychological assets for Group R-S children (Rourke, 1989, 1993).

Group differences were also observed on the Complex Visual-Spatial Relations factor (under both selection criteria) but only when the Category Test was excluded from the analysis. Group A children again performed at lower levels than Group R-S children, consistent with what would be expected based on the dynamics of the NLD model (Rourke, 1989). The addition of the Category Test to this factor removed the significant group differences. Although both groups tended to perform at overall lower levels on this factor when the Category Test was included, the overall level of performance of Group R-S children on this factor was more greatly affected than that of Group A children. Reasons for the influence of the Category Test have been presented above.

The potential presence of a hierarchical arrangement of the five factors was investigated. When all five factors were employed, there was no compelling evidence that the factors increased in complexity. The performance of both groups of learning-disabled children improved on the Complex Visual-Spatial Relations factor, when compared to the Simple-Spatial Motor factor, and then declined on the Speeded Motor Sequencing factor. This was observed under both clinical and statistical selection criteria. The level of performance observed on the Complex Visual-Spatial Relations factor would be expected for Group R-S children (given that their neuropsychological assets are in the area of visual-perceptual functioning). However, the performance of Group A children suggests that the children selected for use in this study were able to use their strong language skills in order to mediate their performance on tasks requiring some visual-perceptual-organizational abilities. Two of the five variables that contribute to the Complex Visual-Spatial Relations factor can be verbally mediated. In one task (WISC Object Assembly) the child is informed of the name of the object to be assembled (on two occasions). This may "prime" the Group A child to utilize verbal mediation strategies.

A partial hierarchy of complexity within the five factors was evident when the Simple Spatial-Motor and Complex Visual-Spatial Relations factors were combined to form a general Visual-Spatial Ability. Under clinical selection criteria conditions, Group A was observed to perform at progressively lower levels as the factors increased in complexity. Significant differences were observed between the Motor Steadiness factor and the Visual-Spatial Ability factor, with Group A performing at lower levels on the latter factor. This suggests that Group A children perform at higher levels on measures of simple motor and complex psychomotor ability than on measures requiring visual-perceptual-organization and the processing of novel and complex information. This is consistent with the characteristics and dynamics of children with NLD, as presented in the model.

Group R-S children, on the other hand, were found to perform at lower levels on the Speeded Motor Sequencing factor when compared to the Visual-Spatial Ability factor. Significant differences were not observed between the other three factors. This observation was consistent with hypotheses that the performance of this subtype of learning-disabled children would be adversely affected (relative to their own performance on previous measures) by the symbolic processing demands of this task.

Under statistical selection criteria, the two groups of children were again found to exhibit different patterns of performance. Group A children performed at lower levels on the Motor Steadiness factor than on the Simple Motor factor but their performance remained relatively stable over the remaining factors.

While Group R-S children also showed a nonsignificant decline in their performance between the same two factors they then tended to improve across the remaining factors. The performance observed from Group A children partially supported the hypotheses in that their performance was adversely affected when measures became more complex in nature and reflected their neuropsychological deficits (i.e., required more complex psychomotor ability and processing of novel information); however, their performance did not show a steady decline across all factors, as expected.

The discrepancy in the findings between the clinical and statistical selection criteria is reflected differentially in Group A and Group R-S. The performance of Group A on the Motor Steadiness factor is lower when statistical selection criteria are employed, perhaps reflecting the inclusion of the Grooved Pegboard Test. This is a test of complex psychomotor ability and directly assesses an area of neuropsychological deficit for these children. Group R-S children's performance on the Speeded Motor Sequencing factor improves under statistical selection criteria. This is likely due to the fact that several tests reflective of their primary neuropsychological assets are added to ones that are more indicative of their deficits.

In addition, the discrepancy between the findings obtained under clinical and statistical selection criteria, may also be attributed to the amount of overlap between the factors with respect to the measures used to identify them. Under statistical selection criteria there was more overlap between the factors, particularly between those that were felt to represent lower steps in the hierarchy (e.g., Motor Steadiness) and those representing higher steps (e.g., Complex Visual-Spatial Relations and Speeded Motor Sequencing). The amount of overlap likely contributed to the finding that evidence for the existence of a hierarchical arrangement of abilities was less strong under statistical selection criteria.

The hypothesized potential hierarchical arrangement of the motor, psychomotor, and visual-spatial factors was partially supported by the data obtained. It is clear that the two groups of children exhibited different patterns of performance across these factors. However, it appears that a "pure" definition of the underlying nature of the factors (i.e., as suggested by clinical selection criteria) resulted in a better understanding of the potential hierarchical arrangement of factors. Under these conditions it appeared that factors were arranged in a hierarchy of motor/psychomotor abilities followed by those requiring more complex and integrative skills and abilities, such as measuring visual-perceptual-organizational functioning. When statistical selection criteria were employed, the amount of overlap between the factors (e.g., shared variables) increased to the point where interpreting patterns of performance was more difficult. Although Group A children performed at higher levels on simple motor tasks (consistent with the NLD model), their performance on the remaining factors was relatively stable, likely reflecting the amount of overlap between the factors. In fact the general Visual-Spatial Ability factor and the

Speeded Motor Sequencing factor have four common variables when selected according to statistical selection criteria.

The fact that the hierarchy was more evident when the two visual-spatial factors were combined suggests that general cognitive abilities (i.e., visual-perceptual processing) underlying both factors are more representative of the development of cognitive abilities in children aged 9- to 12-years, than dividing these abilities into simple and complex skills. As younger Group A children have been shown to perform in a similar manner to Group R-S children on measures underlying both these factors (Ozols & Rourke, 1988, 1991), and older Group A children perform in an inferior manner (Rourke & Finlayson, 1978; Rourke & Strang, 1978; Strang & Rourke, 1978) on the same measures, it may be that the hierarchy would be more apparent if investigated in older Group A children.

It is also clear that both groups of children experience greater difficulty on measures underlying the Simple-Spatial Motor factor when compared to the Complex Visual-Spatial Relations factor. However, they may be performing poorly for different reasons. Group R-S children may be experiencing difficulties on measures underlying this factor due to problems understanding task requirements or guiding their own behaviour, whereas Group A children experience difficulties because of the visual-spatial components of the task. In addition, when tasks of primarily visual-perceptual ability can be verbally mediated, it appears that Group A children rely on their strengths in this area, in order to perform more successfully.

The combination of the Simple Spatial-Motor and Complex Visual-Spatial Relations factors allowed for the examination of a hierarchy of skills moving from simple motor, through complex psychomotor and visual-spatial abilities, to novel, integrative, visual-perceptual-organizational skills. Results obtained indicated that the motor and psychomotor tasks appear to represent the first stage in the hierarchy, followed by those tasks that required more integration and processing of novel information. This indicates a hierarchy of neurocognitive abilities that begins with those factors identified as representing primary abilities in the NLD model and then moves to those that measure more integrative skills representative of tertiary neuropsychological abilities.

The observed pattern of performance (and apparent hierarchical arrangement of abilities) of Group A children is consistent with what would be expected from the NLD model. Group A children performed more poorly on those tasks representative of their neuropsychological deficits. Their performance was better on measures underlying the Simple Motor and Motor Steadiness factors, which are representative of their primary neuropsychological assets. Group R-S children also performed in a manner consistent with their pattern of neuropsychological assets and deficits, in that their performance was worse under conditions reflective of their secondary and tertiary neuropsychological deficits than under those representative of their neuropsychological assets.

Study 3

The results obtained from the analyses of the performance of these two groups on the language factors (in both sample sizes) strongly supported the hypotheses as presented. The two groups of learning-disabled children differed significantly from each other on the General Verbal factor, with Group R-S performing significantly lower than Group A children. Group R-S children have greater difficulty with auditory-verbal and language processing in general than Group A children. This finding was consistent with observations from the original series of studies (Rourke & Finlayson, 1978; Rourke & Strang, 1978; Strang & Rourke, 1983) that Group R-S children performed at lower levels than Group A children on measures representing language and auditory-verbal processing abilities.

With respect to the Semantic and Acoustic Processing factors, it was found that Group A children performed at higher levels than Group R-S children on both factors. In addition, both groups of learning-disabled children performed, as expected, at lower levels on the Acoustic Processing factor when compared to the Semantic Processing factor. Group R-S children exhibited a larger discrepancy between their performance on the Semantic and Acoustic Processing factors than did Group A children. In addition, there was greater overlap between the groups on the Semantic Processing factor when compared to their performance on the Acoustic Processing factor. The two groups exhibited greater disparity on the Acoustic Processing factor than on the

Semantic Processing factor. All these observations, when taken together, suggest that the Semantic and Acoustic Processing factors are tapping different types of language abilities.

The performance of these two groups of children on the language and auditory-verbal measures argues that at least two types of language processing are assessed by the HRNB. Measures underlying the Semantic Processing factor appear to represent the more overlearned, rote aspects of language ability, while those underlying the Acoustic Processing factor are more representative of novel and more complex processing skills. The discrepancy between the Semantic and Acoustic Processing factors also suggests that measures underlying one factor (Semantic Processing) represent the product of auditory-verbal processing skills, whereas measures representative of the Acoustic Processing factor represent the process by which information is manipulated and encoded.

The fact that Group A children performed at lower levels on the Acoustic Processing factor (when compared to the Semantic Processing factor) further supports the tenets of the NLD model which state that they have greater difficulties with the processing of novel and complex material when compared to the processing of rote, overlearned information (Rourke, 1989). It should be noted, however, that Group A children performed within average limits (for their age) on both factors. This indicates that their performance on measures underlying the Acoustic Processing factor is adversely affected by their underlying neuropsychological deficit of difficulties processing novel and complex material, even when that material is verbal in nature (and, therefore, representative of their neuropsychological assets). This finding is consistent with what would be expected based on hypotheses derived from the NLD model (Rourke, 1982, 1987, 1988b, 1989).

The performance of Group R-S children on the langauge factors was also consistent with the proposed hypotheses. The results obtained confirm that the verbal neuropsychological assets of this group of learning-disabled children lie in the area of semantic processing (e.g., speech content and general information) and that their deficits are representative of phonological and output difficulties. These difficulties represent the primary neuropsychological deficits identified in the model for Group R-S children (that of auditory perceptual / acoustic processing difficulties).

This pattern of performance has implications for remediation attempts aimed at Group R-S children. Remediation programs for these children should use an approach that focusses on utilizing their neuropsychological assets in order to overcome their deficits. In other words, Group R-S children could be taught to use their relatively better developed ability to process rote and contextually appropriate information (along with their well-developed visual-spatial abilities) in order to improve their reading skill. A "sight-sound" approach to reading would appear to be appropriate for these children. This approach to remediation attempts would also fit with expectations based on an interactive-compensatory model of reading fluency.

This model of reading fluency was developed from an interactive approach to reading (Rumelhart, 1977) by Stanovich and his colleagues (e.g., Stanovich, 1980, 1990; Stanovich, Natha, & Vala-Rossi, 1986; Stanovich & West, 1989). Reading is conceptualized in this model as an interactive process requiring knowledge about visual feature extraction, orthographics, lexicons, syntax, and semantics. If deficits occur in any one of these knowledge areas, the model proposes that an individual will place greater reliance on one of the other areas available to them. Thus, those individuals who have significant difficulty with reading, and tend to do poorly on tasks requiring phonological analysis of verbal information, should be able to use semantic (or contextual) information as a compensatory aid when it is available to them (Stanovich 1980, 1990; Waterman & Lewandowski, 1993). As Group R-S children appear to be better at the processing of rote, overlearned, and contextually related verbal information, they should be able to use this skill in order to aid in compensating for their difficulties with more novel, acoustic processing. This should, then, eventually result in easier reading fluency and increased comprehension of material. In fact, the pattern of neuropsychological assets and deficits of Group R-S children reveals that their reading comprehension (at least later in their development) is an asset for them (Rourke, 1993). It would appear that their relative strengths for semantic processing of contextually relevant information aid their reading fluency and comprehension in a manner that would be consistent with an interactive-compensatory approach to reading and their patterns of neuropsychological assets and deficits.

In summary, the results obtained from this investigation of the factors of language functioning identified by Davidson (1992) indicate that the modified version of the HRNB for children assesses two different constructs of language processing. The first construct reflects the processing of rote, overlearned verbal material that is somehow contextually based or representative of semantics. The second construct represents those more novel and/or complex language skills, such as phonetic analysis. The results obtained confirm previous findings about the performance of two groups of learning-disabled children. In addition, the NLD model provides a good paradigm within which to examine these two groups of children and hypotheses generated from the model with respect to constructs of language functioning were supported.

## Implications for Assessment, Diagnosis, and Remediation

The primary focus of this series of studies was to continue investigations into the construct validity of a modified HRNB in children. However, the results obtained have implications for the assessment, diagnosis, and remediation of these two subtypes of learning-disabled children.

Results obtained from the first study investigating the predictive validity of the seven factors identified by Francis et al. (1992) and Davidson (1992) revealed that better predictive validity was obtained under conditions where statistical selection criteria were employed. This observation argues against the use of a restricted battery (of a few "representative" variables) for the assessment of learning-disabled children, particularly in the age range of 9- to 12-years old. In order for accurate diagnosis, and therefore the development of appropriate remediation programs, more complete and comprehensive information is required. It does, appear, however, that regardless of how much information is obtained from children in this age range, their verbal abilities (or deficits) are the most contributory for diagnosis, although better rates of accurate classification are obtained when psychomotor skills are also considered.

Results obtained from studies 2 and 3 indicate that, at least for the age range under consideration, cognitive abilities can be hierarchically arranged in terms of motor/psychomotor abilities followed by those skills requiring more integrative functions and the processing of novel information. In addition, the two language factors identified by Davidson (1992) reflect very different aspects of language functioning. Information obtained from these two studies has direct implications for the development of remediation programs for these two subtypes of learning-disabled children.

As the performance of Group A children tends to decline once more integrative and novel information processing becomes necessary, this information should be used in the development of remediation programs. Once a Group A child has been assessed and identified, their pattern of performance can be compared across the dimensions of cognitive ability identified by Francis et al. (1992) and Davidson (1992). While remediation approaches should begin at a level where the child will be successful (i.e., not on tasks requiring integrative and complex information processing) and a systematic approach to remediation should be conducted, tasks used in the remediation program also need to be analysed with respect to their cognitive demands.

If task demands are such that integrative and complex/novel information processing are required, then Group A children would not be expected to benefit from remediation attempts focussing solely on the aspects of these tasks. If, however, the task also requires skills for which the child performs at a higher level (such as basic motor, psychomotor, or language abilities), these skills should be utilized in order to provide compensatory strategies to overcome their deficits or to draw the child's attention to other aspects of the task (that are perhaps more visual in nature). Task analysis should compare the demands of a task with the factors of cognitive ability identified by Francis et al. (1992) and Davidson (1992). This type of analysis and comparison will provide information that will aid the clinician in determining when to move from directly addressing areas of difficulty to focussing on the development of a more practical approach and the implementation of compensatory strategies.

Rourke (1991) has developed a treatment program for children with NLD. This program uses a systematic, "step-by-step" treatment approach that teaches a child by using sequential verbal "steps" and also teaches them to make better use of their visual-perceptual-organizational skills. Although NLD children will tend to focus on using their well-developed verbal skills in order to compensate for their visual-perceptual-organizational deficits, this situation will not result in optimal development of the latter skills. As such, remediation efforts are recommended that focus on encouraging the child to pay attention to visual-perceptual details of situations and tasks. However, the older NLD child should be presented with more functional or practical remedial suggestions and exercises, although areas of difficulty should continue to be addressed.

Group R-S children's obvious difficulties with aspects of language that require phonemic analysis and auditory perception suggest that a "sight-sound" approach to remediation attempts of their reading difficulties might be beneficial for them. Results obtained from both studies 2 and 3 indicate that Group R-S children perform adequately on measures of neuropsychological ability that require visual-spatial analysis. In addition, their performance on measures of auditory-verbal and language ability that are more rote and contextually sensitive is relatively better than that observed on tasks requiring phonemic analysis and auditory perception. As such, Group R-S children should be encouraged to improve their sight vocabulary by utilizing their strengths in these areas. However, given their overall pattern of neuropsychological strengths and weaknesses, the prognosis for improvement in the area of reading and spelling is guarded (Rourke, 1991), although it is clear they are able to use context in order to improve their reading comprehension abilities later in their development.

It is clear that ecological validity studies need to conducted in order to determine how the neuropsychological abilities and deficits exhibited by these children are reflected in tasks of everyday life and in potential remediation tasks. This information can then be used in the development and assessment of remediation programs. The evidence of a partial hierarchical arrangement of cognitive abilities stresses the use of a systematic approach to remediation for children with NLD, as recommended by Rourke (1991).

## Summary and Conclusions

The investigation into the nature of the underlying factors of a modified HRNB has just begun with this study. Continued investigation of underlying factor structure is necessary in order to gain a more complete understanding of the relationship between the factors of cognitive ability. Further confirmatory factor analytic studies should be conducted using other age groups, as well as including measures such as the Category Test in order to more fully determine the underlying constructs of cognitive functioning measured by the HRNB.

The results obtained from this series of studies has established the predictive validity of these factors with respect to Groups R-S and A children. Further research of the predictive validity of these factors should be conducted using other groups of learning-disabled children, as well as those children expected to exhibit the NLD syndrome (i.e., those with known white matter dysfunction).

Although partial evidence for a hierarchical arrangement of cognitive abilities identified by Francis et al. (1992) was found, continued investigation is warranted. A developmental analysis of these factors would prove an interesting "next step" in determining the exact nature of the development of cognitive abilities. In addition, ecological validity studies need to be conducted in order to determine how the identified factors of neurocognitive ability are related to events occurring outside of the testing arena.

The results obtained from the third study in this series indicate that there are at least two very different types of language ability assessed by the HRNB. Continued investigation into how these abilities (along with other abilities assessed by the HRNB) are manifested in life outside of the neuropsychological testing situation could prove fruitful for the development of comprehensive remediation programs.

Although the majority of findings were consistent with tenets of the NLD model, some differences were observed when results were compared with those obtained from the original series of studies (Rourke & Finlayson, 1978; Rourke & Strang, 1978; Strang & Rourke, 1983). Group A children selected for the present study did not exhibit the same pattern of performance as observed in the original series of studies; however, their performance appeared to mirror that of younger Group A children (Ozols & Rourke, 1988, 1991). It may be that a very different (and potentially clearer) picture of the nature of the arrangement of cognitive abilities and the predictive validity of the factors would be obtained if older Group A children were used or if a clinically determined group of NLD children were examined. Once further confirmatory factor analytic studies of the motor, psychomotor, and visual-spatial measures of the HRNB using older children have been conducted in order to confirm the existence of similar underlying constructs of cognitive ability in other age groups, research should further investigate the performance of these groups of children on these factors.

The nature of the underlying constructs of cognitive functioning assessed by the HRNB deserves more complete examination. Although investigations into this have only recently begun, continued examination of these factors of neurocognitive ability will further our understanding of the nature of the tests used in neuropsychological assessment. This ultimately will lead to a better understanding of brain-behavior relationships.

# APPENDIX A

## Correlation matrices for motor and visual-spatial factors: Total sample

### Clinical Selection

| | F1 | F2 | F3 | F4 | F5 |
|---|---|---|---|---|---|
| **F1** | 1.00 | | | | |
| **F2** | .207 | 1.00 | | | |
| **F3** | .159 | .104 | 1.00 | | |
| **F4** | .101 | .095 | .261 | 1.00 | |
| **F5** | .242 | .379 | .159 | .017 | 1.00 |

### Clinical Selection + Category Test

| | F1 | F2 | F3 | F4 | F5 |
|---|---|---|---|---|---|
| **F1** | 1.00 | | | | |
| **F2** | .207 | 1.00 | | | |
| **F3** | .159 | .104 | 1.00 | | |
| **F4** | .095 | .083 | .216 | 1.00 | |
| **F5** | .242 | .379 | .159 | .002 | 1.00 |

### Statistical Selection

| | F1 | F2 | F3 | F4 | F5 |
|---|---|---|---|---|---|
| **F1** | 1.00 | | | | |
| **F2** | .435 | 1.00 | | | |
| **F3** | .242 | .806 | 1.00 | | |
| **F4** | .220 | .623 | .367 | 1.00 | |
| **F5** | .131 | .101 | -.099 | .539 | 1.00 |

APPENDIX A (cont'd)

Statistical Selection + Category Test

| | **F1** | **F2** | **F3** | **F4** | **F5** |
|---|---|---|---|---|---|
| **F1** | 1.00 | | | | |
| **F2** | .435 | 1.00 | | | |
| **F3** | .242 | .806 | 1.00 | | |
| **F4** | .213 | .594 | .348 | 1.00 | |
| **F5** | .131 | .101 | -.099 | .509 | 1.00 |

## APPENDIX B

## Correlation matrices for motor and visual-spatial factors: Group R-S

### Clinical Selection

| | **F1** | **F2** | **F3** | **F4** | **F5** |
|---|---|---|---|---|---|
| **F1** | 1.00 | | | | |
| **F2** | -.099 | 1.00 | | | |
| **F3** | -.042 | .010 | 1.00 | | |
| **F4** | .126 | .194 | .043 | 1.00 | |
| **F5** | .035 | .299 | .223 | .159 | 1.00 |

### Clinical Selection + Category Test

| | **F1** | **F2** | **F3** | **F4** | **F5** |
|---|---|---|---|---|---|
| **F1** | 1.00 | | | | |
| **F2** | -.099 | 1.00 | | | |
| **F3** | -.042 | .010 | 1.00 | | |
| **F4** | .086 | .094 | .065 | 1.00 | |
| **F5** | .035 | .299 | .223 | .105 | 1.00 |

### Statistical Selection

| | **F1** | **F2** | **F3** | **F4** | **F5** |
|---|---|---|---|---|---|
| **F1** | 1.00 | | | | |
| **F2** | .061 | 1.00 | | | |
| **F3** | -.106 | .757 | 1.00 | | |
| **F4** | .024 | .560 | .235 | 1.00 | |
| **F5** | .038 | -.029 | -.224 | .511 | 1.00 |

APPENDIX B (cont'd)

Statistical Selection + Category Test

|  | **F1** | **F2** | **F3** | **F4** | **F5** |
|---|---|---|---|---|---|
| **F1** | 1.00 |  |  |  |  |
| **F2** | .061 | 1.00 |  |  |  |
| **F3** | -.106 | .757 | 1.00 |  |  |
| **F4** | .015 | .490 | .188 | 1.00 |  |
| **F5** | .038 | -.029 | -.224 | .501 | 1.00 |

# APPENDIX C

## Correlation matrices for motor and visual-spatial factors: Group A

### Clinical Selection

| | F1 | F2 | F3 | F4 | F5 |
|---|---|---|---|---|---|
| **F1** | 1.00 | | | | |
| **F2** | .447 | 1.00 | | | |
| **F3** | .332 | .237 | 1.00 | | |
| **F4** | .130 | .088 | .405 | 1.00 | |
| **F5** | .443 | .500 | .095 | -.157 | 1.00 |

### Clinical Selection + Category Test

| | F1 | F2 | F3 | F4 | F5 |
|---|---|---|---|---|---|
| **F1** | 1.00 | | | | |
| **F2** | .447 | 1.00 | | | |
| **F3** | .332 | .237 | 1.00 | | |
| **F4** | .146 | .148 | .312 | 1.00 | |
| **F5** | .443 | .500 | .095 | -.131 | 1.00 |

### Statistical Selection

| | F1 | F2 | F3 | F4 | F5 |
|---|---|---|---|---|---|
| **F1** | 1.00 | | | | |
| **F2** | .670 | 1.00 | | | |
| **F3** | .483 | .835 | 1.00 | | |
| **F4** | .404 | .723 | .490 | 1.00 | |
| **F5** | .296 | .283 | .046 | .537 | 1.00 |

APPENDIX C (cont'd)

Statistical Selection + Category Test

| | **F1** | **F2** | **F3** | **F4** | **F5** |
|---|---|---|---|---|---|
| **F1** | 1.00 | | | | |
| **F2** | .670 | 1.00 | | | |
| **F3** | .483 | .835 | 1.00 | | |
| **F4** | .404 | .718 | .492 | 1.00 | |
| **F5** | .296 | .283 | .046 | .484 | 1.00 |

# APPENDIX D

## Correlation matrices for motor and visual-spatial factors (combined Simple Spatial-Motor and Complex Visual-Spatial Relations factors): Total Sample

### Clinical Selection

| | **F1** | **F2** | **F3 & F4** | **F5** |
|---|---|---|---|---|
| **F1** | 1.00 | | | |
| **F2** | .207 | 1.00 | | |
| **F3& F4** | .168 | .125 | 1.00 | |
| **F5** | .242 | .379 | .125 | 1.00 |

### Clinical Selection + Category Test

| | **F1** | **F2** | **F3 & F4** | **F5** |
|---|---|---|---|---|
| **F1** | 1.00 | | | |
| **F2** | .207 | 1.00 | | |
| **F3& F4** | .170 | .121 | 1.00 | |
| **F5** | .242 | .379 | .126 | 1.00 |

### Statistical Selection

| | **F1** | **F2** | **F3 & F4** | **F5** |
|---|---|---|---|---|
| **F1** | 1.00 | | | |
| **F2** | .435 | 1.00 | | |
| **F3& F4** | .280 | .871 | 1.00 | |
| **F5** | .131 | .101 | .239 | 1.00 |

APPENDIX D (cont'd)

Statistical Selection + Category Test

| | **F1** | **F2** | **F3 & F4** | **F5** |
|---|---|---|---|---|
| **F1** | 1.00 | | | |
| **F2** | .435 | 1.00 | | |
| **F3& F4** | .278 | .864 | 1.00 | |
| **F5** | .131 | .101 | .207 | 1.00 |

# APPENDIX E

## Correlation matrices for motor and visual-spatial factors (combined Simple Spatial-Motor and Complex Visual-Spatial Relations factors): Group R-S

### Clinical Selection

| | **F1** | **F2** | **F3 & F4** | **F5** |
|---|---|---|---|---|
| **F1** | 1.00 | | | |
| **F2** | -.099 | 1.00 | | |
| **F3& F4** | .045 | .126 | 1.00 | |
| **F5** | .035 | .299 | .268 | 1.00 |

### Clinical Selection + Category Test

| | **F1** | **F2** | **F3 & F4** | **F5** |
|---|---|---|---|---|
| **F1** | 1.00 | | | |
| **F2** | -.099 | 1.00 | | |
| **F3& F4** | .013 | .060 | 1.00 | |
| **F5** | .035 | .299 | .236 | 1.00 |

### Statistical Selection

| | **F1** | **F2** | **F3 & F4** | **F5** |
|---|---|---|---|---|
| **F1** | 1.00 | | | |
| **F2** | .061 | 1.00 | | |
| **F3& F4** | -.058 | .846 | 1.00 | |
| **F5** | .038 | -.029 | .145 | 1.00 |

APPENDIX E (cont'd)

Statistical Selection + Category Test

| | **F1** | **F2** | **F3 & F4** | **F5** |
|---|---|---|---|---|
| **F1** | 1.00 | | | |
| **F2** | .061 | 1.00 | | |
| **F3& F4** | -.067 | .824 | 1.00 | |
| **F5** | .038 | -.029 | .128 | 1.00 |

# APPENDIX F

## Correlation matrices for motor and visual-spatial factors (combined Simple Spatial-Motor and Complex Visual-Spatial Relations factors): Group A

### Clinical Selection

| | **F1** | **F2** | **F3 & F4** | **F5** |
|---|---|---|---|---|
| **F1** | 1.00 | | | |
| **F2** | .447 | 1.00 | | |
| **F3& F4** | .301 | .212 | 1.00 | |
| **F5** | .443 | .500 | -.002 | 1.00 |

### Clinical Selection + Category Test

| | **F1** | **F2** | **F3 & F4** | **F5** |
|---|---|---|---|---|
| **F1** | 1.00 | | | |
| **F2** | .447 | 1.00 | | |
| **F3& F4** | .324 | .248 | 1.00 | |
| **F5** | .443 | .500 | .022 | 1.00 |

### Statistical Selection

| | **F1** | **F2** | **F3 & F4** | **F5** |
|---|---|---|---|---|
| **F1** | 1.00 | | | |
| **F2** | .670 | 1.00 | | |
| **F3& F4** | .517 | .907 | 1.00 | |
| **F5** | .296 | .283 | .316 | 1.00 |

APPENDIX F (cont'd)

Statistical Selection + Category Test

| | **F1** | **F2** | **F3 & F4** | **F5** |
|---|---|---|---|---|
| **F1** | 1.00 | | | |
| **F2** | .670 | 1.00 | | |
| **F3& F4** | .518 | .906 | 1.00 | |
| **F5** | .296 | .283 | .273 | 1.00 |

# APPENDIX G

## Explanation of abbreviations for Figure 18

| Abbreviation | Test Name |
|---|---|
| Info | WISC Information Subtest (scaled score) |
| Simil | WISC Similarities Subtest (scaled score) |
| Vocab | WISC Vocabulary Subtest (scaled score) |
| PPVT | Peabody Picture Vocabulary Test |
| SSPT | Speech Sounds Perception Test (total number correct) |
| AC | Auditory Closure (total number correct) |
| SMem | Sentence Memory (total number correct) |
| Tar | Target Test (total number correct) |
| PC | WISC Picture Completion Subtest (scaled score) |
| BD | WISC Block Design Subtest (scaled score) |
| OA | WISC Object Assembly Subtest (scaled score) |
| Pegs | Grooved Pegboard Test (average of right and left hand scores) |
| Mazes | Mazes Test (average of right and left hand scores) |
| CAT | Halstead Category Test (total number of errors) |

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# VITA AUCTORIS

Joanna Margaret Hamilton (née Bryan) was born on 11 December, 1963 in London, England, to Dr. Thomas and Ishbel Bryan. She emigrated to Canada in September 1973. In June 1981 she graduated from Kenner Collegiate and Vocational Institute in Peterborough, Ontario. She enrolled at Trent University in Peterborough and graduated with a Bachelor of Science (Honours) Degree in Psychology in May 1985. She enrolled in the Doctoral programme in Clinical Neuropsychology at the University of Windsor, Ontario, in September 1986. She completed her Master of Arts Degree in December of 1988. Practicum and internship requirements were completed at Peterborough Civic Hospital in Peterborough, Ontario, and with the Acquired Brain Injury Program at Chedoke-McMaster Hospitals in Hamilton, Ontario. Following the completion of her internship requirements, she worked for two and one-half years with the Acquired Brain Injury Program and the Vocational Assessment Unit at Chedoke-McMaster Hospitals. Since March 1993, she has been working with Dr. Gary Burkhart in his private practice in Peterborough, Ontario.

Joanna married Stewart Hamilton in August 1987. Their daughter, Emily, was born in September 1990.