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Neuropsychological characteristics of left-handed learning-disabled children classified according to patterns of academic achievement.

Joanna M. Hamilton
University of Windsor

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by

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ABSTRACT

The purpose of this study was to investigate the neuropsychological characteristics of left-handed learning-disabled children classified according to patterns of academic achievement. Earlier studies utilizing this method of classification have found that right-handed learning-disabled children can be differentiated on a variety of neuropsychological measures. However, the performance of left-handed children has not been examined. In this study, three groups of 9- to 14-year-old learning disabled children (n = 8 in each group) were selected in the following manner: (1) Group 1 children exhibited uniformly deficient performance on the Reading, Spelling, and Arithmetic subtests of the Wide Range Achievement Test; (2) Group 2 children exhibited impaired performance on the Arithmetic subtest in conjuction with even lower performance on the Reading and Spelling subtests; and (3) Group 3 children presented with average to above-average performance on the Reading and Spelling subtests, but were impaired on the Arithmetic subtest. Hypotheses concerning the performance of these children on the verbal and visual-spatial measures were partially supported; however, no support was found for the hypotheses regarding the performance of the groups on the motor, tactile-perceptual, and concept-formation measures. While none of the models of left-handedness could fully account for the patterns of performance observed in the groups of children, Levy's (1969) competition hypothesis was the best predictor of the performance of these groups of children. A comparison of the

performance of right- and left-handed learning-disabled children indicated that the groups were generally similar; however, there were some differences between the groups, especially with respect to patterns of performance within handedness groups. The relationships of the present findings to previous studies, theoretical implications, and suggestions for future research were discussed.

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CHAPTER I

INTRODUCTION

Early research in the area of learning disabilities viewed the learning disabled as a homogeneous population. As a result, researchers would study learning disabled children as a group and compare their performance on various tasks to that of normal children (Fisk & Rourke, 1983). A level of performance paradigm would be used, where poor performance on a given task was assumed to be indicative of a specific deficit that would explain the learning disability (Fletcher & Satz, 1985; McKinney, 1985). Not surprisingly, it was found that learning disabled children differed from normal children on a host of neuropsychological, cognitive, and social measures (Dean, Schwartz, & Smith, 1981; Feagans & McKinney, 1981; Fletcher & Satz, 1985; Naylor, 1980; Rourke, 1975). The results of studies utilizing the level of performance paradigm only served to produce a seemingly endless list of variables that would differentiate learning disabled children from normals (Fisk & Rourke, 1983). In recent years, however, the view that learning-disabled children constitute a homogeneous population has been challenged, and the view that learning disabilities are composed of various distinct subgroups of disorders has been advocated.

Subtyping research has focused almost without exception on right-handed learning-disabled children. While this has led to a clearer understanding of the underlying nature of learning disabilities, it is not certain whether the findings of these studies can be applied to left-handed learning-disabled children. One issue of concern in this area of research relates to the possibility that right- and left-handed individuals differ in terms of their patterns of functional cerebral organization. If in fact they do, the results obtained from studies that employ right-handed subjects may not be directly applicable to left-handed individuals.

In the following sections, the subtyping literature will be reviewed with an emphasis on one particular area of study that has proved successful in distinguishing between various learning-disabled children; that of differentiating groups of these children on the basis of their patterns of academic performance. Next, the issue of differential cerebral lateralization within left-handers will be examined according to various models that have been proposed to account for the apparent disparity between right- and left-handers. Finally, the purpose and design of the present study will be presented.

SUBTYPING STUDIES OF LEARNING-DISABLED CHILDREN

Early Subtyping Studies

Early research that examined the underlying nature of learning disabilities suggested that they could be encountered for various reasons (Boder, 1973; Mattis, French, & Rapin, 1975; Myklebust & Johnson, 1962).

For example, learning-disabled children (in particular, reading-disabled children) can encounter difficulty in the acquisition of a particular skill (i.e., reading) due to a deficit in visual-perceptual abilities or auditory-linguistic abilities, or a combination of the two (Boder, 1973; Myklebust & Johnson, 1962). Furthermore, Rourke has argued that learning-disabled children can no longer be viewed as a homogeneous group with respect to their patterns of abilities and deficits (Fisk & Rourke, 1983; Rourke, 1978, 1981). Subtyping research has, therefore, attempted to delineate more precisely the underlying nature of learning disabilities, in terms of the pattern of abilities and deficits exhibited by various learning-disabled children.

The study of subtypes of learning-disabled children emerged primarily from clinical observations of children who were thought to possess deficiencies in some central processing mechanism (Rourke, 1988). Early observations employed a clinical inferential approach to the identification of underlying subtypes in reading-disabled children (Boder, 1973; Mattis, French, & Rapin, 1975; Myklebust & Johnson, 1962). Myklebust & Johnson (1962) noted that there were children who exhibited a dyslexia characterized by orientation disturbances, topographic disorders, dyschronometria, an inability to write, spelling disability, dyscalculia, an inability to learn a foreign language, and memory disorders. Furthermore, children who exhibited this syndrome of dyslexia could be subdivided according to either their inability to auditorize (i.e., they were unable to learn what letters sounded like), or their inability to visualize (i.e., they were unable to learn what letters looked like).

Further clinical evidence for subtypes within the dyslexic population was provided by Boder (1973). Based on a child's performance on a diagnostic screening battery for dyslexia, three atypical patterns of reading and spelling were identified that were thought to reflect distinct subtypes of dyslexic children. The first subtype identified was composed of those children whose primary deficit in reading was due to an inability to develop phonetic-word analysis skills that arose from a primary deficit in symbol-sound integration. Boder termed this group "dysphonetic dyslexia". Children whose reading and spelling pattern reflected a primary deficit in the ability to perceive letters and words as configurations were classified as "dyseidetic dyslexic". The third group of children were those whose reading and spelling pattern reflected primary deficits in both phonetic word analysis skills and in the perception of letters and words as configurations. These children were called the "mixed dysphonetic-dyseidetic" group. Boder (1973) found that in 107 children who met a standard definition for dyslexia, 100 could be placed into one or another of the subgroups based on their reading and spelling performance. Of these 100 children, 67 were classified as "dysphonetic dyslexic", 10 as "dyseidetic dyslexic", and the remaining 23 fell into the "mixed dysphonetic-dyseidetic dyslexia" group.

In an attempt to isolate the underlying independent deficits or clusters of deficits that would represent the conditions sufficient enough to limit the acquisition of reading skills, Mattis, French, & Rapin (1975) evaluated the performance of three groups of children on an extensive neuropsychological battery. The three groups were: children who had confirmed brain-damage without evidence of dyslexia; children who were brain-damaged and exhibited dyslexia; and, children who were dyslexic but had no evidence of brain damage. Based on the pattern of results obtained through the neuropsychological tests, Mattis et al. (1975) identified three different subgroups of reading-disabilities. These subgroups accounted for 90% of the dyslexic children. The first subgroup was labeled a language disorder subgroup (children who exhibited anomia, and disorders of comprehension, imitative speech, and speech sound discrimination). The second subgroup was composed of children who exhibited deficits in co-ordination (both fine and gross), along with graphomotor disturbances. This group was termed the articulation and graphomotor dysco-ordination subgroup. The remaining subgroup was classified as having a visuo-perceptual disorder and was characterized by poor constructional ability and visual-spatial perception. Mattis et al. (1975) argued that their results supported a model that presumed that dyslexia was the result of any one of multiple independent clusters of cognitive deficits rather than a single unitary cause.

Statistical Subtyping Studies

The application of various statistical techniques such as Q-factor analysis or cluster analysis has also proven useful in the identification of underlying subtypes of learning-disabled children (Doehring & Hoshko, 1977; Doehring, Hoshko, & Bryans, 1979; Fisk & Rourke, 1979; Lyon, 1983; Lyon & Watson, 1981; Lyon, Watson, Reitta, Porch, & Rhodes, 1981; Morris, Blashfield, & Satz, 1986; Petrauskas & Rourke, 1979; Watson, Goldgar, & Ryschon, 1983). For example, Doehring & Hoshko (1977) gave a battery of tests of reading-related skills to two groups of children: the first group (Group R) consisted of children in a summer program for reading problems; and the second group (Group M) was composed of children in a summer program for learning disorders as well as children in public school special classes for learning disorders, language disorders, and mental retardation. The results obtained from Q-Factor analyses indicated that learning-disabled children can be classified statistically into groups that represent different patterns of reading deficits. For Group R three subgroups were obtained that included a poor oral reading group with good visual matching skills; a poor auditory-visual letter matching group with good visual scanning skills; and a group exhibiting poor auditory-visual association of words and syllables in the light of good auditory-visual matching of letters. The factor analysis of Group M also revealed three subgroups. Two of the subgroups were similar to the last two subgroups for Group R, and a third subgroup exhibited poor visual-perceptual skills. These findings were validated in a further study by Doehring, Hoshko, & Bryans (1979).

Other studies that have employed the Q-factor analysis technique have also indicated that learning-disabled children can be classified reliably into meaningful subtypes according to their performance on a variety of neuropsychological measures (Fisk & Rourke, 1979; Petrauskas & Rourke, 1979). Similar general findings have been obtained through the use of cluster analysis (Lyon, 1983; Lyon & Watson, 1981; Lyon, Watson, Reitta, Porch, & Rhodes, 1981; Morris, Blashfield, & Satz, 1986; Watson, Goldgar, & Ryschon, 1983).

Subtyping according to patterns of Academic Performance

Another successful method of subtyping learning-disabled children has focused on the differentiation of groups of children on the basis of their patterns of academic performance and has been studied extensively by Rourke and associates (Fisk & Rourke, 1983). All subjects used in the studies carried out in Rourke's laboratory fit the following fairly standard definition of "learning disabilities": they were markedly deficient in at least one school subject area; FSIQs were within the roughly normal range; they were free from primary emotional disturbance; 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; they had experienced only the usual childhood illnesses; and english was their native language (Rourke, 1975, 1978, in press). This area of subtyping research emerged from studies that examined the relationships 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 related to low VIQ scores (Verbal abilities) and right hemisphere lesions are related to low PIQ scores (Visual-spatial and Visual-motor abilities), it was hypothesized that children who exhibited selective impairment on the Verbal or Performance subtests of the WISC would also demonstrate impairment of the left or right cerebral hemispheres, respectively. Behavioral measures that were known to reflect the functional integrity of the two cerebral hemispheres were used to assess this hypothesis.

Rourke, Young, & Flewelling (1971) examined the relationship between VIQ and PIQ discrepancies and selected verbal, auditory-perceptual, visual-perceptual, and problem-solving abilities in children who were referred for neuropsychological assessment because of suspected learning disabilities. All children were between the ages of 9- and 14-years-old. Ninety subjects who met the outlined criteria were divided into three groups of thirty based on the nature of the discrepancy between VIQ and PIQ. 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 made up of those subjects whose VIQ and PIQ scores were within four points of each other. The last group of subjects (HV-LP) was composed of those subjects whose VIQ was at least 10 points higher than their PIQ. The performance 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 tests measuring visual-perceptual skills. The performance level of the V=P group fell between the other two groups on most of the dependent measures. While the HP-LV group performed better than the HV-LP group on a measure of non-verbal problem-solving ability, this difference was not significant. An a posteriori comparison of the Wide Range Achievement Test (WRAT; Jastak & Jastak, 1965) performance of the three groups revealed that the HV-LP group had statistically different scores between the Reading and Spelling subtests (high) and the Arithmetic subtest (low). On the other hand, the HP-LV group showed a trend (albeit non-significant) towards higher scores on the Arithmetic subtest in comparison to scores on the Reading and Spelling subtests.

Further examination of these three groups of children was carried out using measures of motor and psychomotor abilities (Rourke & Telegdy, 1971). Three groups of children who exhibited patterns of VIQ-PIQ discrepancies similar to those used in Rourke, Young, & Flewelling (1971) were selected. They were between the ages of 9- and 14-years-old and their FSIQs were in the range of 85 to 115. 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. Although the HP-LV and HV-LP groups did not differ in terms of differential hand superiority on the measures employed, as was predicted, there was support for the expectation that the HP-LV group would show superior performance on tasks that involved complex visual-motor co-ordination, due to their demonstrated superiority in visual-spatial abilities.

The results of these two studies suggest that VIQ-PIQ discrepancies on the WISC reflect the differential functional integrity of the two cerebral hemispheres 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 that are thought to be subserved primarily by the right cerebral hemisphere. Of particular interest was the fact that 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 the differential patterns of performance on the WRAT subtests appeared to be related to different patterns of neuropsychological abilities and deficits, further indepth investigation of groups of children exhibiting these performance patterns was conducted. A series of studies by Rourke and associates has highlighted the neuropsychological characteristics of children who are classified according to their patterns of performance on the WRAT (Rourke & Finlayson, 1978; Rourke & Strang, 1978; Strang & Rourke, 1983). Three groups of children (two in the Strang & Rourke, 1983 study), aged between 9 and 14 years, were chosen on the basis of their performance patterns on the WRAT Reading, Spelling, and Arithmetic subtests. Group 1 children were defined as those who exhibited uniform deficiencies on all three subtests. Their grade-equivalent scores on each of the three subtests were at least 2.0 years below their expected grade placement. 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 2 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 3 exhibited normal reading and spelling subtest scores, but showed deficient scores on the arithmetic subtest. The grade-equivalent score for the arithmetic subtest was at least 2.0 years below the grade-equivalent scores for reading and spelling. All three groups have deficient arithmetic scores relative to age-based norms; however, Groups 2 and 3 are superior to Group 1 in arithmetic and do not differ from each other.

In the first study of this series, Rourke & Finlayson (1978) compared these three groups on various measures of verbal and visual-spatial abilities. There were 15 subjects in each of the three groups. All three groups were equated for age and FSIQ on the WISC.

The results of this study indicated that Group 3 children exhibited superior performances, when compared to Groups 1 and 2, on measures of verbal and auditory-perceptual abilities, but were deficient, relative to Groups 1 and 2, on measures of visual-perceptual and visual-spatial skills. The pattern of performance of Group 2 children was the reverse of Group 3 children, in that Group 2 children showed deficits in verbal and auditory-perceptual abilities, while exhibiting strengths in visual-perceptual and visual-spatial skills. Group 1 children performed in a manner similar to Group 2 children. With respect to VIQ-PIQ discrepancies, it was noted that all subjects in Group 1 had a lower VIQ than PIQ, 14 of the 15 subjects in Group 2 had a lower VIQ than PIQ (the remaining subject had equivalent VIQ and PIQ scores), and that all Group 3 subjects exhibited a higher VIQ score than PIQ score.

This finding indicates that Groups 1 and 2 subjects performed in a manner that was 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 3 performed in a manner expected from those children who exhibited a WISC pattern of HV-LP (Rourke et al., 1971). Since there is reason to believe that the pattern of WISC VIQ-PIQ discrepancies reflects the underlying pattern of the functional integrity of the cerebral hemispheres, then it would appear that the basis on which the children in this study were selected is also a reflection of hemispheric integrity (Rourke & Finlayson, 1978). Thus, the findings of the Rourke & Finlayson (1978) study would be consistent with the view that children in Group 3 exhibit poor performance in visual-perceptual and visual-spatial abilities due to compromised functioning of systems within the right-cerebral hemisphere. On the other hand, Groups 1 and 2 children exhibit poor performance in verbal and auditory-perceptual tasks due to compromised functioning of left-hemispheric systems.

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 skills. It was expected that the three groups would exhibit patterns of performance that would reflect the underlying integrity of the cerebral hemispheres. More specifically, it was expected that Group 3 children would be generally deficient on motor and psychomotor tasks when compared to Groups 1 and 2 (Rourke & Telegdy, 1971). Since it was thought that Group 3 exhibited deficits due to compromised functioning of the right cerebral-hemisphere, children in this group were expected to exhibit particularly poor performance with their left hand. Children in Groups 1 and 2, on the other hand, were expected to show relatively intact motor and psychomotor skills, and any deficiency would be evidenced by poor performance with the right hand.

The results indicated that the three groups did not differ with respect to performance on the motor tasks, although each group performed significantly better with their right hand than with their left hand. Groups 1 and 2 performed in an age appropriate fashion on two of the psychomotor tasks (Mazes and Grooved Pegboard) and exhibited superior levels of performance relative to Group 3 on these measures. Only the Tactual Performance Test (TPT) revealed differential hand superiority. Groups 1 and 3 had poor left-hand performance, relative to right-hand performance, on the TPT, whereas Group 2 exhibited the opposite pattern of performance. However, on the "both hands" measure of the TPT Groups 1 and 2 performed in line with the pattern evident for the Mazes and Grooved Pegboard Test, by exhibiting superior performance relative to Group 3 children. Results from a composite measure of tactile-perceptual abilities revealed that Groups 1 and 2 performed in a superior manner to Group 3 for both the right- and left-hands, and that Group 3 children had a tendency to perform better with their right-hand than with their left.

Overall, the results indicate that children in Group 3 have marked deficiencies in some psychomotor and tactile-perceptual abilities, relative to both age-expectation levels and Groups 1 and 2. The marked discrepancy between the performance of Groups 2 and 3 on the TPT offers support for the hypothesis of differential hemispheric integrity advanced in the original study of this series (Rourke & Finlayson, 1978).

The final study in the series compared the performance of Groups 2 and 3 on the Halstead Category Test (a measure of nonverbal-problem solving consisting of six subtests; Reitan & Wolfson, 1985). Group 1 was excluded from this study since other research suggested that they might be composed of several discrete subtypes of learning-disabled children (Fisk & Rourke, 1979; Petrauskas & Rourke, 1979). Two groups of 15 subjects who fulfilled the criteria outlined above were used as subjects in this study. Examination of the total number of errors made on the Category Test revealed that Group 3 made significantly more errors than Group 2. Closer examination of the number of errors made on the subtests of the Category Test indicated that Group 3 performed in an inferior manner to Group 2 on the last three subtests (although there was no significant difference between the groups on subtest 5). Analysis of the errors made on subtest 6 (the review subtest) revealed that Group 2 children appeared to benefit from practice, while Group 3 children appeared to show little ability to benefit from experience.

Summary of Academic Performance Subtyping Studies

From these three studies it is apparent that children who differ in their patterns of academic performance (as measured by the WRAT) exhibit differential patterns of adaptive abilities. The results generally suggest that Group 2 children are deficient on tasks measuring abilities thought to be subserved primarily by the left-cerebral hemisphere, whereas Group 3 children show deficits on tasks that measure abilities thought to be subserved primarily by right-hemisphere systems. The most striking deficiencies exhibited by Group 2 children are in verbal and auditory-perceptual abilities. These deficits are found in conjunction with superior visual-spatial and visual-perceptual skills, good psychomotor abilities and tactile-perceptual abilities, and intact problem-solving skills. Group 3 children, on the other hand, exhibit deficits in visual-spatial and visual-perceptual processing, have bilateral psychomotor problems, show bilateral impairment for tactile-perceptual measures (although the impairment is more marked 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 for Group 2 children.

It is important to note here that two groups of children who were equated for deficient arithmetic performance (Groups 2 and 3) exhibited vastly different patterns of performance on the neuropsychological measures. These differences were, therefore, clearly related to their patterns of academic performance rather than to their levels of performance.

The results of these subtyping studies have far-reaching theoretical ramifications (Fisk & Rourke, 1988; Rourke, 1982, 1988). It is clear that patterns of performance on neuropsychological measures reflect the underlying functional integrity of the cerebral hemispheres. Moreover, subtyping studies have revealed that a particular pattern of academic abilities and deficits is reflected in a particular pattern of neuropsychological abilities and deficits (Rourke, in press). However, since the research has been conducted using right-handed learning-disabled children, it is unclear whether these findings can be applied to left-handed learning-disabled children who may, or may not, exhibit similar patterns of hemispheric integrity and organization. In other words, would left-handed children, chosen according to particular patterns of academic performance, exhibit similar patterns of neuropsychological abilities and deficits to those seen in right-handed children? A recent study by Del Dotto & Rourke (1985) suggests that this might be the case, since it was found that the general adaptive characteristics of right- and left-handed learning-disabled children were highly similar. However, a closer examination of patterns of performance in left-handed learning-disabled children is warranted before definitive conclusions can be drawn.

Researchers studying left-handedness have been struck by the lack of uniformity in cerebral lateralization exhibited by this population (Hecaen & Sauguet, 1971; Levy & Reid, 1978). Models of left-handedness and cerebral lateralization have been proposed that attempt to account for the varied lateralization patterns seen in left-handers. Some of these models will be examined in the following section.

Models of Left-handedness

The nature of human cerebral organization has been the subject of much research since Broca first noted, in 1861, that damage to certain areas of the left-hemisphere resulted in language disturbances (Bryden, 1982; Corballis, 1983). Studies conducted since that time have revealed that, at a very simplistic level, the left-hemisphere is specialized for the processing of verbal and language-related information, while the right-hemisphere is involved primarily in the processing of nonverbal, or visual-spatial information (Bryden, 1982). It has also been suggested that the hemispheres differ in their modes of processing, with the left-hemisphere processing information in an analytical and sequential manner, and the right-hemisphere processing information in a holistic and parallel manner (Bradshaw & Nettleton, 1981, 1983).

While the above pattern of cerebral organization is said to be found in the majority of right handers, the pattern of cerebral organization in left handers is presumed to be more varied. For example, while it is estimated that 97-99% of right-handed individuals have language lateralized in the left cerebral hemisphere, figures indicate that only about 60-70% of left-handers have a similar pattern of language lateralization (Bryden, 1982; Corballis, 1983). The remaining left-handed individuals are presumed to have language represented either bilaterally or in the right-hemisphere (Corballis, 1983; Hardyck & Petrinovich, 1977; Levy, 1969; Satz, 1979). Research examining hemispheric specialization for visual-spatial abilities within the left-handed has also revealed differential cerebral organization (Bryden, 1982; Hecaen, De Agostini, &

Monzon-Montes, 1981). Taken together, these findings suggest that the left-handed population is a diverse group with respect to functional cerebral lateralization patterns.

In order to account for this diversity, several different models of left-handedness and hemispheric lateralization have been proposed (Bakan, 1971, 1975; Bryden, 1982; Levy, 1969; Satz, 1972, 1973). Models of the relationship between handedness and lateralization fall into two general categories: models that characterize the first category suggest that sinistrality indicates that the individual exhibits different functional lateralization patterns from those normally seen in right-handers (Bryden, 1982; Levy, 1969); models that are representative of the second category argue that sinistrality is the result of different functional lateralization that arises from brain damage sustained early in life (Bakan, 1971, 1975; Satz, 1972, 1973).

MODELS OF DIFFERENTIAL FUNCTIONAL LATERALIZATION

Right-hemisphere Language Representation

Bryden (1982) points out that many early researchers assumed that handedness and language lateralization were interrelated. Thus, since the left-hemisphere was dominant for speech in right-handers, the right-hemisphere was assumed to be dominant for speech in left-handers. However, while it is evident that left-handers have a higher incidence rate of right-hemisphere speech lateralization (Kinsbourne & Hiscock, 1978), research examining the incidence of aphasia following unilateral brain damage (e.g., Hecaen & de

Ajuriguerra, 1964; Hecaen & Sauguet, 1971; Humphrey & Zangwill, 1952; see also Corballis, 1982 & Satz, 1979, 1980 for reviews) indicates that left-handers show a more variable pattern of cerebral speech dominance. It is clear that a left-hemisphere lesion will produce speech disturbances in the majority of left-handers; however, some left-handers experience speech problems after right-hemisphere damage (Delis, Knight, & Simpson, 1983; Hecaen & Sauguet, 1971). These observations indicate that this early theory regarding speech lateralization in left-handers is not universally tenable. There are, however, some reports of individual cases of left-handed individuals who show reversed patterns of lateralization from that seen in right-handers (e.g., Delis et al., 1983). This suggests that a more comprehensive theory of speech lateralization in left-handers is needed to explain the discrepancies between the two handedness groups found in studies of aphasia.

Levy's (1969) Competition Hypothesis - Bilateral Language Representation

An alternate descriptive model of different functional lateralization patterns in left-handers was proposed by Levy (1969). Levy (1969, 1976) suggested that clear differentiation of hemispheric functioning was not evident in many left-handers. As a result, language capabilities in these left-handers were thought to be represented bilaterally. Levy argued that this bilateral language representation would lead to deficient performance on visual-spatial and visual-perceptual tasks, since there would be competition for processing by the right hemisphere between verbal and spatial functions.

Levy (1969) tested this hypothesis by comparing the performance of 15 right- and 10 left-handed graduate students on the verbal and performance subscales of the WAIS. She found that, although the two groups did not differ with respect to verbal IQ, there was a significant difference in terms of performance IQ. Right-handed individuals obtained higher performance IQ values than left-handed individuals. The two groups also showed differences in the amount of discrepancy between verbal and performance IQs. Right-handers had an average discrepancy of 8 points, whereas left-handers exhibited a 25 point discrepancy. Levy concluded that the assumed bilateral language representation exhibited by left-handers interfered with the processing of functions thought to be subserved by the right-hemisphere.

Support for Levy's competition hypothesis has been provided by Bradshaw, Nettleton, & Taylor (1981), Johnson & Harley (1980), and Miller (1971). Miller (1971) administered a test of verbal intelligence and a test measuring visual-spatial abilities to 29 right-handed and 23 mixed-handed (left-handed) university students. The results revealed that right- and left-handers did not differ from each other with respect to scores obtained on the measure of verbal intelligence; however, left-handers performed significantly lower than right-handers on the visual-spatial test. Miller concluded that these findings supported Levy's hypothesis and reflected the underlying differences in the organization of functions within the brain shown by right- and left-handers.

Johnson & Harley (1980) tested Levy's hypothesis by comparing verbal and perceptual-spatial abilities in both dextral and sinistral males and females.

Subjects were administered two verbal (Vocabulary and Arithmetic) and two performance (Block Design and Picture Arrangement) subtests from the WAIS. Group tests of both verbal and perceptual-spatial abilities were also given. Johnson & Harley (1980) found that sinistrals scored lower on the group test of perceptual-spatial abilities and higher on the test of verbal abilities than dextrals, regardless of sex. The WAIS subtests did not discriminate between the handedness groups. In general, Johnson & Harley's findings support Levy's hypothesis that left- and right-handers exhibit cognitive differences that reflect differences in the underlying pattern of functional lateralization. Left-handedness was found to be related to deficient spatial performance. However, this finding was only true for those left-handers who exhibited firm left-handedness (i.e., performed all 12 items on a handedness questionnaire with their left hand). Those left-handed individuals who were considered to possess mixed handedness did not differ from dextrals on either measure employed in this study.

In a more complex examination of Levy's competition hypothesis, Bradshaw et al. (1981) administered two tachistoscopic tasks (a lexical decision task designed to measure left-hemispheric functioning and a face discrimination task designed to measure right-hemispheric functioning) and the WAIS to 96 university students. The two tachistoscopic tasks were used as more direct measures of the underlying lateralization of function exhibited by the subjects. Bradshaw et al. found that left-handed subjects (and particularly, those with a familial history of left-handedness) had lower scores on the performance subtests of the WAIS as compared to right-handed subjects, while the two groups did not differ in terms of scores on the verbal subtests. This offered support to Levy's competition hypothesis. Results of the tachistoscopic tests revealed that left-handed individuals exhibited a weaker left visual field advantage for the faces test and a weaker right visual field advantage for the verbal test, when compared to right handers. This suggests that left-handed undergraduates exhibit different types or degrees of hemispheric lateralization than right handers.

While these studies have offered support for Levy's hypothesis that left handers exhibit worse visual-spatial abilities than right handers, other investigations have either failed to find support, or offer only limited support, for this theory (Fennell, Satz, Van Den Abell, Bowers, & Thomas, 1978; Hardyck, Petrinovich, & Goldman, 1976; Hermann & van Dyke, 1978; Piazza, 1980; Sheehan & Smith, 1986). For example, Fennell et al. (1978) administered the Block Design subtest from the WAIS and a visual-spatial subtest from Thurstone's Primary Mental Abilities battery to a group of high school students (28 right-handed and 42 left-handed), and to a group of college students (41 left-handed and 41 right-handed). The results showed that neither sample of left handers exhibited lower scores on the visual-spatial test when compared to right handers. Thus, no direct support for Levy's competition hypothesis was found.

Subjects were also administered a dichotic listening task and a visual half-field task in order to determine if spatial functioning was related to hemispheric specialization for speech. When scores from the visual-spatial tasks were compared for subjects grouped according to ear or half-field preference, no significant differences were found. In fact, in the college sample, those subjects possessing the strongest left ear preference (i.e., those with predicted right-hemisphere or bilateral speech representation) had higher scores on the visual-spatial tests than those subjects with the strongest right ear preference (i.e., left-hemisphere speech representation). When hemispheric lateralization of speech (as measured by the dichotic listening task) was examined between the handedness groups, it was found that left-handed college students exhibited a greater left ear advantage, and a smaller average difference score between the two ears, when compared to right-handed subjects. However, this pattern of results was not found in the high school sample. This finding, therefore, only partially supports the argument that left handers, as a group, possess a different type of hemispheric lateralization for speech than do right handers. Fennell et al. (1978) concluded that Levy's competition hypothesis could not be fully supported by their findings, although there was partial support for one of the underlying assumptions of this theory.

Piazza (1980) examined the relationship between cognitive abilities and hemispheric specialization of verbal and nonverbal functions in a group of university students. Subjects were administered verbal and nonverbal dichotic listening and tachistoscopic tasks, along with the Block Design and Vocabulary subtests of the WAIS. While results indicated that left-handed subjects possessed a different pattern of hemispheric lateralization than right-handed subjects (i.e., they showed weaker ear and visual field advantages), there was no evidence to support the hypothesis that left-handed subjects were deficient for spatial tasks. In fact, on a measure of facial recognition, left handers performed in a superior manner to right handers.

Hermann & van Dyke (1978) have also found that left handers perform in a superior manner to right handers on tests of perceptual processing. Right- and left-handed college students were tachistoscopically presented a pair of visual patterns and required to make same-different judgements. The patterns were presented in various orientations (0°, 45°, 90°, or 135°). Hermann & van Dyke reported that left handers were faster at making comparison judgements and rotated the patterns more rapidly than right handers. These findings do not support Levy's hypothesis of deficient spatial abilities in left-handed individuals.

Recently studies have tested Levy's hypothesis of deficient spatial functioning in left-handers in samples of children (Hardyck et al., 1976; Sheehan & Smith, 1986). Hardyck et al. (1976) examined the proposed relationship between cognitive deficit and left-handedness in a large group of school-aged children. They found that left- and right-handed children did not differ from each other on a variety of verbal and nonverbal (i.e., spatial) measures. This finding indicates that left-handed children do not show deficits in spatial functioning when compared to right-handed children.

Sheehan & Smith (1986) examined the functional lateralization of both verbal and spatial abilities in 67 boys (aged 9 to 11) by administering tachistoscopic consonant-vowel-consonant (CVC) recognition and dot enumeration (DE) tasks. The subjects were also given various psychological tests of verbal and spatial abilities. Subjects were divided into four groups based on their hand preference and the degree of that preference. Consistent handers (either right or left) were defined as those who used their preferred hand for all of six "primary" items on a handedness questionnaire, while inconsistent handers used their preferred hand for the majority of the six items. Sheehan & Smith (1986) found that inconsistent left-handers were less well lateralized for speech than consistent left handers and both types of right handers. No significant differences in performance on the verbal and spatial tasks were found between any of the handedness groups. These results indicated that there was no evidence for any deficit in spatial abilities in normal left-handed children. Additionally, it was found that the degree of overall lateralization of verbal and spatial skills was positively related to performance on tests measuring spatial abilities, but not related to performance on tests of verbal abilities. Sheehan & Smith (1986) argued that this partially supported Levy's competition hypothesis, in that smaller degrees of cerebral lateralization were related to deficient spatial ability.

Overall, support for Levy's competition hypothesis has been equivocal. Several studies have reported lowered spatial abilities in left handers (Bradshaw et al., 1981; Johnson & Harley, 1980; Levy, 1969; Miller, 1971). Some of these studies have shown that decreased spatial ability is only exhibited by particular groups of left handers (i.e., those with firm handedness preference or those with a familial history of sinistrality), and that this is especially true in adult populations (Bradshaw et al., 1981; Johnson & Harley, 1980). Other investigators have failed to find support for this hypothesis. These studies have reported that left handers, in general, do not differ from right handers with respect to spatial functioning. However, some evidence has been provided by these studies that suggests there may be partial support for Levy's hypothesis and its underlying assumptions (Fennell et al., 1978; Sheehan & Smith, 1986). Fennell et al. (1978) found that there was some evidence to suggest that left-handed college students possess different patterns of speech lateralization than right-handed college students, thus supporting one of the underlying assumptions of Levy's hypothesis (i.e., that left handers exhibit different patterns of hemispheric lateralization for speech). Sheehan & Smith (1986) found that smaller degrees of lateralization were related to deficient performance on measures of spatial functioning in children. This finding supports the other underlying assumption of the competition hypothesis; that is, that different patterns of lateralization from that seen in right handers are related to deficient spatial abilities.

Though early studies examining Levy's hypothesis are not conclusive, it appears that there is some merit to the underlying suppositions, and that there may also be some evidence for a relationship between handedness and deficient spatial abilities. The remaining two theories to be presented argue that left handedness is a result of brain pathology sustained early in life, and that this pathology results in differential patterns of performance on various psychological measures.

PATHOLOGICAL MODELS OF LEFT-HANDEDNESS

Bakan's (1971, 1975) model - Handedness and Birth Stress

Until the early 1970's the predominant view of the etiology of left-handedness was a genetic one (Hicks & Kinsbourne, 1976). However, Bakan (1971) noted that the evidence for a genetic explanation of handedness was inconclusive. He argued that the main evidence for a genetic theory of left-handedness, that of a familial tendency, was an inadequate argument for a genetic basis, since the majority of left-handed children had two right-handed parents (Bakan, 1975). While twin studies have also been used to bolster the position of a genetic basis of handedness, Bakan noted that the increased incidence of sinistrality observed in twins was evident for both identical and fraternal twins, indicating the existence of possible non-genetic factors in the etiology of handedness. Bakan (1971) also observed that the incidence of left-handedness was higher in males and in various groups of individuals suffering from language related disorders. Since these factors are known to be associated with greater pre- and peri-natal complications, Bakan argued that left-handedness was related to stressful pre-natal and birth conditions. Thus, Bakan's model views right-handedness as the norm, and assumes that left-handedness is a deviation from this norm that is a concomitant of neuropathology sustained during traumatic pregnancy and birth. The most likely cause of this neuropathology is hypoxia. The pathological effects of hypoxia will depend on the particular brain areas that are deprived of oxygen, but are most likely to be found within left-hemisphere systems since the left hemisphere appears to have a greater need for oxygen and a more active metabolism (Bakan, 1975; Bakan, Dibb, & Reed, 1973).

Bakan (1971) investigated the relationship between left-handedness and birth order in a group of 95 left-handed university students. A control group of 553 right-handed students was also employed. Birth order was divided into two categories: high risk (first birth or fourth and later births) and low risk (second and third births). Results indicated that more left-handed subjects fell into the high risk category than would be expected by chance. This finding was most noticeable for the male subjects. That is, while more left-handed individuals fell into the high-risk category than the low-risk category, the difference was significant only for males, and not for females. Bakan interpreted these results as indicating a relationship between handedness and birth order, which in turn suggested a relationship between left-handedness and neurological insult that was associated with high risk birth factors. This finding was further confirmed in a later study using a different sample of post-secondary students (Bakan, 1977).

Since high risk births are known to be associated with increased birth stress conditions, Bakan hypothesized that there would be a relationship between left-handedness and birth stress. To further test this relationship, Bakan et al. (1973) asked 510 university students to complete a handedness questionnaire and indicate the birth stress conditions that were associated with their birth. While the use of self-report may lead to some bias toward an under-reporting of the amount of birth stress, Bakan et al. (1973) argued that there was no reason to believe that the findings would be invalidated by this potential bias. Bakan et al. (1973) found a significant relationship between birth stress and left-handedness, with 40% of left handers reporting birth stress and 22% of right handers reporting some incidence of birth stress. Closer examination of the data indicated that left-handed and ambilateral subjects were found significantly more often among the high risk category than among other categories.

Leviton & Kilty (1976) examined Bakan's hypothesis regarding birth order and handedness in a group of fifth- and sixth- grade students. They found that, similar to Bakan's (1971) finding, the strongest birth order effect was in males. While females showed an increased risk of left-handedness with increased birth order, the effect was not as noticeable as in males. The birth order effect in males was found to have a U-shaped distribution, with the incidence rate of left-handedness declining after the first birth order category (i.e., being the first born) and then increasing after the fourth birth order category. Females, on the other hand, showed a more variable distribution, with the highest incidence of left-handedness being evident in children who were born sixth or later. Leviton & Kilty (1976) concluded that there was support for a relationship between handedness and birth order, but that this relationship was a complex one that reflected the influence of various factors.

While these studies have provided support for Bakan's theory, other studies have failed to find any evidence of a relationship between handedness and birth order or birth stress (Schwartz, 1977; Hicks, Pellegrini, & Evans, 1978). Schwartz (1977) argued that previous studies examining the proposed relationship had failed to use rigorous procedures for classifying handedness, and simply relied upon the subject's self-report. This method is seen as unreliable and inadequate. Schwartz (1977) utilized a more rigorous approach for classifying handedness by giving his subjects a series of fourteen manual tasks, which they were to pantomime before giving a written response. The subjects were also asked questions regarding the nature of their mother's pregnancy and their birth. Schwartz (1977) found that there was no increase in the incidence of left-handedness in high-risk pregnancy categories based on birth order. When subjects were divided on the basis of the strength of their laterality no differences between incidence rates were found. Further examination of the data indicated no increase in left-handedness when groups were compared with respect to complications in pregnancy. Schwartz (1977) concluded that his results showed no evidence for a relationship between sinistrality and birth-order or pregnancies marked by complications during gestation or delivery. While the existence of pathological left-handedness was not disputed, Schwartz (1977) argued that there was no support for Bakan's contention that all left-handedness is a result of early brain insult.

In defense of his theory, Bakan (1977) argued that Schwartz's (1977) findings could have been biased by the type of birth-stress question that was posed. In an earlier study, Bakan et al. (1973) had their subjects fill out a checklist of possible complications associated with pregnancy and birth, while Schwartz (1977) simply asked for a yes-no response to a question regarding the presence of complications during pregnancy and birth. Bakan (1977) argued that this type of questioning would yield a high number of negative responses, and no meaningful information regarding pregnancy and birth would be obtained. If Schwartz (1977) had used a more stringent approach (as he used for questioning handedness), he may have obtained different results. However, Schwartz's study makes it clear that more careful questioning of handedness and birth stress is required in order to gain a more complete understanding of the proposed relationship between the two factors.

Hicks et al. (1978) attempted to replicate Bakan's original study using a sample of university students carefully chosen to approximate Bakan's sample. In the original study, Bakan (1971) had noted that this relationship held only for males (although there was a trend toward the occurrence of the relationship in females). However, later studies (with the exception of Leviton & Kilty, 1976) failed to consider the possible effect of sex in the nature of this relationship. Hicks et al. (1978) examined the proposed relationship between handedness and birth order, but also considered sex as a variable. Handedness was assessed using a handedness questionnaire, and birth order was established by self-report. Complications of birth and pregnancy were not assessed. Hicks et al. (1978) failed to find a significant relationship between birth order and handedness for males, females, and the total sample. Like Schwartz

(1977), Hicks et al. (1978) did not dispute the existence of pathological left-handedness, but argued that not all sinistrality could be viewed as a concomitant of pathology.

While Bakan's theory of a direct relationship between sinistrality and pathology is intriguing, it is clear that it has not obtained strong validity in further testing. Several investigators have failed to replicate Bakan's original findings in samples that could not be considered distinguishably different from Bakan's samples. However, those studies that fail to replicate the original findings have not disputed the existence of some form of pathological left-handedness. Thus, it appears that Bakan's theory of the etiology of left-handedness may be too broad in its attempted application. The last theory regarding the etiology of left-handedness has narrowed the focus of pathological influences and argues that some left-handedness is the result of early brain insult.

Satz's (1972, 1973) model of Pathological Left-handedness

It has long been thought that left-handedness is associated with a variety of clinical conditions, including mental retardation and epilepsy (Hecean & de Ajuriaguerra, 1964; Silva & Satz, 1979), pervasive developmental disorders, (Fein, Waterhouse, Lucci, Pennington, & Humes, 1985) and learning disabilities (Geschwind & Behan, 1982; Zurif & Carson, 1970). The incidence rate of left-handedness in clinical populations such as these has been reported to be twice as high as that found in normal populations (Satz, 1972, 1973).

An early explanation (Hecean & de Ajuriaguerra, 1964) for the increase in manifest left-handedness within clinical populations, proposed that damage to the left-hemisphere resulted in a mild hypofunction of the right hand, in natural right handers, which caused the child to switch to using the left hand for manual activities. This theory, however, does not adequately address the possibility of pathological right-handedness, or the probability of a manual "switch" that would result in manifest left-handedness. In order to address these issues, Satz proposed a model that assumed an equal distribution of lesion laterality, estimated the probability of a manual "switch" from one hemisphere to the other, and accounted for the reported twofold increase in sinistrality incidence rates.

At a very basic level, Satz's (1972, 1973) model suggests that the frequency of manifest left-handedness in presumably brain-damaged populations increases as a function of early left hemisphere damage in natural right handers. The model also suggests that pathological right-handedness is rarely evident due to the relative lower frequency of left-handedness in the normal population. Using hypothetical data, Satz was able to demonstrate mathematically the increased incidence of left-handedness in clinical populations. The model also generated some testable hypotheses, some of which were logically derived from the model, while the remaining hypotheses were indirectly related to the model. Satz (1972) then tested this model on data provided by the Montreal Neurological Institute. He found that the hypotheses generated by the model were supported by the data. Satz concluded that the model could be accepted tentatively as an explanation for the higher frequency of sinistrality in clinical populations.

Silva & Satz (1979) investigated the relationship between manifest left-handedness and the localization of EEG abnormalities in a group of 1409 mentally retarded individuals. Silva & Satz found that there was an increased rate of left-handedness in those individuals with abnormal EEGs. The results of this study also showed that significantly more left-handed individuals than right-handed individuals had left-hemisphere brain damage. This suggests that there is a relationship between manifest handedness and lateralization of brain dysfunction and offers further support to Satz's model of pathological left-handedness.

The model of pathological left-handedness as proposed by Satz (1972, 1973) was tested by Satz, Baymur, & Van der Vlugt (1979) in a cross-cultural examination. Four studies from centers in Canada, Turkey, The Netherlands, and the United States, were compared and the rate of manifest left-handedness was examined. The results indicated that there was fairly consistent support for the model. In general, Satz et al. (1979) concluded that the raised incidence level of left-handedness in adult clinical populations was due largely to a small number of right-handers who, due to early left-hemisphere damage, transfer manual preference and speech to the opposite hand and hemisphere.

While the model appears to explain the increased incidence rate of left-handedness in clinical populations, it fails to account for the incidence of ambiguous, or mixed, handedness. In order to rectify this, Soper & Satz (1984) modified the model to include an explanation of the occurrence of ambiguous handedness. The revised model assumed that early bilateral brain damage would result in ambiguous handedness, since neither hemisphere would remain sufficiently intact for the expression of manual dominance. The model was able to demonstrate mathematically the incidence rates of manifest left-handedness, ambiguous handedness, and manifest right-handedness within a hypothesized clinical population. Based on the obtained incidence rates various predictions were made with regard to damage within particular etiological subgroups.

Examination of this model of pathological left-handedness has resulted in support for the view that some left-handedness is the result of early brain damage. Schwartz (1977) argued that his findings offered indirect support for Satz's model, since there was evidence that not all left-handers in his study suffered from cerebral pathology. Satz's model adequately accounts for naturally occurring left-handedness, as well as left-handedness occurring due to pathological influences.

A more recent examination of Satz's model was conducted by Liederman & Coryell (1982). The origin of left-hand preference was examined using prospective data obtained from infants with and without perinatal complications. Infants with a history of perinatal complications did not show the usual right head-turning preference observed in infants without perinatal complications. Liederman & Coryell (1982) argued that perinatal complications might also delay the establishment of hand preference, and increase the probability of left-handedness. They concluded that their data best supported Satz's model of the origin of left-sided preference. Bakan's model was not supported by their data, since there were cases of non-right head-turning preference in infants whose births were free from complication. In general, Liederman & Coryell's 1982) findings suggested that some, but not all, deviations from a right-sided preference are due to brain damage caused by perinatal complications.

Bishop (1980, 1984) has extended Satz's model of pathological left-handedness to populations that exhibit less obvious impairment than those used in its formulation. Bishop (1980) examined the rate of pathological left-handedness in an unselected group of children. Of the group of 170 children, 23 were left-handed (i.e., wrote with their left hand). All children were given a measure of intelligence, a reading test, and tests of manual dexterity. A target group of children who performed in a particularly impaired manner with the non-preferred hand on a measure of motor skill was also selected. It was expected that, if the model of pathological left-handedness could be extended to a less-impaired population, there would be an increased incidence of left-handedness in the target group of children. Bishop's findings confirmed this expectation. However, these children did not have an increase in reported birth-risk. There was evidence that suggested that children in the target group had a higher incidence of neurological disorders in childhood, and had significant cognitive impairment, when compared to the remaining children.

Bishop (1980) concluded that the pathological left-handedness model could be extended to groups without gross signs of brain damage, and that a form of mild unilateral brain abnormality was responsible for the non-preferred hand difficulties exhibited by children in the target group. Bishop argued that this mild abnormality was associated with the increased incidence of sinistrality observed in this group.

Bishop (1984) confirmed this general finding in a group of children selected on the basis of poor manual skill of the non-preferred hand. These children had been selected out of a larger sample of children. This larger group of children represented those born in the United Kingdom in 1958, and were, therefore, not selected to represent any particular clinical group. Again, the results indicated a raised incidence of left-handedness within the selected children, and were interpreted in favor of Satz's model of left-handedness.

Satz's (1972, 1973) model of pathological left-handedness adequately explains the higher frequency of left-handedness, and ambiguous handedness, in various clinical populations. However, early insult to the left-hemisphere is also related to other sequelae, such as the reorganization of speech functions, so that the right-hemisphere participates in the processing of speech (Rasmussen & Milner, 1977). Bullard-Bates & Satz (1983) and Orsini & Satz (1986) examined the features associated with known or suspected damage to the left-hemisphere that was sustained early in life. These features include: manifest left-handedness; atypical or right-sided hemispheric speech representation; hypoplasia of the right-sided extremities; motor impairment of the right hand; impaired visual-spatial functioning; and a low probability of family history of sinistrality.

Bullard-Bates & Satz (1983) present a case study of a 37 year-old woman with pathological left-handedness who exhibited the features mentioned above. Her birth history indicated that brain injury was likely suffered due to a prolonged delivery and anoxia. She experienced sensory and motor difficulties on the right-side of her body, had a smaller right hand and foot, and had no history of familial sinistrality. Neuropsychological testing revealed deficits in visuo-spatial and nonverbal skills in the light of superior performance on verbal measures. There was no evidence of aphasia. While the pattern of performance on the cognitive measures might suggest right-hemisphere damage, the motor and sensory findings would not support this conclusion. The patient was then administered a dichotic listening task, and right-hemisphere language was inferred, since she showed a very large left ear asymmetry. CT scans indicated left-hemisphere atrophy. Thus, Bullard-Bates & Satz concluded that the patient had suffered early damage to the left hemisphere that had resulted in the transfer of language abilities to the right hemisphere, a switch from the right to the left hand for manual abilities, and a decreased ability to perform nonverbal functions that would normally have been subserved by the right hemisphere.

Orsini & Satz (1986) further examined the clinical features thought to be associated with pathological left-handedness in a group of brain-damaged subjects. The incidence rates of each of the concomitant features of early left-hemisphere injury was examined. Brain-damaged subjects were divided into groups according to the age of lesion onset. Early lesion onset was defined as damage to the left hemisphere before the age of 6-years, while late onset was defined as damage after that age. Orsini & Satz (1986) found that atypical speech lateralization, a shift in hand preference, motor impairment of the right hand, and hypoplasia of the right foot were the most significant features related to early brain damage and pathological left-handedness. The remaining traits that had been associated previously with pathological left-handedness were not found to be significant features in this study. Thus, there was no support for the finding that visual-spatial functions are lowered in individuals who sustained early left-hemisphere insult. In fact, Orsini & Satz (1986) found that both verbal and visual-spatial abilities were impaired in their sample. Further examination of the integrity of verbal and visual-spatial abilities in pathological left-handers is needed to determine whether cognitive functioning is reorganized in these individuals.

Summary of Theories of Left-handedness

The nature of cerebral organization in left-handers has intrigued researchers for many years. Several theories that attempt to explain the underlying nature of the hemispheres in sinistrals have been proposed. These theories can be categorized as follows: those advocating that sinistrality is a reflection of different hemispheric organization from that seen in dextrals; and those that advocate that sinistrality is the result of some type of neuropathology.

The theories that represent the first category argue that left-handers show different patterns of hemispheric asymmetry than those observed in right-handers. One of the earliest theories argued that left-handed individuals showed reversed laterality to right-handers; that is, language was represented in the right hemisphere, and nonverbal processing was undertaken by the left hemisphere. While this theory is now rejected as being the universal explanation for the underlying representation of function in left-handers, it is clear that a few left-handers do exhibit this pattern of cerebral organization.

Another theory that has been proposed to explain the differences between right- and left-handers, argues that left-handed individuals possess bilateral representation of language (Levy, 1969). This bilateral representation of language results in lowered performance on visual-spatial tasks, since there is competition within the right-hemisphere for the processing of these tasks. While this theory has failed to receive unequivocal support, there is some evidence that it may explain why some left-handers exhibit depressed scores on visual-spatial tasks.

Theories that are representative of the second category have received more attention in recent years. Bakan's model proposes that all left-handedness is a departure from the norm of right-handedness and is the result of left-hemisphere brain damage sustained during pregnancy or birth, due primarily to hypoxia. This causes a shift from the right-hand to the left-hand for preferred hand usage. Thus, all left-handers would be natural right-handers. While Bakan (1971, 1975) does not make explicit predictions for the underlying functional organization of the cerebral hemispheres, it is assumed that the right-hemisphere takes over left-hemisphere processes, due to the brain insult. Specific deficits, however, would depend on the area of the brain damaged due to the deprivation of oxygen. This model is somewhat limited since it can not explain the existence of those left-handed individuals who have no evidence of early brain damage due to complications during pregnancy or at birth.

Research has indicated that left-handedness occurs in clinical populations at about twice the rate that it occurs in the normal population. Satz (1972, 1973) has proposed a model that accounts for this increased incidence rate. This model takes a more focused approach than the one proposed by Bakan (1971, 1975), since it suggests that only a small proportion of (as opposed to all) left-handedness results from brain damage. Satz argues that early brain damage to the left-hemisphere in natural right-handers results, at the very least, in a switch of manual hand preference to the right-hemisphere, thus causing the child to manifest left-hand preference. This model indicates that the increased incidence of sinistrality in clinical populations is due to the fact that more natural right-handers will become pathological left-handers than natural left-handers becoming pathological right-handers. Thus, the increase in incidence is in the manifest incidence of sinistrality, and not in genotypic incidence. Certain neurological and psychological characteristics have been shown to be related to pathological left-handedness. These characteristics include atypical cerebral speech representation, motor impairment of the right hand, and hypoplasia of the right foot.

Each of the models presented attempt to explain the nature of the relationship between handedness and lateralization of function. However, it is clear that the models are not mutually exclusive. One can, for example, see overtones of Levy's intra-hemispheric competition hypothesis in Satz's model of pathological left-handedness. Satz's model has received the most favorable support of all the models presented here. It accounts well for the observed increase of sinistrality within clinical populations, while allowing for the presence of natural left-handedness, pathological right-handedness, and ambiguous handedness. It has also been extended to groups of children who do not exhibit gross signs of brain damage.

The above review of these models of left-handedness indicates that the relationship between handedness and cerebral organization is far from clearly understood. While it is clear that left-handers as a group exhibit more varied patterns of lateralization than right-handers, the underlying nature of the organization of cognitive functioning in left-handers is still a highly debated issue.

PURPOSE OF THE PRESENT STUDY

Research examining the functional integrity of the cerebral hemispheres in right-handed learning-disabled children has indicated that children selected according to patterns of academic performance on the WRAT (Jastak & Jastak, 1965) show particular patterns of performance on various neuropsychological measures. For example, children who are chosen on the basis of deficient arithmetic scores in the presence of average to superior reading and spelling scores on the WRAT are known to exhibit a pattern of performance on neuropsychological tests that is consistent with a hypothesis of right-hemisphere dysfunction. On the other hand, children whose reading and spelling scores are lower than their arithmetic scores exhibit a pattern of performance suggestive of dysfunctional left-hemisphere processes.

While these patterns of academic and adaptive performance are known to reflect the underlying functional integrity of the cerebral hemispheres in right-handed learning-disabled children, it is not known whether the same findings are applicable to left-handed learning-disabled children chosen according to similar patterns of academic performance. The first purpose of the study was to investigate whether or not left-handed learning-disabled children, selected according to patterns of academic achievement, show similar patterns of underlying functional hemispheric integrity as those previously observed in right-handers.

A secondary purpose of the present study was to determine which of the models of left-handedness presented above best predicts the performance of left-handed learning-disabled children on measures that are known to be sensitive to the underlying functional integrity of the cerebral hemispheres.

Children were selected for this study on the basis of their patterns of academic performance, as measured by the WRAT Reading, Spelling, and Arithmetic subtests (Jastak & Jastak, 1965). Group 1 children exhibited deficient performance on all three subtests. Group 2 children exhibited deficient Arithmetic subtest scores but even more deficient Reading and Spelling scores. Group 3 children exhibited normal Reading and Spelling subtest scores but deficient scores on the Arithmetic subtest. All subjects were left-handed. The performance of these subjects was compared for measures of verbal, auditory-perceptual, visual-spatial, visual-perceptual, psychomotor, motor, tactile-perceptual, and complex nonverbal problem solving skills.

If left-handers do not differ from right-handers in terms of their pattern of adaptive abilities (Del Dotto & Rourke, 1985) and functional lateralization, then one would expect that they will exhibit similar patterns of performance on neuropsychological measures to those observed previously in right-handers. Thus, it was expected that Group 2 children would exhibit a pattern of performance consistent with a hypothesis of left-hemisphere dysfunction. This would be evident in deficient performance on verbal and auditory-perceptual tasks, relative to their superior performance on visual-spatial and visual-perceptual tasks. Group 2 children were also expected to show good psychomotor, motor, and tactile-perceptual abilities. They would also exhibit good concept-formation skills. A similar pattern of performance was expected for Group 1 children.

Conversely, Group 3 children were expected to show a pattern of performance indicative of right-hemisphere dysfunction. Thus, they would show deficits on measures of visual-spatial and visual-perceptual abilities, while performing at, or above, normal levels on verbal and auditory-perceptual tasks. In addition to this pattern of abilities and deficits, Group 3 children were expected to exhibit bilateral psychomotor and motor problems, along with deficiencies in tactile-perceptual abilities. They would also show poor concept-formation abilities and a lack of ability to benefit from feedback.

The above expectations regarding the performance of left-handed learning-disabled children selected according to patterns of academic achievement reflect the most simplistic view of the relationship between handedness and cognitive functioning in left-handers; that is, that they exhibit the same relationship between handedness and cognitive functioning as found in right-handers. However, models of left-handedness suggest that this may, in fact, not be true. Thus, expectations for the present study also examined the possible differences between right- and left-handers.

Levy (1969) assumed that left-handers possessed bilateral language representation. This bilateral language representation resulted in poorer visual-spatial and visual-perceptual abilities, relative to right-handers, since there was competition for right-hemisphere processors. If this accurately describes the nature of the underlying functional integrity of the hemispheres in left-handers, then it would be expected that Group 3 children would show a similar pattern of performance to that seen in right-handers. Their performance on visual-spatial and visual-perceptual measures would be deficient, relative to Group 2, while they would exhibit superior verbal and auditory-perceptual abilities. This would offer support to the hypothesis proposed by Rourke & his colleagues (Rourke & Finlayson, 1978; Rourke & Strang, 1978; Strang & Rourke, 1983) that Group 3 children suffer from deficits in right-hemisphere processes.

However, children in Groups 1 and 2 would be expected to show different patterns of performance than those seen in right-handers. They would still exhibit poor performance for verbal and auditory-perceptual measures, but their performance on visual-spatial and visual-perceptual measures would not be the same as seen in right-handers. They would show lower levels of performance than those seen for right-handed children on these measures due to the competition within the right-hemisphere for both verbal and spatial functioning. This would suggest that while right-handed Group 2 children suffer from dysfunctional left-hemisphere processes, left-handed Group 2 children are at an increased disadvantage for achievement, since their right-hemisphere processing abilities are also compromised.

Psychomotor, motor, tactile-perceptual, and concept-formation performance patterns for the groups were expected to remain similar to those observed in right-handers, since Levy's theory only presupposes deficient spatial performance in left-handers.

The two models of pathological left-handedness assume that individuals are left-handed due to early left-hemisphere brain damage. Satz has also provided some information with regard to cognitive sequelae associated with his model of pathological left-handedness. These sequelae include: atypical lateralization of speech, motor impairment of the nondominant (i.e., right hand), and hypoplasia of the right foot. Other sequelae that may be related to Satz's model of pathological left-handedness are: impaired visuo-spatial functioning relative to preserved verbal functions, hypoplasia of the right hand, and a low probability of familial sinistrality.

Bakan's theory simply states that left-handedness is the result of early left-hemisphere brain damage which, in turn, results in a switch to the right-hemisphere for motor functioning. It is assumed that other left-hemisphere processes are rendered dysfunctional due to the early brain damage. If this theory can be applied to the left-handers in this study, then Groups 1 and 2 children would be expected to show similar patterns of performance to those observed in right-handers. They would be deficient on measures of verbal and auditory-perceptual abilities, while showing normal to above average visual-perceptual and visual-spatial abilities. However, in contrast to the superior psychomotor and motor abilities exhibited by right-handers, the left-handers would be expected to show deficient performance with their right-hand on measures of psychomotor and motor abilities, due to damage to left-hemisphere areas thought to subserve these functions for the right-hand. Concept-formation abilities were expected to be similar to those seen in right-handed learning-disabled children.

Group 3 children, on the other hand, would be expected to show a pattern of performance that is suggestive of global dysfunction. They would exhibit deficient visual-spatial and visual-perceptual abilities but would also exhibit lower levels of performance than those seen in right-handers on measures of auditory-perceptual and verbal abilities. Scores on measures in these latter two ability areas were expected to be lower than those observed in right-handers, although they still may be better than scores obtained for visual-spatial and visual-perceptual measures (reflecting a similar pattern of performance to that seen in right-handers). In addition to these deficits, Group 3 left-handers were also expected to exhibit poor psychomotor and tactile-perceptual performance. Like Group 2 children, they would show particularly poor performance on motor tests with their right-hand. Concept-formation abilities would be similar to those exhibited by right-handers. In general, Bakan's theory predicts that the pattern of performance of Group 3 children would be indicative of global dysfunction, while Groups 1 and 2 children would show a pattern of performance reflecting dysfunctional left-hemisphere processes.

Satz's model predicts that Groups 1 and 2 left-handed children would show similar patterns of performance to those observed in right-handed Groups 1 and 2 children. However, based on observations that individuals with pathological left-handedness exhibit impaired visuo-spatial functioning, it was also expected that Groups 1 and 2 children would exhibit lower scores on measures of visual-perceptual and visual-spatial functions than those observed in right-handers. While the pattern of superior nonverbal-deficient verbal skills may still be evident in left-handed Groups 1 and 2 children, the differences between these two ability areas may not be as striking as in right-handers. Satz has also observed that some pathological left-handers show depressed verbal abilities (relative to normals) as well. Thus, Groups 1 and 2 may show even lower scores on verbal measures relative to those obtained in studies of right-handed learning-disabled children. Groups 1 and 2 children were also expected to show motor impairment of their right-hand, but would otherwise exhibit a pattern of performance on the neuropsychological measures that is similar to that observed in right-handers. This particular pattern suggests deficits in abilities thought to be subserved primarily by the left-cerebral hemisphere, with some possible compromise of functions subserved by the right-cerebral hemisphere, due to competition for right-hemisphere processing capabilities.

According to Satz's theory, Group 3 children would perform in a manner that, like hypotheses generated from Bakan's model, is suggestive of a more global dysfunction. Group 3 children were expected to show deficient performance on measurs of visual-perceptual and visual-spatial abilities, deficient psychomotor abilities (particularly with the right hand), and deficient tactile-perceptual abilities. However, since their left-handedness is thought to be due to damage to the left-hemisphere, they would also exhibit problems with verbal and auditory-perceptual tasks. Thus, these children would exhibit a pattern of performance that is suggestive of deficits in abilities thought to be subserved by the right-hemisphere and also by the left-hemisphere.

The hypotheses generated for each of the models of left-handedness are summarized in Tables 1, 2, and 3.

Table 1

Hypotheses for Verbal, Auditory-Perceptual, Visual-Perceptual, and Visual-Spatial Measures

	Verbal and Auditory-Perceptual Measures		Visual-Perceptual and Visual-Spatial Measures	
Groups	2[1]	3	2[1]	3
Hypotheses	Predictions			
Similar to Right-handers	Below average scores	Average to above average scores	Average to above average scores	Below average scores
Levy's Theory	Below average scores	Average to above average scores	Lower scores than right-handers	Below average scores
Bakan's Theory	Below average scores	Lower scores than right-handers	Average to above average scores	Below average scores
Satz's Theory	Lower scores than right-handers	Lower scores than right-handers	Lower scores than right-handers	Below average scores

1 - Predictions for Group 1 are identical

Table 2

Hypotheses for Tactile, Motor, and Psychomotor Measures

	Tactile-Perceptual Measures		Motor and Psychomotor Measures	
Groups	2[1]	3	2[1]	3
Hypotheses	Predictions			
Similar to Right-handers	Average to above average scores	Below average scores	Average to above average scores	Below average scores
Levy's Theory	Average to above average scores	Below average scores	Average to above average scores	Below average scores
Bakan's Theory	Average to above average scores	Below average scores	Average to above average scores (impaired right-hand)	Below average scores (impaired right-hand)
Satz's Theory	Below average scores	Below average scores	Average to above average scores (impaired right-hand)	Below average scores (impaired right-hand)

1 - Predictions for Group 1 are identical

Table 3 .

Hypotheses for the Measure of Concept-Formation

	Concept-Formation Measure	
Groups	2	3
Hypotheses	Predictions	
Similar to Right-handers	Average concept-formation skills	Poor concept-formation skills
Levy's Theory	Average concept-formation skills	Poor concept-formation skills
Bakan's Theory	Average concept-formation skills	Poor concept-formation skills
Satz's Theory	Average concept-formation skills	Poor concept-formation skills

CHAPTER II

METHODOLOGY

Subjects

Subjects were selected from 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.

The subjects in this study were in the age range of 9- to 14- years old. Their 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 to be in need of psychiatric treatment for an emotional disorder, (2) they did not exhibit 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) they showed no evidence of a visual defect, (4) they were not considered to be "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.

The subjects in this study were all left-handed, as determined primarily by their reported hand preference for writing, and their scores on the Harris Tests of Lateral Dominance. This test examines the preferred hand usage for the following seven manipulative tasks: throwing a ball, hammering a nail, cutting with a knife, turning a door knob, using scissors, using an eraser, and name-writing. The child is required to demonstrate each task (Rourke, Fisk, & Strang, 1986). It was hoped that all subjects would receive scores on this test that suggested that they were "pure" or "firm" left-handers (i.e., they would perform all seven tests with their left-hand); however, not all subjects met this criteria. When this criteria was not reached, subjects were required to use their left hand for writing and also for a minimum of 4 of the remaining 6 items on the test, in order to be defined as left-handed.

Since not all subjects were pure left handers, a laterality quotient was determined for each subject (see Appendix A). This quotient is used to determine the degree of handedness (scores closer to 100 indicate strong right-handedness and scores closer to -100 indicate strong left-handedness) and was calculated by using a method similar to that described by Von Seggren, Ginn, & Harrell (1988). A one-way ANOVA on the laterality quotients derived for each subject indicated that the three groups did not differ in terms of their degree of left-handedness, although children in Group 3 showed a smaller degree of left-handedness than children in the other two groups [F $(2,21) = 2.55$, $p<.10$].

From the subjects who met the above initial selection criteria, 24 were selected for inclusion in this study. These subjects were selected based on the following criteria: Group 1 was composed of children whose grade-equivalent scores on the Wide Range Achievement Test (WRAT; Jastak & Jastak, 1965) Reading, Spelling, and Arithmetic subtests were at least 2.0 years below their expected grade placement. As well, 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 2 children had Reading and Spelling grade-equivalent scores at least 1.4 years below their grade-equivalent scores for Arithmetic and the centile scores for the subtests did not exceed 16. Group 3 was composed of children whose WRAT Reading and Spelling grade-equivalent scores exceeded their Arithmetic grade-equivalent scores by at least 2.0 years. The WRAT Arithmetic centile scores did not exceed 25 for children in this group.

Subject selection criteria were the same as those used by Rourke & Finlayson (1978), Rourke & Strang (1978), and Strang & Rourke (1983) with the exception of the criterion for Group 2 children. It was necessary to modify the original criterion (WRAT Reading and Spelling grade-equivalent scores at least 1.8 years below their WRAT Arithmetic grade-equivalent score with centile scores less than 14) to include two more children so as to have an equal number of subjects per group. The modified criterion is felt to represent adequately those children exhibiting a pattern of deficient reading and spelling performance relative to better (although still deficient) arithmetic performance.

All three groups were deficient relative to age-based norms on the Arithmetic subtest. Analyses of variance (ANOVAs) on the groups WRAT performance indicated that Groups 2 and 3 showed significantly higher Arithmetic Grade Equivalent scores than Group 1 and did not differ from each other [F (2,21) = 11.07, $p<.0005$]. The groups also differed significantly from each other with respect to their performance on the Reading and Spelling subtests [F (2,21) = 41.82, $p<.0001$; F (2,21) = 68.11, $p<.0001$, respectively]. Post-hoc analyses indicated that Group 3 children performed in a superior manner to children in Groups 1 and 2 (who did not differ from each other) on both the Reading and Spelling subtests.

The three groups were equated for age and Full Scale I.Q. on the WISC. Results of ANOVAs on the mean group differences indicated that the three groups did not differ from one another with respect to age [F (2,21) = 2.55, $p<.10$] or Full Scale I.Q. [F (2,21) = 1.43, $p<.26$]

Subject selection criteria are summarized in Table 4 and the mean group grade equivalent scores on the Reading, Spelling, and Arithmetic subtests of the WRAT are presented in Figure 1 (where the bold line represents expected grade level).

Table 4

Descriptive Statistics for Subject Selection Criteria

	Group ($\underline{N}$ = 8 for each)		
	1	2	3
Sex			
Male	7	8	5
Female	1	0	3
Age (in years)[1]			
$\underline{M}$	11.23	11.17	12.67
$\underline{SD}$	0.97	1.81	1.59
Laterality Quotient [1]			
$\underline{M}$	-78.57	-85.72	-60.72
$\underline{SD}$	25.32	15.27	26.17
WISC Full Scale I.Q.[1]			
$\underline{M}$	94.13	100.88	101.00
$\underline{SD}$	7.06	10.37	10.10
WRAT Reading[2] (grade-equivalent score)			
$\underline{M}$	2.45	2.53	9.24
$\underline{SD}$	0.91	0.80	2.69
WRAT Spelling[2] (grade-equivalent score)			
$\underline{M}$	2.40	2.24	7.30
$\underline{SD}$	0.73	0.61	1.42
WRAT Arithmetic[3] (grade-equivalent score)			
$\underline{M}$	2.68	4.41	4.66
$\underline{SD}$	0.68	0.93	1.10

1 - No significant differences between the groups
2 - Group 3 > Group 2 = Group 1 ($\underline{p}$<.0001)
3 - Group 3 = Group 2 > Group 1 ($\underline{p}$<.0001)

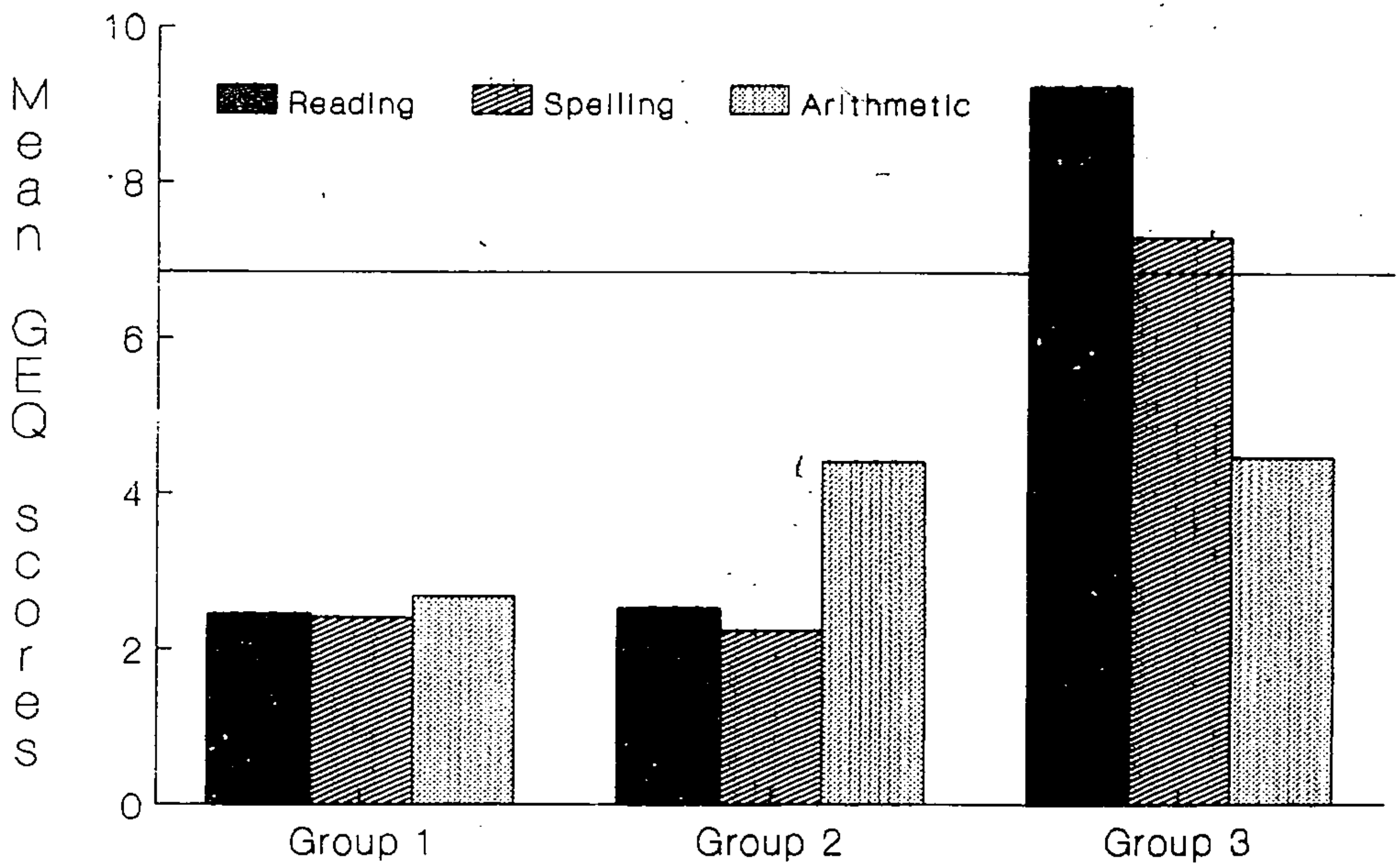

Figure 1. WRAT Grade Equivalent Scores for each Group

Measures

The WRAT Reading, Spelling, and Arithmetic subtests 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 et al., 1986).

The dependent measures used in this study can be divided into six categories: (1) Verbal and Auditory-Perceptual, (2) Visual-Perceptual and Visual-Spatial, (3) Motor, (4) Psychomotor, (5) Tactile-Perceptual, and (6) Concept- Formation.

The Verbal and Auditory-Perceptual tasks included the Information, Comprehension, Similarities, Arithmetic, Vocabulary, and Digit Span subtests of the WISC (see Rourke et al, 1986 for a brief description of each of these subtests); Peabody Picture Vocabulary Test I.Q. (PPVT; Dunn, 1965); the number of aphasoid errors of Reitan's modification of the Halstead-Wepman Aphasia Screening Test for older children (Reitan & Davison, 1974); the first 30 items on the Speech-Sounds Perception Test (Reitan & Davison, 1974); the Auditory Closure Test; and the Sentence Memory Test (Benton, 1965).

The Visual-Perceptual and Visual-Spatial tests included the Picture Completion, Picture Arrangement, Block Design, and Object Assembly subtests of the WISC (see Rourke et al., 1986 for a brief description of each); and the Target Test (Reitan & Davison, 1974).

The Motor tests included the Finger Tapping Test and the Strength of Grip Test (Reitan & Davison, 1974). Psychomotor tests included the time measures for the Maze Test, the Grooved Pegboard Test, and the Tactual Performance Test (Reitan & Davison, 1974; Rourke et al., 1986).

Tactile-Perceptual ability was measured by tests designed to assess sensory-perceptual disturbances (Reitan & Davison, 1974). These tests include measures of tactile-imperception (i.e., the incorrect identification, without the use of vision, of the hand or face (left or right) that receives tactile stimulation), Finger Agnosia, Finger Dysgraphasthesia (Finger-Tip Number-Writing), and Astereognosis.

The test for Concept-Formation abilities used in this study was the Halstead Category Test (Reitan & Davison, 1974). The measure employed here was the number of errors on each of the six subtests of the Category Test and the total number of errors made on the test.

Statistical Analyses

For the ease of comparison between the findings obtained in the previous series of studies using right-handers, the data from the present investigation were divided into three analyses. The first analysis was conducted on the verbal, auditory-perceptual, visual-spatial, and visual-perceptual measures (Rourke & Finlayson, 1978). The second analysis was performed on the data obtained for the motor, psychomotor, and tactile-perceptual measures (Rourke & Strang, 1978). The third analysis was performed on the measure of concept formation (Strang & Rourke, 1983).

The raw data obtained from these children were converted to T-scores using the norms provided by Knights & Norwood (1980). This allows for direct comparisons to be made among the tests. The T-scores were adjusted so that higher performance is represented in one direction (above 50) and lower performance is represented in the opposite direction (below 50). The T-score data were analysed using one-way multivariate analysis of variance (MANOVA). Thus, three MANOVAs were performed on the data obtained in this study: one for each of the three groups of variables that correspond to the original studies. One-way ANOVAs were then calculated for each dependent variable and significant effects were analysed using the Tukey's HSD (Honestly Significant Difference) Test. Verbal and Performance I.Q. scores were analysed separately using one-way ANOVAs.

In order to examine the similarities between the neuropsychological performance of left- and right-handed learning disabled children, the raw data were also converted to T-scores using the mean and standard deviation of the sample. The T-scores were then analysed in the same manner as that employed for the normative T-scores (see above). The patterns of performance exhibited by the three groups of learning-disabled children in this study were compared graphically to those exhibited in the previous series of studies using right-handers.

All statistical analyses were conducted using the Statistical Analysis System (SAS; Proc GLM; SAS Institute, 1985).

CHAPTER III

RESULTS

The major analyses investigating the performance of the three groups on the three sets of dependent variables are presented. Since the criteria from the original series of studies had to be modified to allow for the inclusion of two more subjects in Group 2, the data obtained in this study were analysed using a sample size of 24 (8 subjects per group) and of 18 (6 subjects per group). The pattern of results was identical in most of the analyses. Therefore, results from the analyses of the data obtained from all 24 subjects (n = 8 per group) will be presented here and results obtained from the analyses of the smaller sample (N = 18; n = 6 per group) will be presented only when differences between the findings occur. Results will be presented for the analyses of T-scores derived from normative information (i.e., from Knights and Norwood, 1980) and from the sample. The results from the MANOVAs for both sets of analyses across all three variable domains are found in Appendices B through G.

Verbal and Performance I.Q. measures were not included in the analyses of dependent variables, since they are highly correlated with many of the variables employed in this study. Instead one-way ANOVAs were calculated separately for these two variables. The ANOVAs revealed that the three groups did not differ significantly among themselves with respect to these measures [VIQ: F (2,21) = 2.92, p<.08; PIQ: F (2,21) < 1.00, p<.67]. The means and standard deviations are presented in Table 5.

ANALYSES OF NORMATIVE T-SCORE DATA

Verbal, Auditory-Perceptual, Visual-Spatial, and Visual-Perceptual Measures

The means and standard deviations of the raw data for the measures used in this domain are presented in Table 6. It was noted that one child in Group 1 was missing data on the Auditory Closure, Sentence Memory, and Target Test measures and two children in Group 3 were missing data on the Auditory Closure and Sentence Memory Test. However, subsequent analysis of the data indicated that this missing data did not significantly affect the pattern of results.

The raw data were converted to T-scores using the norms provided by Knights & Norwood (1980). A one-way multivariate analysis of variance (MANOVA) for Group across the measures did not reveal any significant differences among the groups [F (32,4) = 3.27, p<.21]. One-way ANOVAs revealed highly significant group differences for the following measures: Arithmetic [F (2,18) = 12.51, p<.0004]; Aphasia Screening Test [F (2,18) = 13.93, p<.0002]; and the Speech Sounds Perception Test [F (2,18) = 21.97, p<.0001]. Group differences on the Target Test approached significance [F (2,18) = 3.52, p<.0513].

Table 5

Means and Standard Deviations for Verbal and Performance I.Q.

	Group 1	Group 2	Group 3
Verbal I.Q.			
M	88.38	96.00	98.13
SD	7.36	8.14	9.76
Performance I.Q			
M	101.88	106.75	104.13
SD	8.51	13.50	10.09

Table 6

Means and Standard Deviations for the Verbal, Auditory-Perceptual, Visual-Spatial, and Visual-Perceptual Measures

	Group 1	Group 2	Group 3
Information (scaled score)			
M	7.125	8.000	8.250
SD	1.553	2.000	2.435
Comprehension (scaled score)			
M	9.250	9.875	10.250
SD	3.327	3.357	4.200
Similarities (scaled score)			
M	10.125	11.500	10.875
SD	1.885	2.000	2.532
Vocabulary (scaled score)			
M	9.375	8.750	9.750
SD	0.916	2.053	2.550
Digit Span (scaled score)			
M	7.250	9.375	9.750
SD	1.982	3.068	2.866
Arithmetic (scaled score)			
M	5.625	9.375	9.000
SD	1.768	1.996	1.069
PPVT I.Q.			
M	101.625	102.125	106.125
SD	10.113	16.375	14.307

Table 6 (cont'd)

	Group 1	Group 2	Group 3
Aphasia Screening Test (number of errors)			
M	13.875	12.875	5.000
SD	3.399	3.643	2.878
Speech Sounds Perception Test (number correct)			
M	16.875	18.250	26.750
SD	5.276	2.121	2.188
Auditory Closure[1] (number correct)			
M	12.125	11.714	15.167
SD	2.475	3.546	4.916
Sentence Memory[1] (number correct)			
M	11.625	13.143	14.167
SD	3.204	1.864	2.229
Picture Completion (scaled score)			
M	11.625	11.875	9.750
SD	2.875	3.523	1.753
Picture Arrangement (scaled score)			
M	10.625	10.875	10.000
SD	2.200	2.100	2.000
Block Design (scaled score)			
M	10.375	12.250	10.750
SD	1.685	3.240	2.053

Table 6 (cont'd)

	Group 1	Group 2	Group 3
Object Assembly (scaled score)			
M	11.500	10.875	12.250
SD	3.780	2.696	3.151
Target Test[2] (number correct)			
M	12.813	16.643	16.625
SD	3.872	1.749	3.998

1 - Only 7 subjects in Group 2 and 6 subjects in Group 3
2 - Only 7 subjects in Group 2

Pairwise comparisons were conducted using Tukey's Honestly Significant Difference (HSD) Test. These comparisons indicated that Group 3 children performed in a superior manner to children in Groups 1 and 2 on the Aphasia Screening Test and the Speech Sounds Perception Test. On the Arithmetic subtest of the WISC the pattern of results indicated that children in Group 1 performed at significantly lower levels than children in Groups 2 and 3 (who did not differ from each other). A similar pattern of performance was observed for performance on the Target Test, although pairwise comparisons were not significant.

A quantitative index of the sensitivity of the F values that approached significance was obtained by calculating power values. Power refers to the probability of correctly rejecting the null hypothesis when it is false. It is also defined in terms of the probability of making a Type II error (Glass & Hopkins, 1984). The power values obtained for Sentence Memory and Block Design (0.84 and 0.80, respectively) indicated that the chance of making a Type II error was slight. However, a power value of 0.66 was obtained for the Similarities subtest of the WISC, suggesting the possibility that a Type II error was made on this test.

Figure 2 is a graphic representation of T-score means for each test for each of the three groups (for explanation of abbreviations see Appendix H). Examination of this graph indicates that all three groups performed in a similar manner across the measures. However, Group 3 children showed higher levels of performance on the Aphasia Screening Test and the Speech Sounds

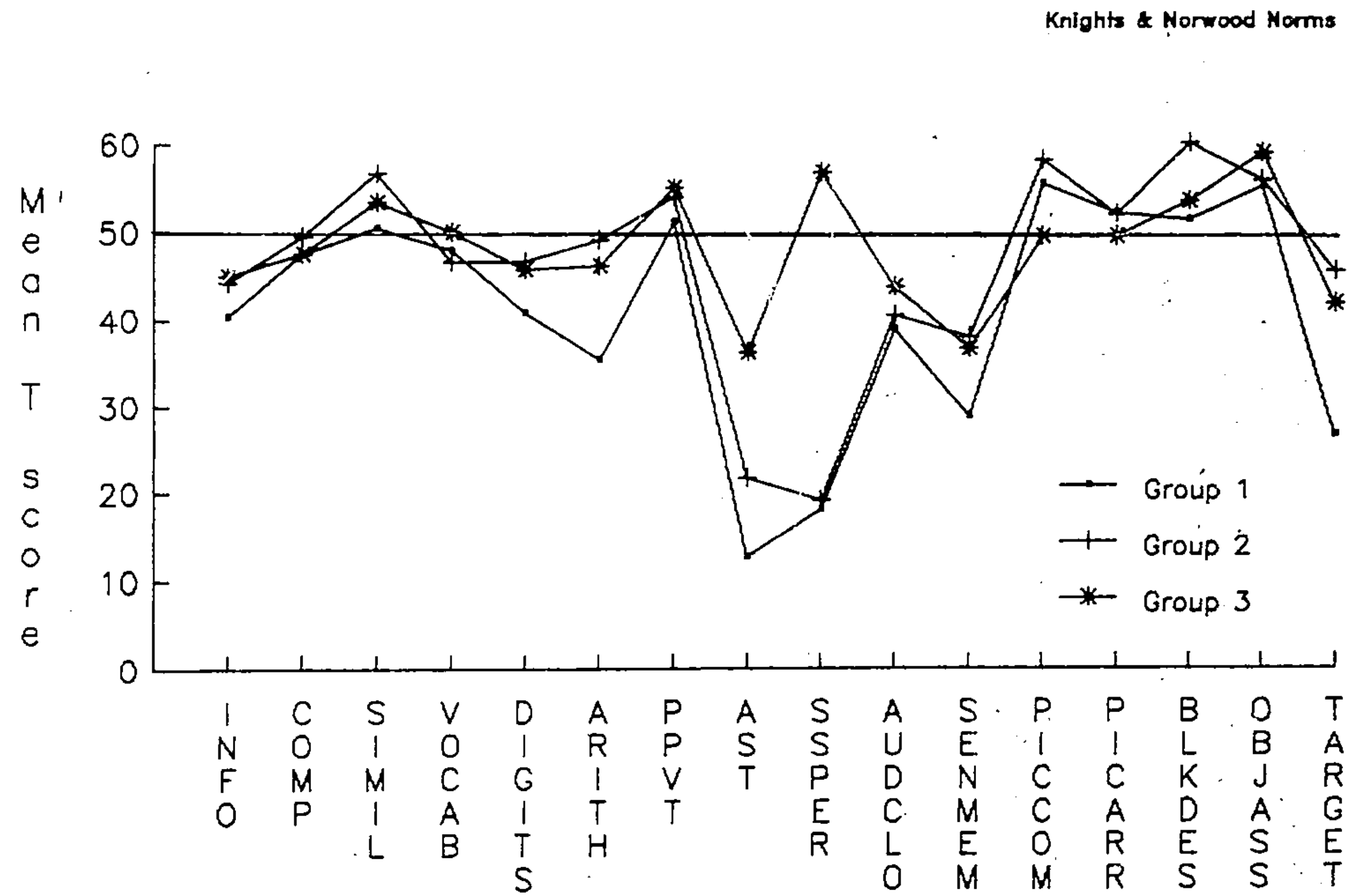

Figure 2. T–score means for Verbal and Visual–Perceptual Measures

Perception Test than did children in the other two groups. Children in Groups 1 and 2 did not show lower levels of performance on the Verbal and Auditory-Perceptual measures relative to their performance on the Visual-Spatial and Visual-Perceptual measures, as was expected; neither did Group 3 children exhibit the expected pattern of superior performance on Verbal and Auditory-Perceptual measures relative to performance on Visual-Spatial and Visual-Perceptual measures.

Motor, Psychomotor, and Tactile-Perceptual Measures

The means and standard deviations for the raw data are presented in Table 7. Since Knights & Norwood do not provide norms for a composite measure of Tactile-Perceptual abilities (like the one employed in the original series of studies), all measures of Tactile-Perceptual abilities were included in the analysis of the data in this domain.

A one-way MANOVA for Group across all variables was not significant [F (38,4) = 1.66, p<.3372]. One-way ANOVAs for each dependent variable revealed significant group differences for Astereognosia (Right Hand) [F (2,21) = 4.73, p<.02] and Astereognosia (Left Hand) [F (2,21) = 7.05, p<.0046]. Tukey's post-hoc analyses indicated that in both cases children in Group 3 made significantly fewer errors than did children in Group 1. Group 2 children did not differ significantly from either of the other two groups in terms of the number of errors made on this test.

Table 7

Means and Standard Deviations for the Motor, Psychomotor, and Tactile-Perceptual Measures

	Group 1	Group 2	Group 3
Strength of Grip			
Left			
M	15.032	16.387	23.009
SD	3.462	2.996	8.154
Right			
M	16.604	17.357	21.925
SD	6.208	3.612	8.987
Tapping Test			
Left			
M	35.450	36.354	39.121
SD	8.805	5.754	5.398
Right			
M	34.275	35.034	36.366
SD	7.691	5.730	7.076
Maze Test (time measure)			
Left			
M	13.971	3.752	4.575
SD	29.324	4.757	4.616
Right			
M	5.365	7.956	6.037
SD	5.000	4.164	5.883
Grooved Pegboard Test (time measure)			
Left			
M	80.125	83.500	75.750
SD	11.407	17.180	16.808
Right			
M	83.750	86.500	80.125
SD	5.120	16.466	21.590

Table 7 (cont'd)

	Group 1	Group 2	Group 3
Tactile Perception			
Left			
M	0.750	0.500	0.500
SD	1.488	0.535	1.414
Right			
M	0.375	0.750	0.625
SD	1.061	1.389	1.188
Finger Agnosia			
Left			
M	1.875	2.250	1.750
SD	2.475	2.188	2.915
Right			
M	2.750	2.250	2.375
SD	4.097	2.252	2.774
Finger Tip Number-Writing			
Left			
M	5.625	5.875	3.500
SD	3.068	4.086	3.665
Right			
M	5.875	6.375	2.750
SD	4.086	4.274	3.694
Astereognosia			
Left			
M	3.625	2.125	1.000
SD	1.506	2.167	0.756
Right			
M	2.375	1.625	0.375
SD	1.847	1.506	0.518

Table 7 (cont'd)

	Group 1	Group 2	Group 3
Tactual Performance Test (time measure)			
Dominant Hand			
M	4.681	4.981	3.942
SD	1.676	3.239	2.153
Nondominant Hand			
M	2.524	2.537	2.176
SD	1.767	2.520	0.937
Both Hands			
M	2.025	1.236	0.951
SD	1.533	0.639	0.726

A power value for the variable (Grip Strength - Left Hand) that approached significance was also calculated. The power value obtained (0.74) indicated a relatively low probability of making a Type II error for this variable.

Figure 3 is a graphic representation of the T-score means of the three groups across the dependent variables in this domain (for explanation of abbreviations see Appendix H). From the graph it can be seen that the three groups performed in a similar manner across the dependent measures. All groups generally exhibited lower scores on measures of perceptual ability (except the measures of Tactile-Percpetion Right and Tactile-Perception Left) relative to the Motor and Psychomotor measures.

Children in Group 1 exhibited somewhat better right-hand than left-hand performance on all Motor and Psychomotor measures. Their performance on the Tactile-Perceptual measures was more variable, with three of the four tests indicating better right-than left-hand performance (Tactile-Perception, Finger Tip Number Writing, and Astereognosis), and the remaining test (Finger Agnosia) indicating the opposite pattern. Group 3 children showed a similar pattern of performance across the Motor and Psychomotor measures. They exhibited somewhat higher left-hand than right-hand scores on the measures of Tactile-Perception and Finger Agnosia, and they showed somewhat lower levels of performance with their left hand on Finger Tip Number Writing and Astereognosis. Children in Group 2 exhibited better performance with their right hand on all Motor and Psychomotor measures (except the Maze Test). However, they exhibited higher levels of performance with their left hand on all

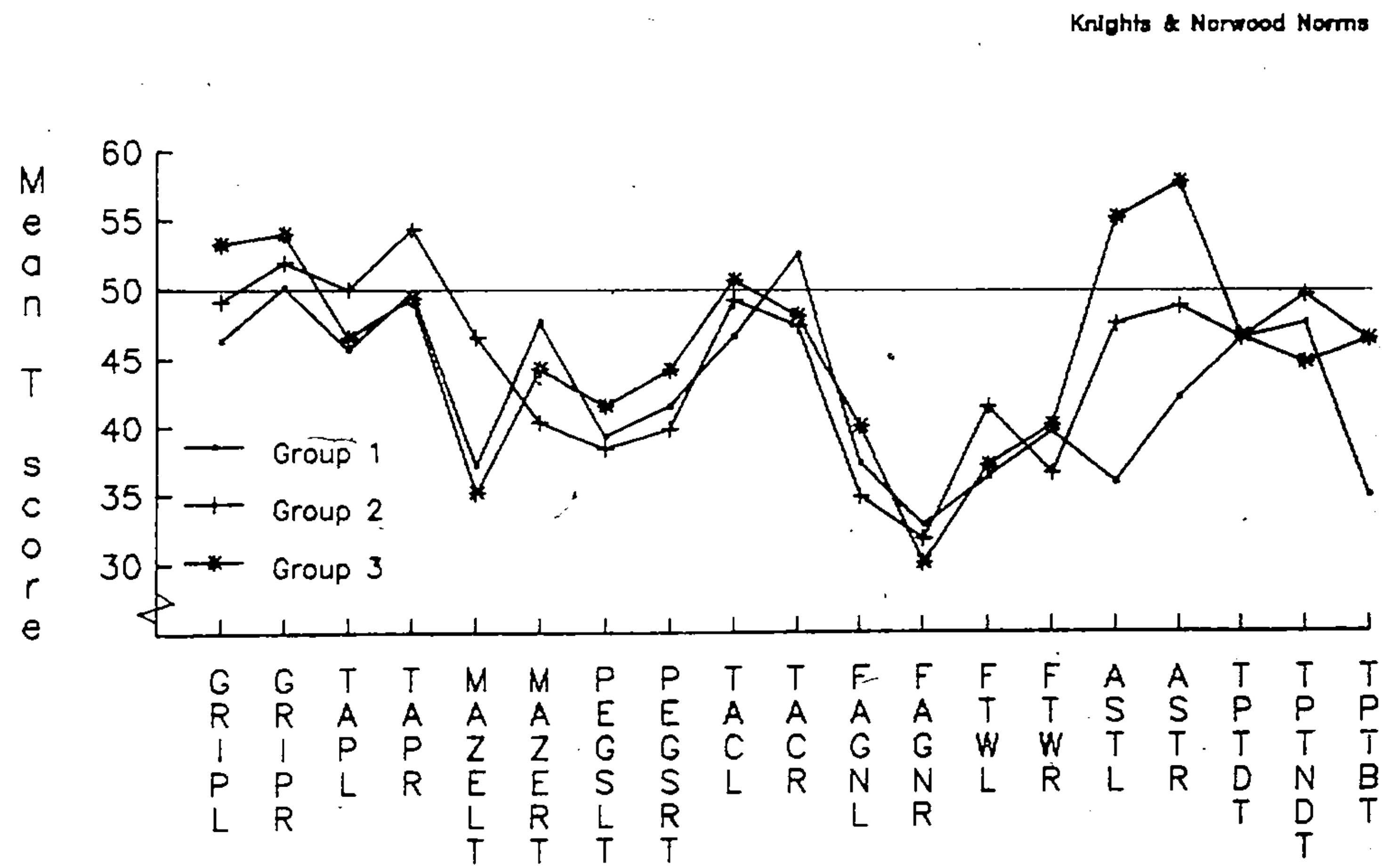

Figure 3. T—score means for Motor, Psychomotor, and Tactile—Perceptual Measures

the sensory measures, with the exception of Astereognosis where the level of performance between the two hands was almost equivalent.

Concept-Formation Measure

The concept-formation measure (Halstead Category Test) is composed of six subtests. The number of errors on each of the six subtests, along with the total number of errors, constituted the scores of interest. The means and standard deviations for each of the three Groups across this measure are presented in Table 8. Since the series of studies examining the performance of right-handed learning-disabled children did not include an analysis of the performance of Group 1 children on this measure, the data obtained here were analysed with and without Group 1 information. The overall pattern of results between these two analyses was quite similar.

The results of the MANOVA comparing the performance of all three groups on this measure revealed no overall significant differences among the groups [F (2,21) = 1.80, p<.0896]. One-way ANOVAs for each subtest indicated that there were significant group differences on the fourth subtest [F (2,21) = 4.44, p<.0247] and on the sixth subtest [F (2,21) = 3.53,p<.0477]. Post-hoc analyses revealed that Group 1 children performed in an inferior manner relative to Group 3 children on the fourth subtest. They also performed in an inferior manner relative to Group 2 children on the sixth subtest. Power analyses for the subtests that approached significance indicated that the probability of making a Type II error was low (power values

Table 8

Means and Standard Deviations for the Concept Formation Measure

	Group 1	Group 2	Group 3
Subtest 1			
M	0.625	0.375	0.125
SD	0.744	0.744	0.354
Subtest 2			
M	0.250	0.000	0.250
SD	0.463	0.000	0.463
Subtest 3			
M	16.875	8.875	11.375
SD	13.293	9.296	11.795
Subtest 4			
M	15.125	13.500	5.875
SD	6.512	7.964	2.295
Subtest 5			
M	14.625	16.250	12.000
SD	3.068	7.649	5.928
Subtest 6			
M	5.625	2.750	3.000
SD	2.504	2.435	2.268
Total number of errors			
M	52.625	41.750	32.625
SD	15.116	18.336	17.720

of 0.73 for Subtest 2 and 0.82 for the total number of errors made on this test).

A MANOVA on the results of the analysis of the data obtained from children in Groups 2 and 3 indicated no significant overall group differences [F (2,21) = 1.74, p<.2278]. Since there were only two levels of the independent variable, this analysis is essentially a multivariate t-test (or Hotellings T^2). One-way ANOVAs (t-tests) were calculated for the performance of the two groups on each subtest of the Category Test subtests. Significant group differences were noted only for the fourth subtest [F (1,14) = 5.80, p<.0304]. Post-hoc analysis indicated that children in Group 3 made fewer errors on this subtest than Group 2 children.

The mean T-scores obtained by the three groups across the subtests of the Category Test are illustrated in Figure 4. From this graph it can be seen that children in Groups 1 and 2 made more errors on the first subtest than did children in Group 3. Children in Groups 1 and 2 showed a drop in the level of performance (i.e., made more errors) on the fourth subtest relative to the second and third subtests. Group 3 children, on the other hand, exhibited better performance (relative to the norms) as the test progressed.

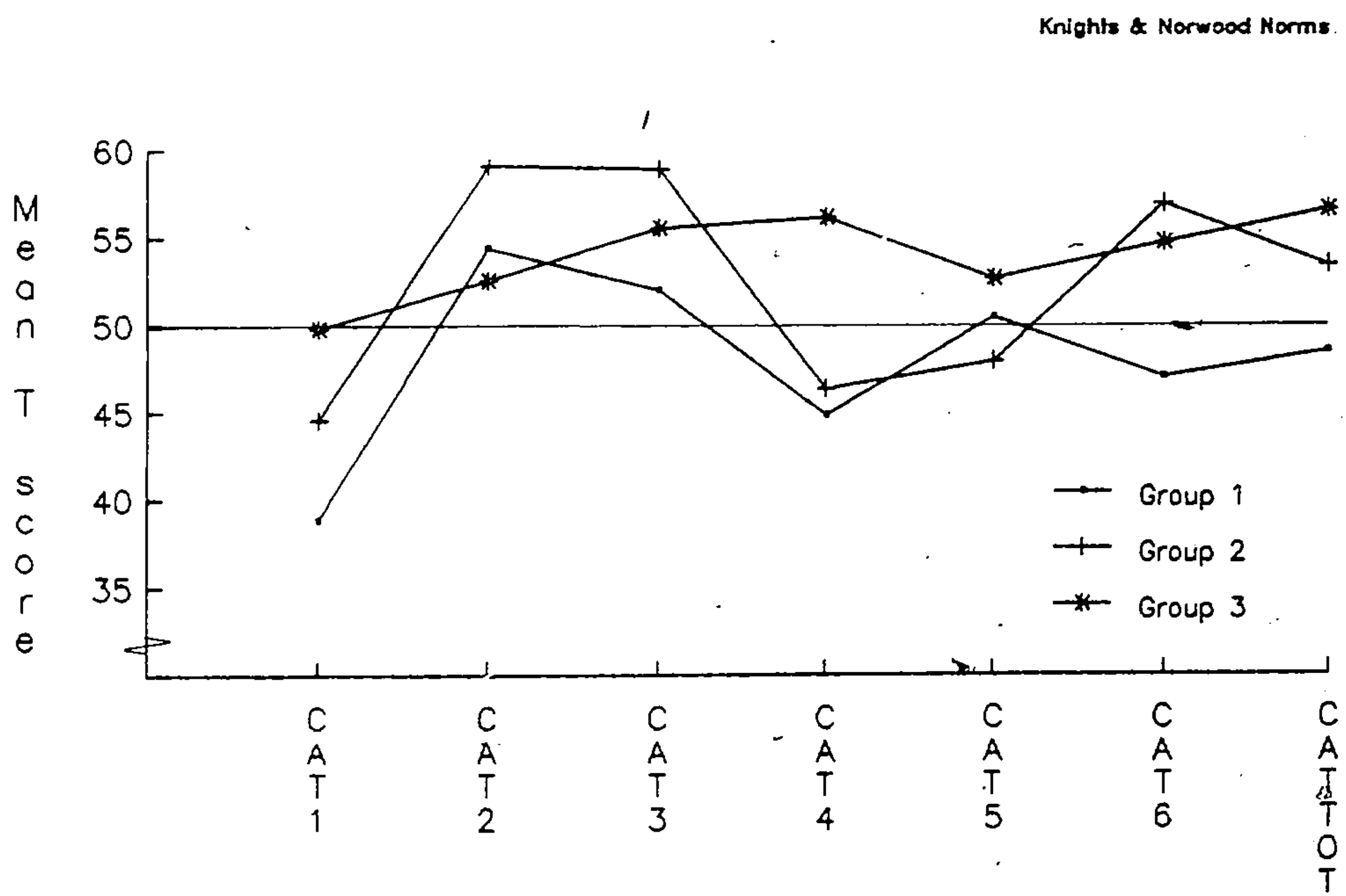

Figure 4. T-score means for the Concept-Formation Measure

ANALYSES OF SAMPLE T-SCORE DATA

Verbal, Auditory-Perceptual, Visual-Spatial, and Visual-Perceptual Measures

The raw data were converted to T-scores using the means and standard deviations of the sample. Missing data did not significantly affect the pattern of results obtained for the measures in this domain.

A one-way MANOVA for Group across the variables in this domain did not yield an overall significant difference among the groups [F (32,4) = .60, p<.8151]. One-way ANOVAs for each of the dependent variables revealed significant group differences for Arithmetic [F (2,18) = 12.51, p<.0004], Aphasia Screening Test [F (2,18) = 11.40, p<.0006], and Speech Sounds Perception Test [F (2,18) = 12.61, p<.0004]. Group 3 children performed in a superior manner to children in Groups 1 and 2 on both the Aphasia Screening Test and the Speech Sounds Perception Test. On the Arithmetic subtest of the WISC children in Group 1 exhibited significantly lower scores than children in the other two groups. These findings are similar to those obtained in the analysis of the normative T-scores.

The power values obtained from the analyses of the variables that approached significance (the Similarities and Block Design subtests of the WISC, the Auditory Closure Test, the Sentence Memory Test, and the Target Test) were high (i.e., > 0.80). Thus, the probability of making a Type II error on these variables was low.

The mean sample T-scores are presented in Figure 5. From the graph it can be seen that Group 1 children exhibited the lowest level of performance of the three groups on the majority of the Verbal and Auditory-Perceptual measures. Group 3 children showed the highest level of performance on the Aphasia Screening, Speech Sounds Perception, Auditory Closure, and Sentence Memory Tests.

Group 3 children appeared to show lower levels of performance on the Visual-Spatial and Visual-Perceptual measures relative to their performance on the Verbal and Auditory-Perceptual measures. Group 1 and 2 children, on the other hand, did not exhibit any marked discrepancy between their level of performance on the Verbal and Auditory-Perceptual measures and the level of performance on the Visual-Spatial and Visual-Perceptual measures.

Motor, Psychomotor, and Tactile-Perceptual Measures

Raw data were converted to T-scores using the mean and standard deviation of the population. A composite score for all the Tactile-Perceptual measures was developed and included in the analysis of the data. This procedure allowed for comparison between the present findings and those obtained from the study examining the performance of right-handed children (Rourke & Strang, 1978). The Tactile-Perceptual measures were also examined separately to allow for comparison with the findings obtained from the analysis of the normative T-score data.

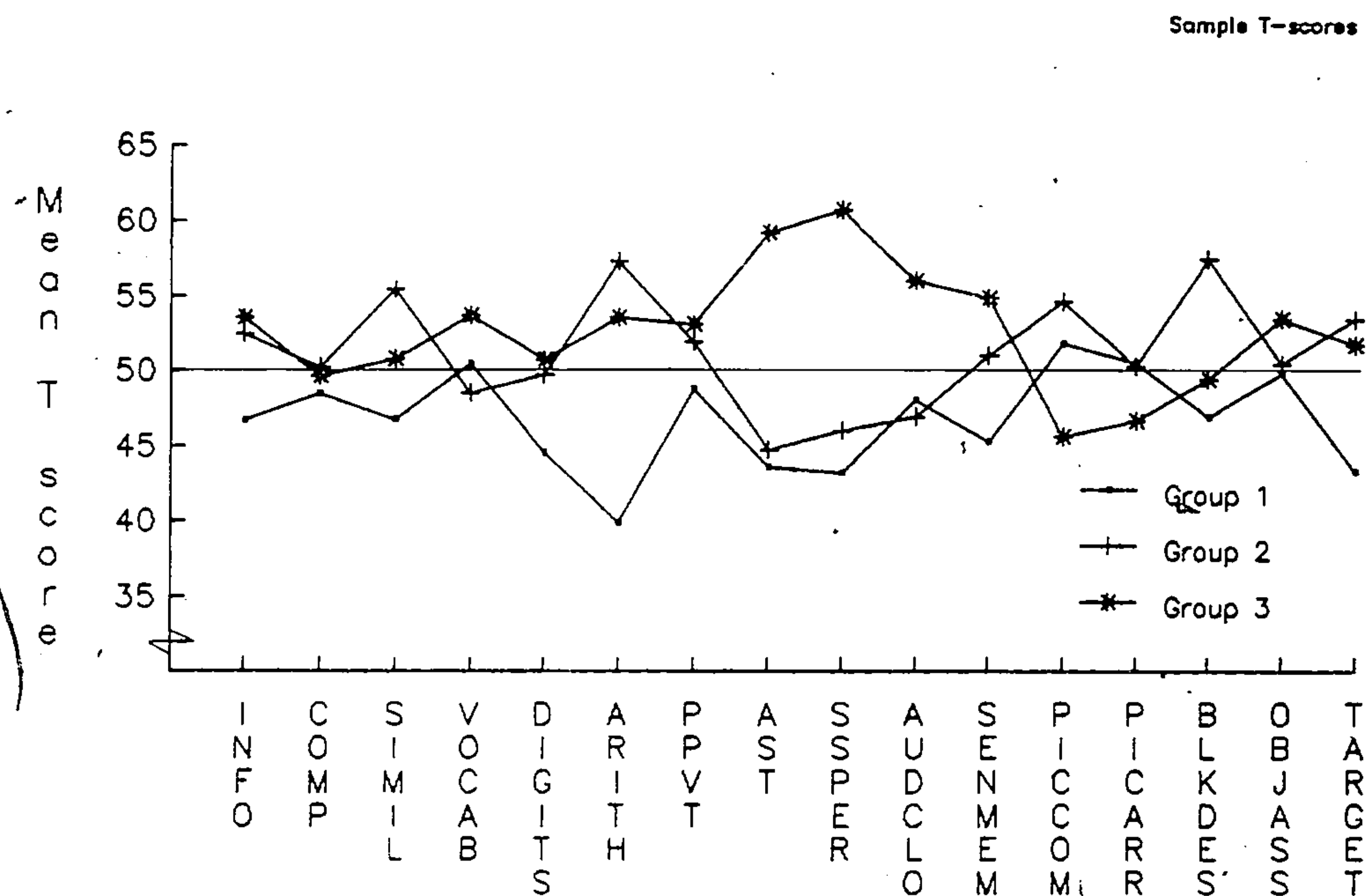

Figure 5. T-score means for Verbal and Visual-Perceptual Measures

The result of the MANOVA for overall group differences did not reach significance [F (40,2) = 4.68, p<.1916]. Significant group differences were found for the measures of Astereognosia [Right hand - F (2,21) = 4.12, p<.0309; Left hand - F (2,21) = 5.52, p<.0118] and for Strength of Grip [Left hand - F (2,21) = 5.00, p<.0168].

Analyses of the power values of the dependent variables that approached significance levels indicated values of 0.86 for Strength of Grip (Right Hand), 0.88 for the Tactual Performace Test (Both hands), 0.86 for Finger-Tip Number Writing (Right Hand), 0.74 for Finger-Tip Number Writing (Left Hand), and 0.32 for both the Right and Left Hand measures of the composite tactile perceptual score. These findings suggest a low probability of making a Type II error.

Post-hoc tests on the variables that reached significance indicated that, in all cases, children in Group 3 performed in a significantly superior manner to children in Group 1. Group 2 children did not differ significantly from either Group 1 or Group 3 children in terms of their performance on these measures.

While significant differences among the groups were noted for the Astereognosis measure, no differences were observed for the composite Tactile-Perceptual measure. This finding was not consistent with those obtained in Rourke & Strang (1978) and indicates that the three groups of left-handed learning-disabled children did not differ in terms of their overall performance on tactile-perceptual measures.

Figure 6 is a graphic representation of the mean of the sample T-scores obtained by each group across the dependent variables. Examination of the graph reveals that Group 3 children showed the highest levels of performance across the majority of the measures employed. This was particularly evident for the simple motor measures (i.e., Strength of Grip and Tapping) and some of the Tactile-Perceptual measures. Groups 1 and 2 children showed similar patterns of performance across the Motor measures. However, they differed slightly in terms of their performance patterns on the Psychomotor measures (e.g., on the Mazes Test) and the Tactile-Perceptual measures (e.g., on the Astereognosis Test).

An examination of the differences between right- and left-hand performance on the dependent measures for each of the three groups suggests that Group 3 children performed better with their left-hand on the motor and psychomotor measures, but showed better right-hand performance on measures of Tactile-Perception. Group 2 children appeared to show somewhat better left-hand performance for the Tactile-Perception measures (with the exception of Finger Agnosia) while showing a varied pattern of differential hand performance on the Motor and Psychomotor measures (e.g., Left-hand performance on the Maze test was better than right-hand performance, however on the Strength of Grip Test the pattern was reversed). Group 1 children tended to show right-handed superiority for the majority of Tactile-Perceptual and Psychomotor measures. On the simple motor measures they exhibited somewhat higher left-hand performance for the Tapping Test.

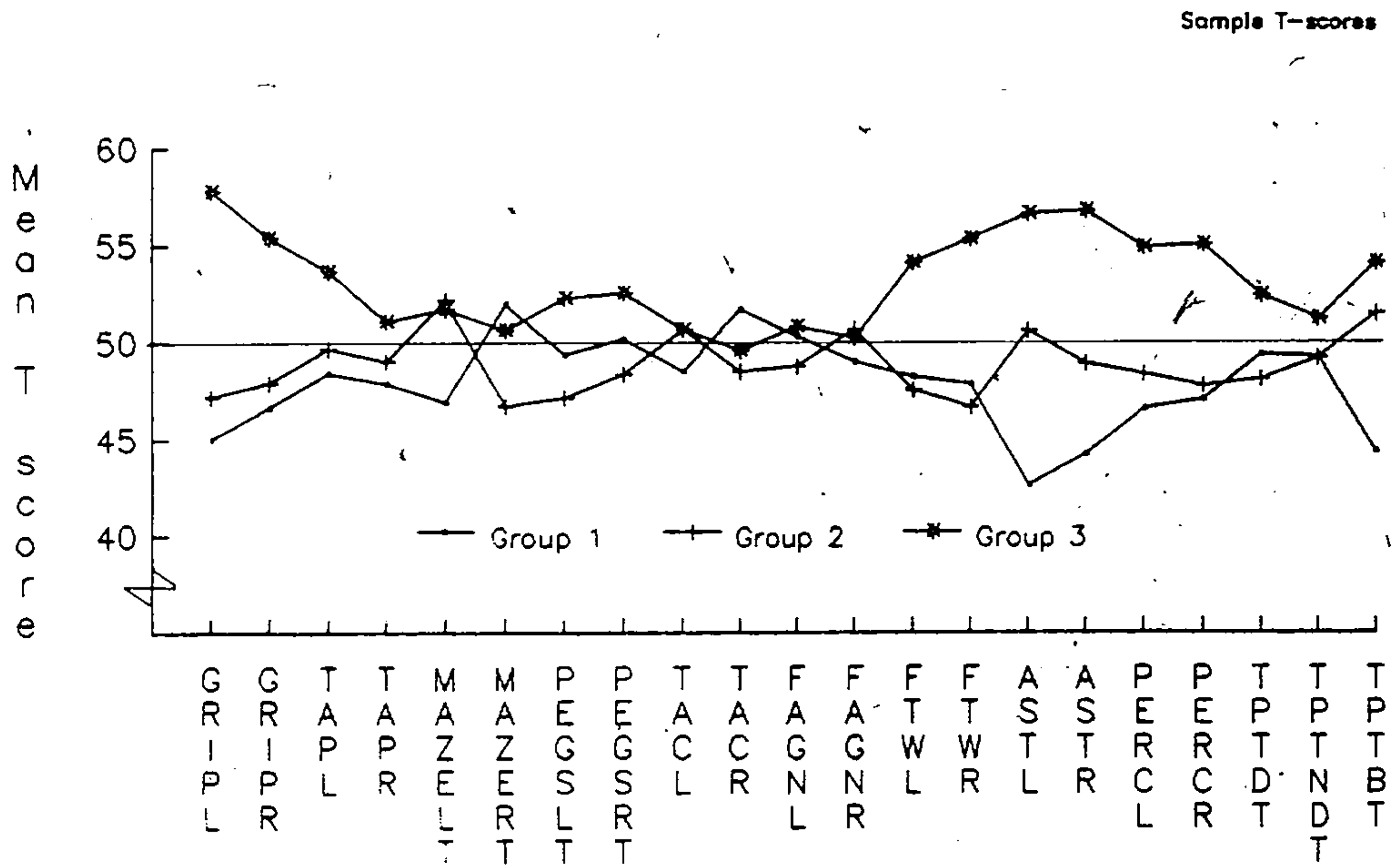

Figure 6. T–score means for Motor, Psychomotor, and Tactile–Perceptual Measures

Group 1 children also exhibited lower levels of performance on the Tactual Performance Test when they were required to use both hands, relative to their performance with either their left or right-hand. This pattern was not observed in the other two groups.

Concept-Formation Measure

Once again the analyses for this measure were conducted with and without Group 1 data. Analyses conducted for the entire sample with an $\underline{n} = 6$ per group revealed somewhat different findings than those conducted on the data from all 24 subjects. Therefore, all results will be presented here.

The MANOVA conducted on all 24 subjects did not reveal any statistically significant group differences [$\underline{F}$ (14,28) = 1.41, $\underline{p}$<.2108]. One-way ANOVAs for each subtest of this measure, as well as for the total number of errors made on this test, indicated that significant group differences occurred on the fourth subtest [$\underline{F}$ (2,21) = 5.27, $\underline{p}$<.0140] and the sixth subtest [$\underline{F}$ (2,21) = 3.51, $\underline{p}$<.0484]. Pairwise comparisons for the fourth subtest indicated that Group 3 children performed significantly better (i.e., made fewer errors) on this subtest than did children in Group 1. Children in Group 2 performed at a level between the other two groups and did not differ significantly from either group. Pairwise comparisons for the groups performance on the sixth subtest were not significant. However, the direction of the effect suggested that Group 1 children had lower levels of performance than children in either of the other two groups.

Power analysis for the total number of errors made on the Category Test indicated that the probability of making a Type II error was low (power value of 0.91).

When Group 1 children were omitted from the analysis, the only significant group difference was for performance on the fourth subtest [$\underline{F}$ (1,14) = 6.77, $\underline{p}$<.0209]. Post-hoc analysis of the performance of Groups 2 and 3 on this subtest revealed that Group 3 children performed in a superior manner to Group 2 children. However, the power value obtained for this variable was only 0.50, indicating that the probability of making a Type II error was approximately 50%.

The analysis of the data obtained from 18 subjects ($\underline{n}$ = 6 per group) did not indicate any overall significant group differences [$\underline{F}$ (14,16) = 1.18, $\underline{p}$<.3727]. The results of one-way ANOVAs revealed significant group differences for performance on the sixth subtest [$\underline{F}$ (2,15) = 6.35, $\underline{p}$<.01] and for the total number of errors made [$\underline{F}$ (2,15) = 3.71, $\underline{p}$<.0492]. Group 1 performed at significantly lower levels than both groups on the sixth subtest and made more errors than children in Group 3. The results of power analyses on these variables indicated that they both were highly sensitive to between group differences (power values > 0.94).

Figure 7 is a graphic representation of the mean of the sample $\underline{T}$-scores obtained by each group across the concept-formation measure. The entire sample ($\underline{N}$ = 24) was used for this graph. From this graph it can be seen that Group 1 children showed the lowest level of performance across all subtests

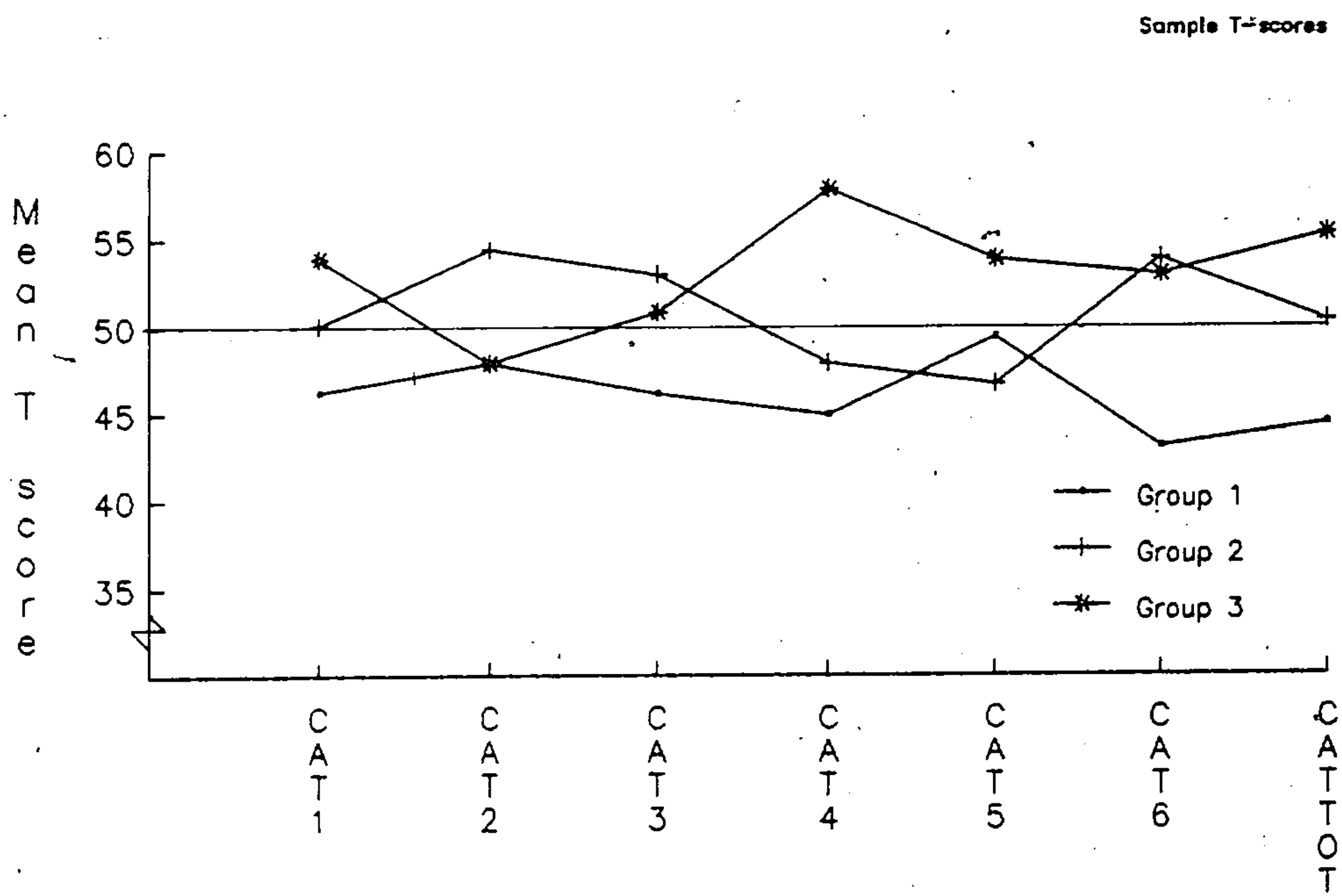

Figure 7. T–score means for the Concept–Formation Measure

(with the exception of subtest 5) and also made more errors (resulting in a lower T-score) over the whole test. Group 3 children, on the other hand, exhibited higher levels of performance on the more complex subtests (i.e., subtests 4 and 5) and made fewer errors overall.

COMPARISON OF RIGHT- AND LEFT-HANDERS

Verbal, Auditory-Perceptual, Visual-Spatial, and Visual-Perceptual Measures

In order to compare the three groups of left-handed learning-disabled children with the three groups of right-handed learning-disabled children, the mean T-scores (as derived from sample data) were plotted against one another. For ease of comparison, both right- and left-handers for each group were plotted on a separate graph (see Figures 8, 9 and 10). It should be noted that the Comprehension and Arithmetic variables were not included in the original series of studies using right-handers and were therefore dropped from the present comparison procedure.

All three figures indicate that the groups of left- and right-handed learning disabled children exhibited similar patterns of performance across these measures. Group 1 left-handed children showed lower levels of performance than Group 1 right-handed children for some measures of visual-spatial and visual-perceptual abilities. While right-handed Group 1 children exhibited higher levels of performance for visual-spatial and visual-perceptual measures relative to verbal and auditory-perceptual measures, this pattern was

Right- and Left-handers

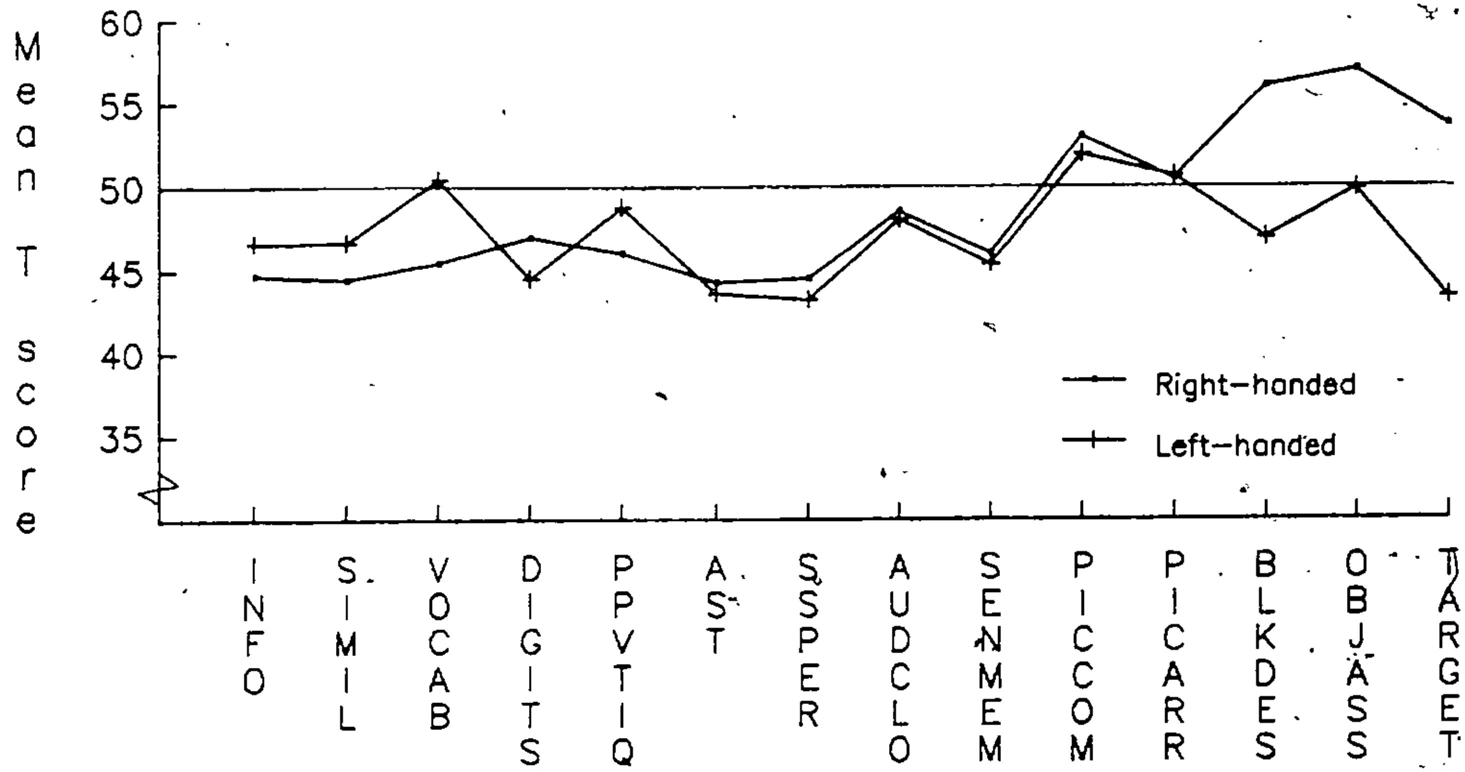

Figure 8. Mean T scores for Right- and Left-handed Group 1 children on Verbal and Visual-Perceptual Measures

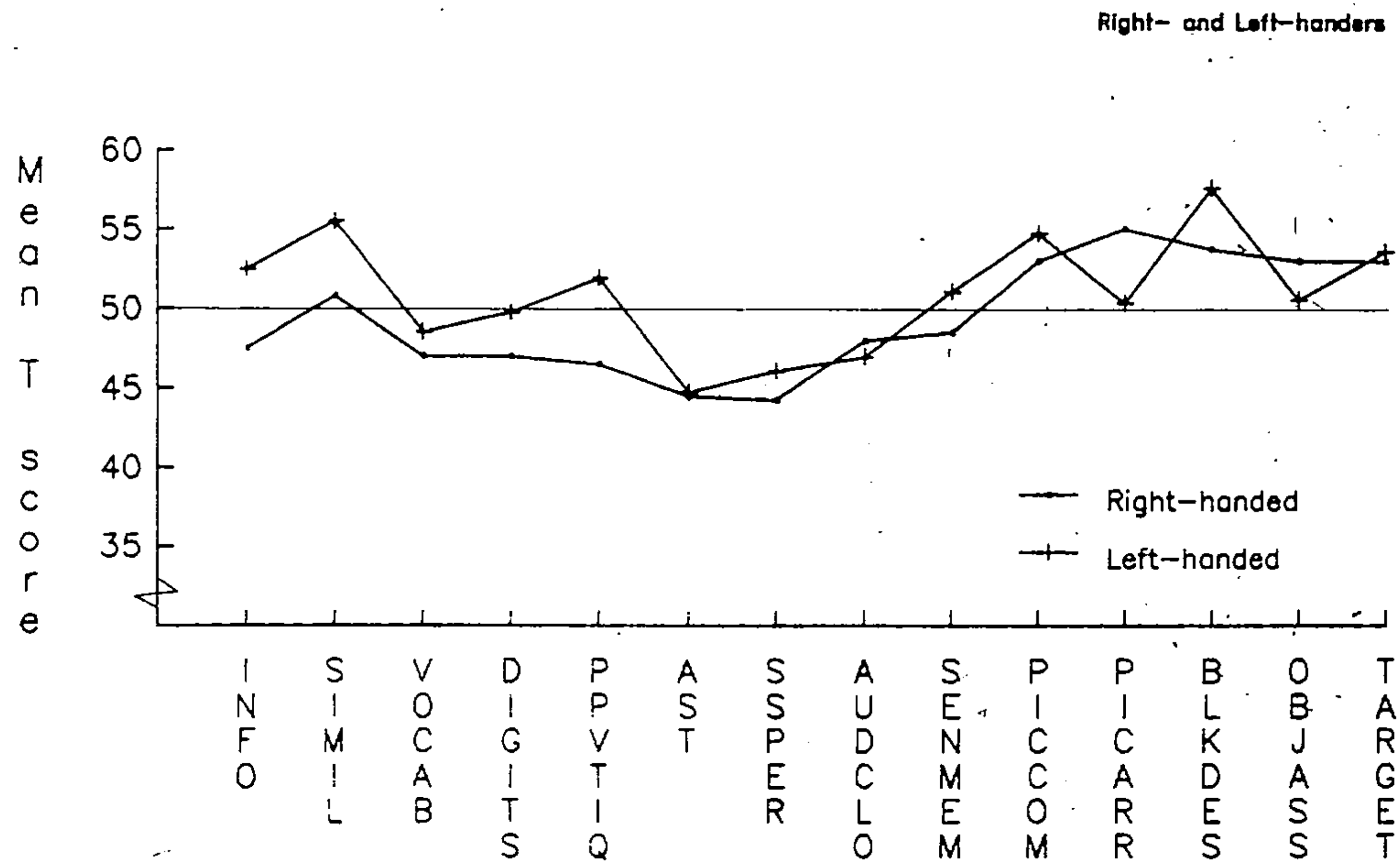

Figure 9. Mean T scores for Right- and Left-handed Group 2 children on Verbal and Visual-Perceptual Measures

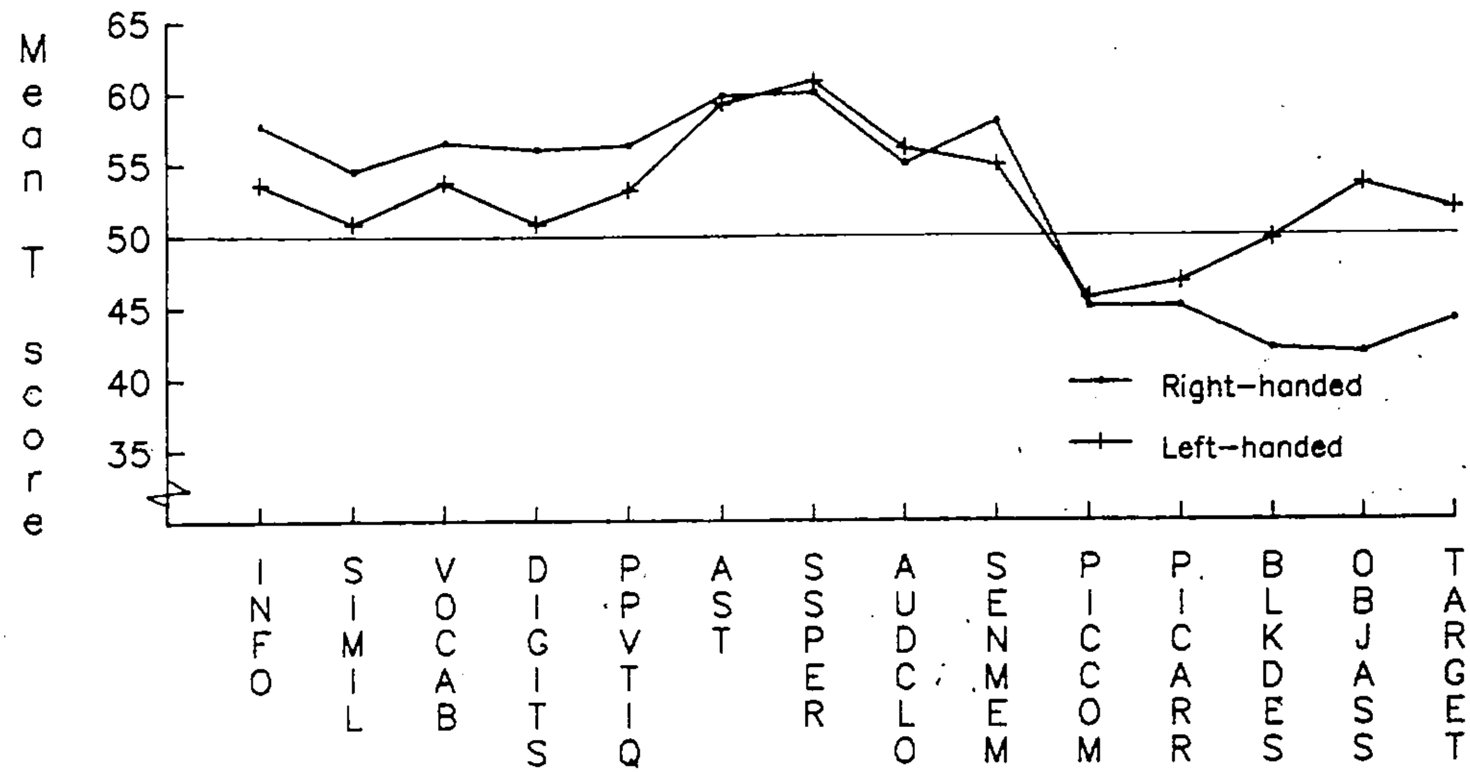

Figure 10. Mean T scores for Right- and Left-handed Group 3 children on Verbal and Visual-Perceptual Measures

not observed in left-handers. Left-handed Group 1 children exhibited roughly the same level of performance across all the variables in this domain.

Left-handed Group 2 children performed in a similar manner to right-handed Group 2 children across the variables in this domain (see Figure 9). However, they exhibited higher levels of performance than did right-handers on measures of verbal ability. Left-handed Group 2 children did not exhibit the pattern observed in right-handed Group 2 children (i.e., higher levels of performance for visual-spatial or visual-perceptual abilities relative to performance on verbal and auditory-perceptual measures).

Group 3 children, be they right- or left-handed, showed higher performance levels for measures of verbal and auditory-perceptual ability relative to their performance levels on visual-spatial or visual-perceptual measures (Figure 10). Left-handed Group 3 children performed at slightly lower levels, relative to right-handed Group 3 children, on the verbal and auditory-perceptual measures. However, their performance on the visual-spatial and visual-perceptual measures was somewhat better than that observed in right-handers.

Motor, Psychomotor, and Tactile-Perceptual Measures

The performance of the three groups of right- and left-handed learning-disabled children are plotted in Figures 11, 12, and 13. The patterns of performance exhibited by the three groups of right-handers differ to some extent from those exhibited by left-handers. In order to facilitate comparisons

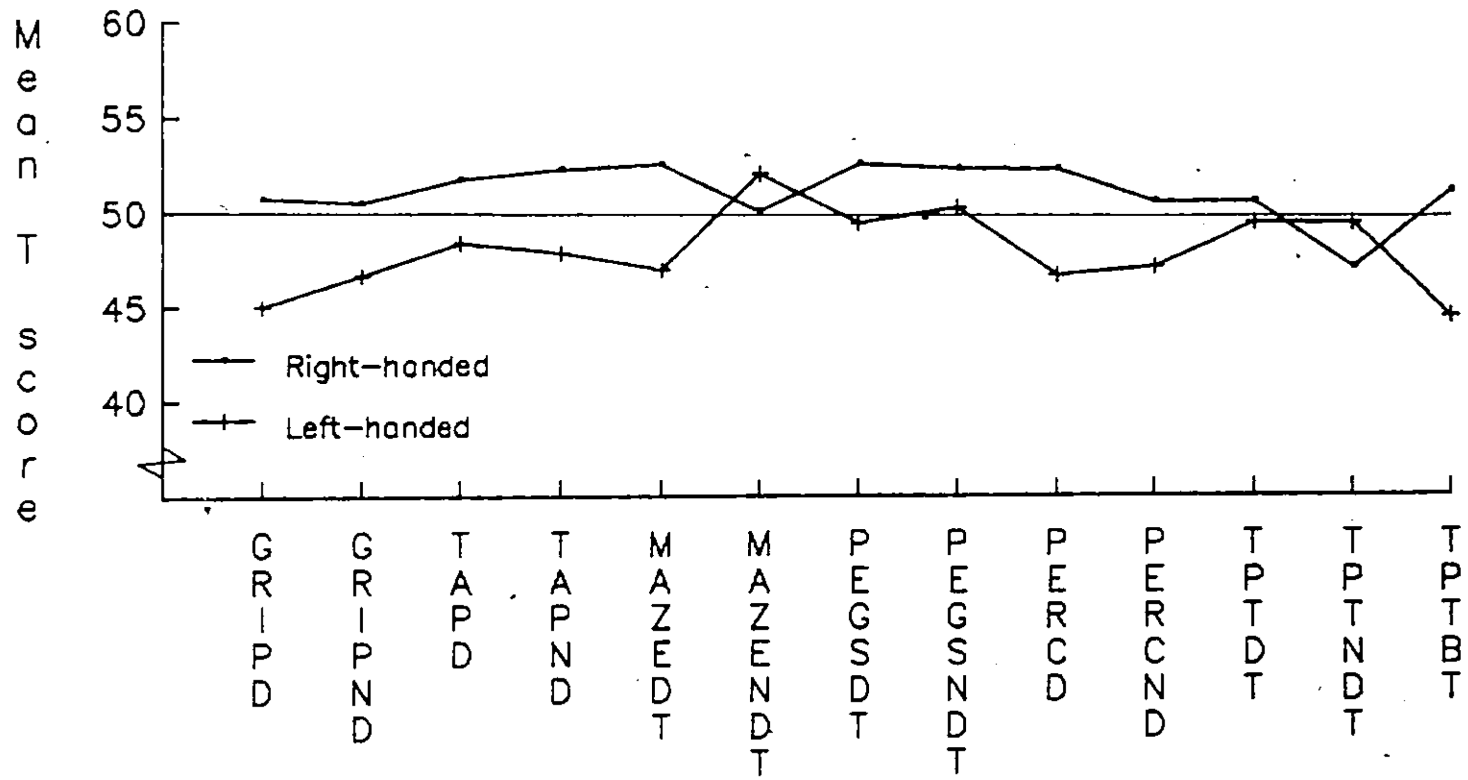

Figure 11. Mean T scores for Right- and Left-handed Group 1 children on Motor, Psychomotor and Tactile Measures

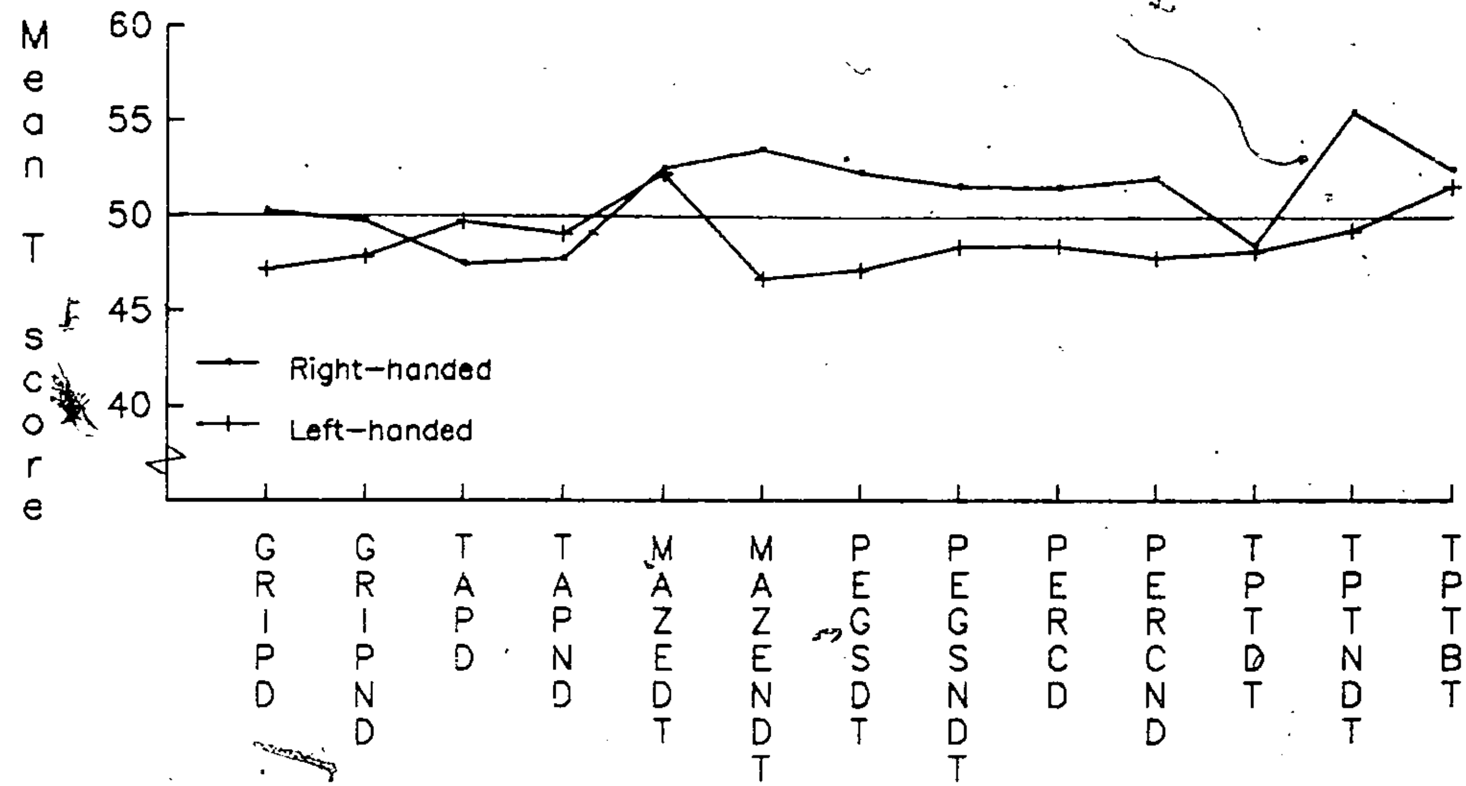

Figure 12. Mean T scores for Right- and Left-handed Group 2 children on Motor, Psychomotor and Tactile Measures

Right– and Left–handers

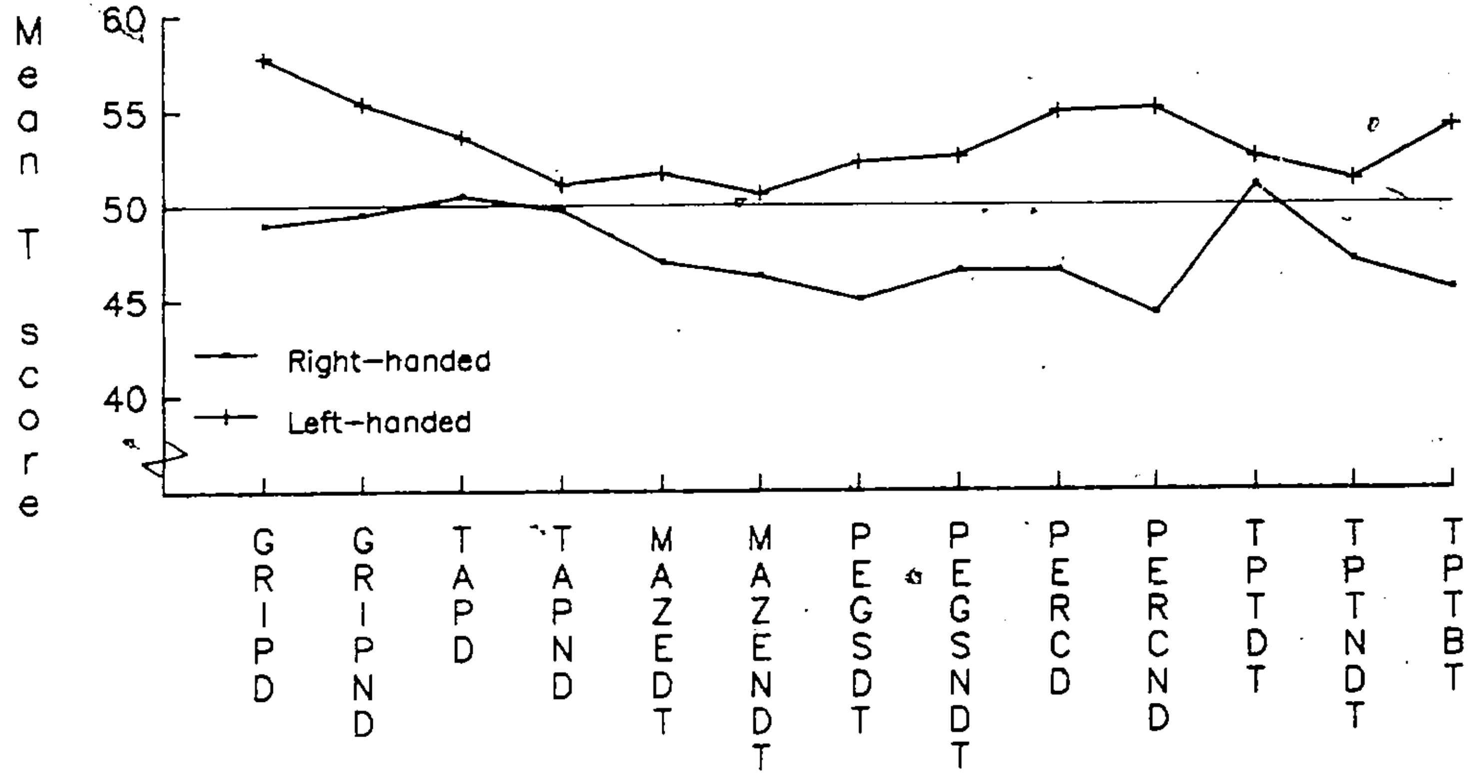

Figure 13. Mean T scores for Right– and Left–handed Group 3 children on Motor, Psychomotor and Tactile Measures

between the performance of right- and left-handed children, the individual measures of Tactile-Perceptual ability were dropped in favour of the overall composite measure used in the series of studies involving right-handers. Also variable names have been changed to represent either the "Dominant Hand" or the "Non-Dominant Hand", rather than right or left in order to compare performance between the two hands across right- and left-handers.

Left-handed Group 1 children (see Figure 11) exhibited lower levels of performance relative to right-handed Group 1 children across the majority of measures in this domain. A similar pattern was observed for Group 2 children (see Figure 12). However, left-handed Group 3 children (see Figure 13) performed in a superior manner to right-handed Group 3 children across all the Motor, Psychomotor, and Tactile-Perceptual measures. None of the groups of left-handed children exhibited a consistent deficient performance for their non-dominant hand on the motor and psychomotor measures

Concept-Formation measure

Only children in Groups 2 and 3 could be compared graphically since Group 1 children were not included in the studies of right-handed children. The performance of both right- and left-handed Groups 2 and 3 children are presented in Figures 14 and 15, respectively. Mean T-scores derived from normative data are plotted. Inspection of these graphs indicates that right- and left-handed learning-disabled children differ in terms of their concept-formation abilities.

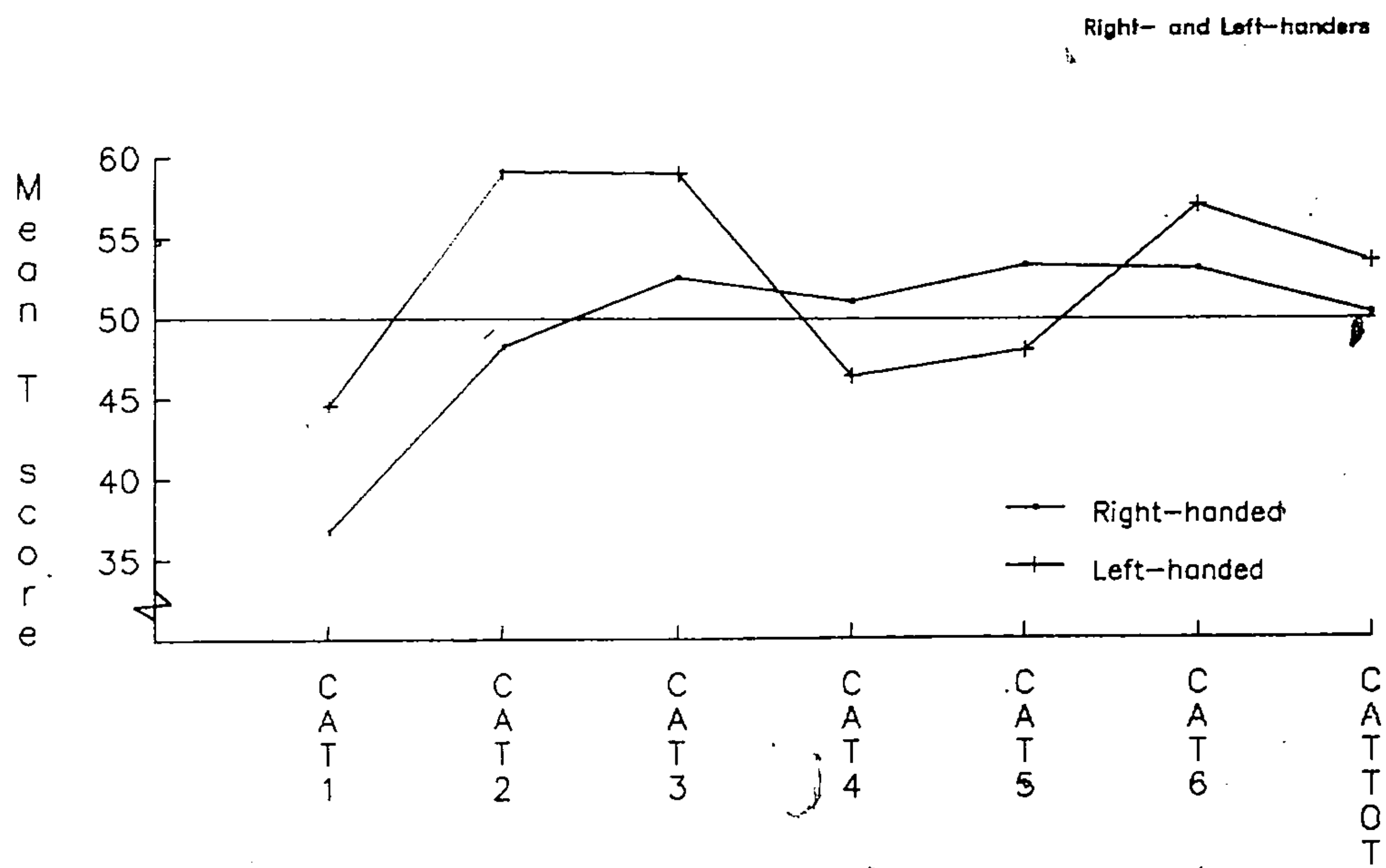

Figure 14. Mean T-scores for Right- and Left-handed Group 2 children on the Concept-Formation Measure

Right– and Left–handers

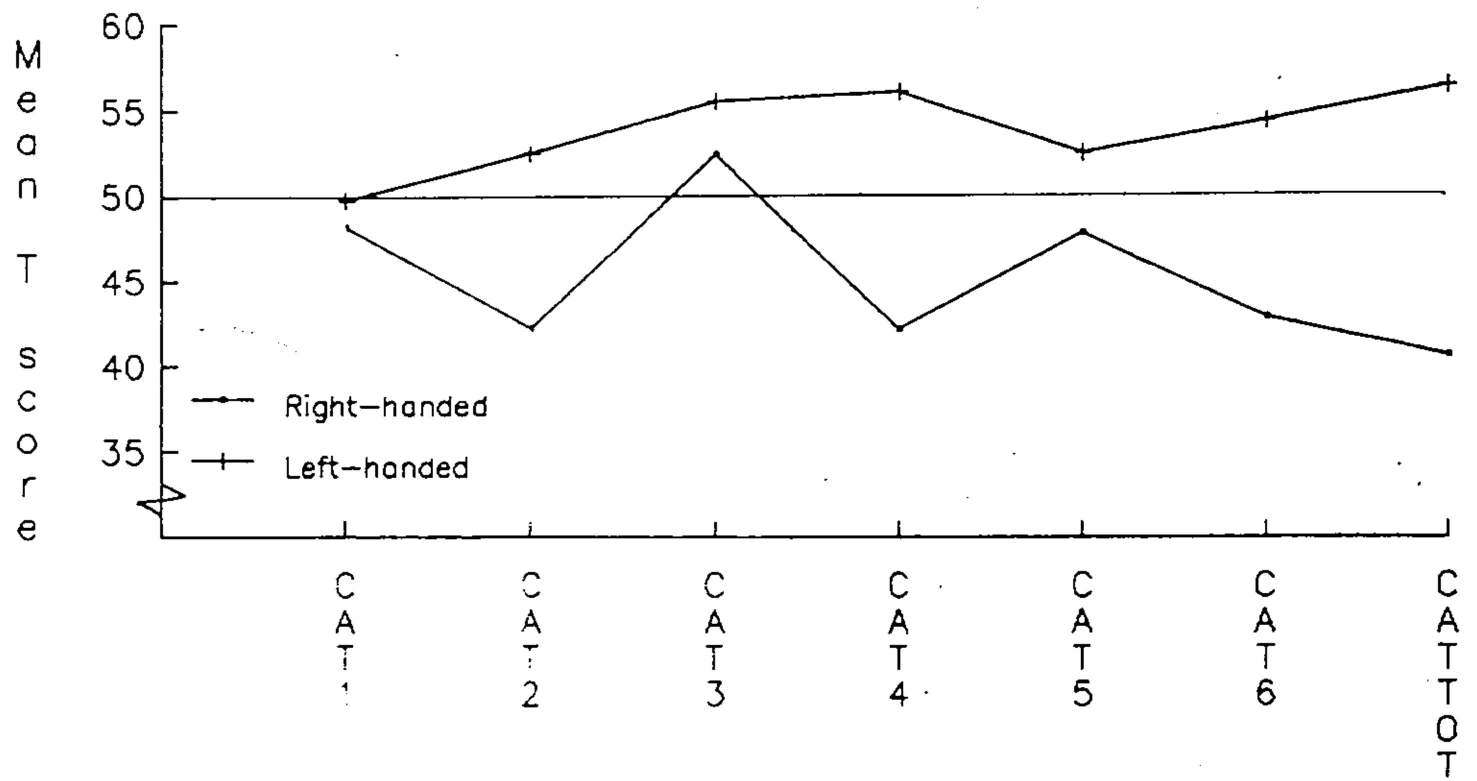

Figure 15. Mean T–scores for Right– and Left–handed Group 3 children on the Concept–Formation Measure

Figure 14 illustrates the differences in performance across the concept-formation measure for right- and left-handed Group 2 children. Left-handed Group 2 children showed superior levels of performance relative to right-handed Group 2 children on the first two subtests of the Category Test. However, their performance on the fourth and fifth subtests was inferior to that of right-handed Group 2 children.

The performance of both right- and left-handed Group 3 children is presented in Figure 15. From this graph it can be seen that left-handed Group 3 children exhibited higher levels of performance than did right-handed Group 3 children on all subtests. Left-handed Group 3 children appeared to have more difficulty with the earlier subtests of the test (those requiring simply counting ability) and the least difficulty with the more complex, visual-perceptual, stimuli. The groups differed in terms of their performance on the last subtest and in terms of the number of total errors made on the test, with left-handed Group 3 children performing in a superior manner to right-handed Group 3 children in both cases.

CHAPTER IV

DISCUSSION

The purpose of this study was to investigate the neuropsychological performance of groups of left-handed learning-disabled children selected according to patterns of academic achievement. The hypotheses for the study were generated according to various theories of left-handedness in order to determine which theory would best predict the performance of these children on various neuropsychological measures. While unequivocal support for the various hypotheses was not obtained, there was some support for the hypothesis that left-handed learning-disabled children perform in a similar manner to right-handed learning-disabled children on neuropsychological tests.

The present investigation examined the performance of three groups of children selected from a clinical population. As Satz (1972, 1973) has noted, it is within this type of population that anomalies of lateralization are sometimes detected. These anomalies take the form of a higher incidence rate of sinistrality or ambiguous handedness. In order to verify Satz's claim the 5000 cases from which this sample was drawn were reviewed. It was found that approximately 16% of these cases exhibited some form of sinistrality. This figure is considerably higher than that observed in the normal population and is consistent with Satz's (1972, 1973) estimation of the incidence rate within clinical populations.

A general overview of the findings is presented, followed by a summary and discussion of the results for each domain of neuropsychological measures (i.e., verbal, auditory-perceptual, visual-spatial, and visual-perceptual; motor, psychomotor, and tactile-perceptual; concept-formation). Shortcomings of the present study are presented next, followed by directions for future research in this area.

GENERAL OVERVIEW OF RESULTS

In general, the results partially supported the hypotheses regarding the performance of the three groups of left-handed learning-disabled children. The hypotheses regarding the performance of these children on the verbal and visual-spatial measures were partially supported; however, no support was found for the hypotheses regarding the performance of the groups on the motor, tactile-perceptual, and concept-formation measures. None of the theories of left-handedness could fully account for the patterns of performance observed in these children.

Comparison of the performance of right- and left-handed children indicated similarities between their performances on the neuropsychological measures (particularly for performance on the verbal and visual-spatial measures). However, it was observed that left-handed learning-disabled children did not show the striking differences among subgroups that are observed in right-handed children. Significant differences were observed on only a few of the measures employed in this study. The differences observed on the verbal and visual-spatial measures were in the expected direction; however, those obtained on the remaining measures went against expectations.

SUMMARY AND DISCUSSION OF RESULTS

Verbal, Auditory-Perceptual, Visual-Spatial, and Visual-Perceptual Measures

The results of both of the statistical analyses (i.e., using normative _T_-scores and those derived from sample means) comparing the three groups of children on these measures indicated that they did not differ from each other on the majority of measures employed. Group differences were observed for the Arithmetic subtest of the WISC, the Aphasia Screening Test, and the Speech Sounds Perception Test. Group 3 children showed superior performance to children in the other two groups on the Aphasia Screening Test and the Speech Sounds Perception Test; children in Group 1 performed at significantly lower levels than children in Groups 2 and 3 on the Arithmetic subtest of the WISC.

The performance of Group 3 children indicates that they were better able to discriminate aurally between similar sounding graphemes and that they exhibited fewer aphasic signs than children in either Group 1 or 2. They also showed high levels of performance (relative to Group 1 children) on a test of verbal mathematical ability. This pattern of performance was consistent with the observed superiority of right-handed Group 3 children, relative to Groups 1 and 2 children, on measures of verbal and auditory-perceptual abilities (Rourke & Finlayson, 1978). This finding was also consistent with predictions arising from Levy's (1969) theory (i.e., that left-handed Group 3 children would perform in a similar manner to right-handed Group 3 children on verbal and auditory-perceptual measures).

The three groups did not differ significantly among each other on the visual-spatial and visual-perceptual measures, indicating that groups of left-handed learning-disabled children do not differ in terms of their visual-spatial or visual-perceptual abilities. This finding did not support any of the hypotheses stating that there would be differences between the three groups (favoring children in Groups 1 and 2) on these measures.

Examination of the performance of the three groups relative to normative data indicated that the groups performed in the average range on all of the visual-spatial and visual-perceptual measures. This observation did not support the expectation that Group 3 children would exhibit below average abilities in this area; however, the performance of Group 1 and 2 children on these measures was consistent with expectations. The performance of the three groups on the verbal and auditory-perceptual measures indicated that they were impaired, relative to norms, on the Aphasia Screening Test and the Sentence Memory Test. Children in Group 1 were also impaired, relative to norms, on the Arithmetic subtest of the WISC, Speech Sounds Perception Test, and Auditory Closure Test. This pattern of performance suggests that left-handed Group 1 children exhibit deficits, relative to norms, on a wide range of psycholinguistic measures. Since right-handed children who exhibit uniformly deficient performance on the WRAT are known to show impairment in the area of psycholinguistics (Rourke & Finlayson, 1978), this finding is not surprising and supports the predictions made regarding the group of left-handed children.

A similar pattern of performance was observed for Group 1 children in the analysis of the T-scores derived from sample information. They exhibited lower levels of performance, relative to children in Groups 2 and 3, on the majority of the verbal and auditory-perceptual measures, revealing their difficulty with psycholinguistic tasks. Children in Group 3 performed in a manner that was consistent with the hypotheses. They exhibited higher scores on the verbal and auditory-perceptual measures relative to the scores obtained on the measures of visual-spatial and visual-perceptual abilities (Rourke & Finlayson, 1978). Groups 1 and 2 children, however, did not exhibit the expected pattern of low verbal, high visual-spatial scores. They also did not show the expected superior performance relative to Group 3 children on these measures. These findings are contrary to the predictions made based on the performance of right-handed children; however, both Levy's (1969) and Satz's (1972, 1973) models can account for the lack of discrepancy between performance on verbal measures and on visual-spatial measures.

According to Levy's competition hypothesis, language is represented bilaterally and competition occurs within the right-hemisphere for processing mechanisms. This competition results in a decrease in the ability to process visual-spatial information. Since children in Groups 1 and 2 did not show the expected pattern of performance, relative to children in Group 3 and to their own performance on the verbal measures, competition within the right-hemisphere for both verbal and visual-spatial processing was assumed to interfere with their ability to process visual-spatial information.

Satz and his colleagues (Bullard-Bates & Satz, 1983; Orsini & Satz, 1986) have suggested that pathological left-handers exhibit atypical speech lateralization (i.e., in the right hemisphere) and poor visual-spatial abilities. The patterns of performance exhibited by Groups 1 and 2 appear to support this argument (since they do not exhibit the marked discrepancy between verbal and visual-spatial abilities seen in right-handers).

When these three groups of children were compared to their right-handed peers a somewhat clearer picture of their performance appeared. Both right- and left-handed Group 1 children performed in a similar manner on the verbal and auditory-perceptual measures. However, their pattern of performance differed on the measures of visual-spatial and visual-perceptual abilities. Left-handed Group 1 children showed lower levels of performance on these measures as compared to right-handed children and their performance on the psycholinguistic measures. As mentioned above, this pattern of performance can be accounted for by the models of left-handedness proposed by Levy (1969) and Satz (1972,1973).

Both left- and right-handed Group 2 children exhibited similar patterns of performance on the measures employed in this domain. However, the right-handed children exhibited clearly higher scores on measures requiring visual-spatial abilities when compared to their performance on measures of psycholinguistic skills. Left-handed children, on the other hand, did not exhibit such a striking discrepancy; while their level of performance on the visual-spatial measures was somewhat higher than that observed for the verbal measures, they exhibited better performance on the verbal measures than right-handed Group 2 children. This would suggest that left-handed Group 2 children possess moderately better language skills than right-handed Group 2 children, which reduces the amount of discrepancy between performance on verbal tasks and on visual-spatial tasks. This finding partially supports the predictions made for this group based on the performance patterns exhibited by right-handed children. However, the moderately better performance exhibited by left-handed children, as compared to right-handed children, on the verbal measures was unexpected.

Left- and right-handed Group 3 children also show similar patterns of performance on all the measures. They exhibit better performance on the verbal and auditory-perceptual measures than the visual-spatial and visual-perceptual ones. Somewhat surprisingly, however, left-handed Group 3 children exhibited higher levels of performance than right-handed children on the visual-spatial and visual-perceptual measures. While the pattern of performance exhibited by the group of left-handed children is consistent with the hypothesis that they would perform similarly to right-handed children (Rourke & Finlayson, 1978), the level of their performance on the visual-spatial measures is not consistent with expectations. The performance of the left-handed children is difficult to account for; however, it may be that since left-handed Group 3 children have average to above average verbal skills, they employ a verbal mediational strategy when solving problems with a visual-spatial component. Further research examining the performance of left-handed Group 3 children on visual-spatial problems is warranted.

Overall, there was partial support for the hypotheses regarding the performance of the three groups on variables in this domain. The three groups of left-handed children exhibited similar patterns of performance to those observed in right-handed children. However, they did not exhibit the striking discrepancies between verbal and visual-spatial abilities that are observed in right-handers. No one theory could fully account for the performance of all the groups on the verbal and visual-spatial measures.

Motor, Psychomotor, and Tactile-Perceptual Measures

Statistical analyses of the performance of the three groups on these measures indicated that they differed only on the measure of Astereognosis (for both hands). Analysis of the sample T-scores also indicated significant group differences on the measure of Strength of Grip with the left hand. In all cases children in Group 3 children performed in a superior manner to Group 1 children. This finding was contrary to expectations.

An examination of the level of performance of the three groups relative to norms indicates that they perform in the normal range on the majority of the motor and psychomotor measures. The groups were impaired relative to norms on some tactile-perceptual measures (i.e., Finger Agnosia and Finger-Tip Number Writing). These observations contrast with the observation made by Rourke & Strang (1978) that right-handed children (in particular, Group 3 children) perform well below age expectation levels on psychomotor and tactile-perceptual measures.

The patterns of performance exhibited by the three groups did not differ across the measures in this domain. All three groups exhibit better performance on simple motor measures than on psychomotor measures. The groups appear to show better performance with their non-dominant (i.e., right) hand on the motor and psychomotor measures. The only exception to this pattern of performance was for the Mazes Test, where Group 1 children showed better performance with the left hand. On a problem-solving measure that requires the ability to benefit from tactile-kinesthetic feedback, Group 1 children were impaired when required to use both hands to complete the task. All three groups performed in the average range when using each hand separately. These findings do not support the pathological theories of left-handedness (Bakan, 1971; Satz, 1972, 1973), since each model presupposes that there will be deficient right-hand performance for motor and psychomotor tasks.

When the sample T-score data was examined a somewhat different picture of the groups performance emerged. Group 3 children exhibited higher levels of performance on the measures relative to children in Groups 1 and 2. These latter groups exhibited fairly similar patterns of performance across the measures in this domain. These observations did not support any of the stated hypotheses regarding the performance of the three groups on these measures.

Examination of the groups performance for each hand on the motor and psychomotor measures indicated that Group 3 children exhibited better left- than right-hand performance. Groups 1 and 2 children performed similarly with both their right and left hands on the motor and psychomotor measures. This pattern of performance exhibited by the three groups would be expected given their stated hand preference. There was no evidence that their right hand performance levels were impaired; thus, there was no support for the expectation derived from theories of pathological left-handedness, that left-handers would exhibit right-handed impairment for motor and psychomotor measures (Bakan, 1971; Satz, 1972, 1973).

The fact that left-handers show no evidence of impairment with their right-hand is perhaps not all that surprising. Since the majority of people are right-handed, the world is organized in a "right-handed" fashion (e.g., doorknobs are on the left side of doors so that they are easier to use if one uses the right-hand). While left-handers state a preference for using their left-hand for manual tasks, in reality they may use both hands equally (or at least, also use their right-hand for various manual tasks). This would indicate that they are more proficient in using their non-dominant hand than right-handers. The fact that left-handers may also be proficient with their right-hand suggests that performance of this hand on motor tests may not be impaired, due to the amount of "practice" left-handers get in using their right-hand.

The performance of left-handed children was compared to that observed previously in right-handed children (Rourke & Strang, 1978). Left- and right-handed Group 1 children exhibit a similar pattern of performance across all measures, with right-handed children exhibiting somewhat better performance than left-handed children. Group 2 children perform in a similar manner to that observed for the Group 1 children. Left-handed Group 2 children exhibit lower performance for their non-dominant hand, relative to their dominant one, on the Mazes Test. This pattern is not seen in right-handed children.

Group 3 children also exhibit similar patterns of performance across the measures. However, left-handed Group 3 children perform in a superior manner to right-handed Group 3 children. This was unexpected but may be related to the idea that left-handers show better performance with their dominant hand (due to hand preference) and are also proficient in using their non-dominant hand (since they live in a right-handed world). Left-handed Group 3 children were also less-lateralized (i.e., less left-handed) compared to the other two groups of children used in this study. Children in this group had a higher tendency to report, on the Harris Tests of Lateral Dominance, that they used their right-hand for some manual tasks. It may be that these children are more proficient in using both hands (relative to the other two groups), and that they show less preference for using their left-hand over their right-hand for various motor tasks. The increased proficiency may lead to better performance on motor and psychomotor measures with both hands (thus no evidence for an impairment with one hand relative to the other) and to better performance than seen in individuals who tend to be proficient in one hand only.

Overall, there was no support for any of the hypotheses put forward. Left-handed children did not exhibit the same pattern of performance observed in right-handed children on measures of motor, psychomotor, and tactile-perceptual abilities. There was also no evidence for a right-hand impairment on the motor measures, as was predicted by the theories of pathological left-handedness. The superior performance of left-handed Group 3 children was attributed to both their <u>preferred</u> left-handedness and their possible superior <u>proficiency</u> with their non-dominant hand, relative to right-handers.

<u>Concept-Formation Measure</u>

Results of the statistical analyses of the performance of the groups on this measure indicated that there were significant differences among Groups for performance on the fourth and sixth subtest of the Halstead Category Test. On both subtests children in Group 1 showed the lowest level of performance. Group 3 children showed high levels of performance on these subtests. This did not support the hypothesis that Group 3 children would exhibit poor concept-formation abilities. The results also did not support the finding by Strang & Rourke (1983) that Group 3 children exhibited particular difficulty with those subtests requiring visual-spatial analysis.

Comparison of the performance of the three groups to normative data indicated that all groups performed in the normal range on all subtests of the Category Test. Children in Groups 1 and 2 exhibit similar patterns of performance across the subtests. They exhibit better performance on the second and third subtest (which involve counting and the "oddity principle", respectively) than on those subtests that require more complex analysis of a visual-spatial nature (i.e., subtests 4 and 5). Group 3 children perform at the same level across all subtests (i.e., they do not show better performance on the earlier subtests than on the later subtests or vice versa). On the last subtest (a review subtest), Group 1 children exhibit the lowest level of performance. This would appear to indicate that these children have more difficulty in benefitting from feedback, relative to children in the other two groups. This is consistent with their performance on the Tactual Performance Test (discussed above).

Comparison of the performance of the groups according to sample T-scores indicated that Group 1 showed the lowest level of performance on all subtests except subtest 5. These children performed at an impaired level, relative to Group 2 and 3 children, on the review subtest (subtest 6), again suggesting that they have problems in benefitting from feedback. Group 2 children exhibited lower levels of performance on the subtests requiring visual-spatial analysis relative to their performance on the earlier subtests of the Category Test. Children in Group 3 showed the opposite pattern of performance to that seen in Group 2 children.

Since Group 1 children were not included in the original study examining right-handers (Strang & Rourke, 1983), only the performance of Groups 2 and 3 could be compared across handedness. Left-handed Group 2 children exhibited better performance than their right-handed peers on the first three subtests of the Category Test. However, the performance of left-handed children on the fourth and fifth subtest was lower than that observed in right-handed children. The pattern of performance suggests that as the stimuli become more complex (i.e., require more visual-spatial processing), left-handed Group 2 children become less adept at forming the correct concept. Thus, it would appear that Group 2 children have some problem with the visual-spatial components of the test. This would be consistent with Levy's (1969) theory of intra-hemispheric competition and Satz's (1972, 1973) observation that left-handers exhibit some problems with visual-spatial processing.

Left-handed Group 3 children exhibit somewhat better performance on those subtests that require visual-spatial analysis, relative to those subtests that do not. This pattern of performance is contrary to what was expected based on the performance of right-handed Group 3 children. However, their performance is consistent with the observation that left-handed Group 3 children perform better on measures of visual-spatial and visual-perceptual abilities than right-handed Group 3 children. Since left-handed Group 3 children exhibit well developed psycholingusitic abilities, it is conceivably possible that they employ some type of verbal-mediational strategy in order to form the correct concept in subtests requiring visual-spatial analysis. This is not seen in left-handed Group 2 children since their verbal abilities are somewhat inferior to those observed in Group 3 children.

Overall, the performance of the groups of left-handed children on the measure of concept-formation did not support the hypotheses presented. In fact, left-handed Group 3 children exhibited better concept-formation abilities than children in any other group, regardless of handedness. This pattern of performance was attributed to the possible use of verbal-mediational strategies. Group 2 children exhibit lower scores on the subtests requiring visual-spatial processing relative to their performance on the subtests requiring less complex skills (i.e., counting and matching). Both Levy's theory of intra-hemispheric crowding and Satz's observations that left-handers have deficient visual-spatial processing abilities can account for this finding. This group of children is not assumed to apply verbal mediational strategies due to the fact that they are weak in psycholinguistic ability.

General Conclusions

The results of this study only partially support the hypotheses proposed. While the three groups of left-handed children generally performed in a manner consistent with that seen in right-handed children, there were a few significant differences among the groups of left-handed children for the measures employed in this study.

Left-handed children who were selected according to patterns of performance on the WRAT that indicated superior performance on the Reading and Spelling subtests in the context of deficient performance on the Arithmetic subtest, exhibited higher levels of performance on measures of verbal ability than on measures of visual-spatial ability. This is consistent with the pattern of performance observed in right-handers. However, the performance of left-handed Group 3 children on measures of visual-spatial abilities was higher than expected. They also exhibited superior performance on the visual-spatial components of a nonverbal problem solving/concept-formation task. This group of left-handed children did not exhibit evidence of motor, psychomotor, or tactile-perceptual deficits. The pattern of performance exhibited by these children is not entirely consistent with that of a hypothesis of right-hemisphere dysfunction (Rourke & Finlayson, 1978; Rourke & Strang, 1978; Strang & Rourke, 1983).

Group 2 children also exhibited no evidence of motor or psychomotor deficiencies. Their performance on the verbal and visual-spatial measures was similar to that observed in right-handed Group 2 children; however, their level of performance on the visual-spatial measures was lower than expected on the basis of the performance of right-handed children. They exhibited better concept-formation abilities for subtests that did not require visual-spatial analyses. Left-handed Group 1 children exhibited a similar pattern of performance to children in Group 2; however, their performance on measures requiring visual-spatial processing was lower than that observed in Group 2 children. The pattern of performance exhibited by these two groups (and in particular, Group 2 children) does not fully support the findings observed in right-handed Group 2 children, and therefore does not suggest a hypothesis of left-hemisphere dysfunction (Rourke & Finlayson, 1978; Rourke & Strang, 1978; Strang & Rourke, 1983).

While no one theory adequately explains the performance of the three groups of left-handers, there is some evidence to suggest that Levy's (1969) theory of intra-hemispheric competition and Satz's (1972, 1973) model of pathological left-handedness can be used to account for some of the findings. Bakan's theory of pathological left handedness received no support from the results of this study. Each theory of left-handedness will be discussed in light of the present findings.

There was no evidence to support Bakan's (1971) theory of pathological left-handedness. The predicted performance of Group 2 children on the visual-spatial measures was not supported. There was no evidence from the analysis of the motor and psychomotor measures to suggest impairment of the non-dominant hand for any of the groups. The performance of the three groups on the concept-formation measure also went against expectations based on this model.

Results of the analyses on the verbal and visual-spatial measures support both Levy's (1969) and Satz's (1972, 1973) models of left-handedness. It would appear then, that left-handed children exhibit difficulty with visual-spatial processing due to crowding of the right-hemisphere. This processing difficulty results in lower performance on measures of visual-spatial ability. However, Group 3 children exhibited higher levels of performance on measures requiring visual-spatial processing than those observed in right-handers. It was suggested that Group 3 children (since they are quite adept for psycholinguistic abilities, especially relative to Group 2 children) may be employing a verbal mediational strategy when presented with visual-spatial information. Levy (1969) argues that when there is competition for resources within a cerebral hemisphere, verbal processing will be performed at the expense of visual-spatial processing. If this is the case then left-handed Group 3 children may process all information using a decidedly more verbal manner than right-handed Group 3 children. Group 2 children (either right- or left-handed) will not use this approach since they are not as adept at linguistic processing as Group 3 children. A similar argument can be used to explain the findings of the concept-formation measure.

The results of the analyses of the motor, psychomotor, and tactile-perceptual measures do not offer any support to Satz's (1972, 1973) model of pathological left-handedness. None of the groups showed evidence for right-handed impairment. The predictions for the performance of the three groups on these measures, based on Levy's (1969) theory, were also not supported.

It appears then, that while Levy's theory of intra-hemispheric competition is not fully supported by the results of this study, there is evidence to suggest that it obtains partial support. Of the theories presented, it is the best predictor of the performance of these three groups of left-handed children.

The performance patterns within the three groups of left-handed children differ somewhat from those observed in right-handed children. Right-handed

Group 1 and 2 children exhibit similar patterns of performance across neuropsychological measures. In general, they exhibit many relatively poor psycholinguistic skills in the context of well-developed visual-spatial-organizational, tactile-perceptual, psychomotor, and nonverbal problem-solving skills and abilities. In contrast, Group 3 right-handed children exhibit deficits in visual-spatial-organizational, tactile-perceptual, psychomotor, and nonverbal problem-solving skills along with strengths in psycholinguistic areas (Rourke, 1988). The apparently "opposite" patterns of strengths and weaknesses exhibited by these groups has direct ramifications for intervention techniques. There is some evidence to suggest that Group 3 children tend to fare much worse than Group 2 children with respect to both remediation attempts and in complex social situations (Rourke, 1988; Rourke, in press).

While right-handed learning-disabled children exhibit patterns of neuropsychological performance that are diametric to each other (e.g., strong verbal-poor visual-spatial abilities vs. poor verbal-strong visual-spatial abilities), similar discrepancies are not seen in left-handed learning-disabled children. Even though different patterns of performance are observed within groups of left-handed learning-disabled children, these patterns of performance have different implications concerning prognosis and treatment than those observed in right-handed children. The pattern exhibited by Group 3 children of average to above-average psycholinguistic, visual-spatial-organizational, tactile-perceptual, psychomotor, and concept-formation abilities would suggest that they are far better off, in a neuropsychological sense, than their right-handed peers. In addition, they exhibit better adaptive abilities than either of the other two groups of left-handed children. Group 1 left-handed learning-disabled children, for example, possess deficits in virtually all ability areas. This group of children would appear to be the worst off in terms of prognosis. Consequently, it would appear that within groups of left- and right-handed learning disabled children there are differences with respect to the patterns of neuropsychological functioning, and that the prognosis concerning these groups of learning-disabled children will differ according to handedness.

Limitations of the study and directions for future research

The overall patterns of performance exhibited by left-handed learning-disabled children in this study generally resemble those of right-handed learning-disabled children. However, left-handers do not exhibit the striking discrepancies among the groups that are observed in right-handers. There are some limitations to the study that could account for the lack of significant differences among groups of left-handed learning-disabled children.

Firstly, the patterns of performance exhibited by right-handed learning-disabled children selected according to patterns of academic achievement are known to be associated with particular Verbal and Performance I.Q. discrepancies. Right-handed Group 3 children exhibit higher Verbal I.Q.s relative to Performance I.Q.s, and right-handed Group 2 children show the opposite pattern (Rourke, Young, & Flewelling, 1971). Children in this study were selected according to their patterns of academic achievement. No differences were found among the groups with respect to Verbal and Performance I.Q.s. Closer examination of the discrepancy between Verbal and Performance I.Q. revealed that the majority of left-handed children in this study had higher Performance than Verbal I.Q. scores. Six children in Group 1, five children in Group 2 and five children in Group 3 showed this pattern. Only three children in the entire sample (two in Group 2 and one in Group 3) had higher Verbal than Performance I.Q.s. The remaining children exhibited equivalent scores on these measures. If the left-handed children in this study had been chosen according to both I.Q. discrepancy patterns and the pattern of performance on the WRAT, significant differences among the groups may have been observed.

A second factor that needs to be examined further is that of gender differences. While Canning, Orr, & Rourke (1980) observed no sex differences for children with learning-disabilities on measures similar to those employed in this study, research examining the performance of left-handers on various cognitive measures indicates that females may be less laterally differentiated than males (Levy & Reid, 1978). Since only four of the subjects used in this study were female (one in Group 1 and three in Group 3) analysis of possible sex differences could not be performed due to the small sample size. Future research examining the performance of subtypes of left-handed learning-disabled children should also examine sex differences in order to determine the role that they play in the cognitive functioning of sinistral children.

More often than not, studies examining the performance of left-handers on various cognitive measures have found that gender interacts with other variables such as familial sinistrality and writing posture (Kocel, 1977; Levy & Reid, 1978; Tinkcom, Obrzut, & Poston, 1983; Zurif & Bryden, 1969). These are two other variables that were not controlled for in the present study and that may have contributed to the lack of significant findings.

Familial sinistrality has been shown to be related to lateralization effects exhibited by left-handers (Zurif & Bryden, 1969). However, there are conflicting claims for the effects of familial sinistrality on the cerebral organization observed in left-handers. Zurif & Bryden (1969) observed that left-handers with no history of familial sinistrality performed in a similar fashion to right-handers on a visual-recognition task. Hecaen & Sauget (1971), on the other hand, found that individuals with a familial history of left-handedness exhibited a pattern of cerebral organization similar to that observed in right-handers. Tinkcom, Obrzut, & Poston (1983) supported Hecaen & Sauget's findings only for performance on a nonverbal dichaptic task. Performance on a verbal dichaptic task was not found to be affected by familial sinistrality.

Regardless of the lack of conclusive evidence regarding the role of familial sinistrality in the cerebral organization of left-handers, it would appear necessary to try to control for the influence of this variable. The majority of subjects in this study did not have any history of familial sinistrality (five children in Group 1; four children in Group 2; and six children in Group 3). Once again, it was not possible to analyze the performance of the children in this study on the basis of a familial history of sinistrality, due to the small sample size.

Levy & Reid (1976) have found that writing posture is related to cerebral organization. Those individuals who wrote with a "hooked", or inverted, writing posture were shown to have a reversed pattern of laterality than those individuals who wrote in a normal, or non-inverted writing position. Gregory & Paul (1980) have found that left-handers who write with an inverted hand position performed more poorly than right-handers, or left-handers with a normal handwriting position, on tests measuring verbal abilities. Future research examining the neuropsychological performance of left-handed learning-disabled children might consider the role that handwriting posture plays in the performance exhibited by these children.

A final point needs to be made with respect to the "purity" of the handedness exhibited by these children. Although no significant differences were observed among the groups with respect to the degree of laterality, it was noted that Group 3 children were less lateralized (i.e., less left-handed) than children in the other two groups. This may have contributed to the lack of significant findings on the measures employed in this study.

The investigation of the performance of particular subtypes of left-handed learning-disabled children has just begun with this study. It appears as though left-handed learning-disabled children differ somewhat from right-handed learning-disabled children, and therefore, more investigation of the performance of left-handed learning-disabled children on neuropsychological measures is necessary. Variables that do not seem to influence the performance of right-handed children may influence the performance of left-handed children and need to be controlled for in the study of their performance on neuropsychological measures. Future research in this area would further clarify the nature of learning disabilities in left-handed learning-disabled children.

Appendix A
Laterality Quotients for each Subject

Laterality Quotients were determined using the same formula as the one provided by Von Seggren, Ginn, & Harrell (1988) for the Edinburgh Handedness Inventory. The formula is as follows:

$$\text{Laterality Quotient (LQ)} = \frac{\text{Sum of Right} - \text{Sum of Left}}{\text{Sum of Right} + \text{Sum of Left}} \times 100$$

where - Sum of Right = the total number of items on the Harris Tests of Lateral Dominance that were endorsed with the right-hand
- Sum of Left = the total number of items on the Harris Tests of Lateral Dominance that were endorsed with the left-hand

<u>Laterality Quotients for each subject across Groups</u>

Group 1	Group 2	Group 3
-100.00	-100.00	- 42.86
-100.00	-100.00	- 42.86
- 42.86	-100.00	-100.00
- 71.43	- 71.43	- 42.86
-100.00	- 71.43	-100.00
- 71.43	- 71.43	- 42.86
-100.00	- 71.43	- 71.43
42.86	100.00	42.86

Appendix B

Summary of ANOVA and MANOVA Results for
Verbal, Auditory-Perceptual, Visual-Spatial,
and Visual-Perceptual Measures (Knights and Norwood Norms)

Variable		Mean Square	df	F	p
Information		44.478	2	1.06	0.3662
	error	41.854	18		
Comprehension		8.069	2	0.05	0.9499
	error	156.599	18		
Arithmetic		387.070	2	12.51	0.0004
	error	30.949	18		
Similarities		72.917	2	2.76	0.0904
	error	26.465	18		
Vocabulary		18.154	2	0.51	0.6100
	error	35.725	18		
Digit Span		71.561	2	1.03	0.3783
	error	69.709	18		
PPVT I.Q.		29.345	2	0.40	0.6750
	error	73.043	18		
Aphasia Screening Test		956.749	2	13.93	0.0002
	error	68.668	18		
Speech Sounds Perception Test		3122.126	2	21.97	0.0001
	error	142.083	18		

Appendix B (cont'd)

Variable	Mean Square	df	F	p
Auditory Closure	40.555	2	0.53	0.5968
error	76.336	18		
Sentence Memory	186.409	2	1.87	0.1835
error	99.907	18		
Picture Completion	125.165	2	1.40	0.2713
error	89.150	18		
Picture Arrangement	14.054	2	0.26	0.7713
error	53.347	18		
Block Design	151.488	2	2.73	0.0921
error	55.478	18		
Object Assembly	28.042	2	0.29	0.7545
error	98.001	18		
Target Test	750.345	2	3.52	0.0513
error	213.192	18		
MANOVA		32 4	2.37	0.2085

Note: The Hotelling-Lawley Trace was used for the MANOVA F test.

Appendix C

Summary of ANOVA and MANOVA Results for
Motor, Psychomotor, and Tactile-Perceptual Measures
(Knights and Norwood Norms)

Variable	Mean Square	df	_F_	_p_
Tapping Test				
Right Hand	61.024	2	0.35	0.7091
error	174.608	21		
Left Hand	40.995	2	0.21	0.8140
error	197.301	21		
Strength of Grip				
Right Hand	29.926	2	0.51	0.6098
error	59.079	21		
Left Hand	96.966	2	1.82	0.1874
error	53.404	21		
Mazes (time)				
Right Hand	108.401	2	0.33	0.7229
error	328.993	21		
Left Hand	297.196	2	0.68	0.5150
error	433.877	21		
Pegboard (time)				
Right Hand	38.413	2	0.12	0.8853
error	313.489	21		
Left Hand	21.203	2	0.07	0.9320
error	299.956	21		

Appendix C (cont'd)

Variable	Mean Square	df	F	p
Tactual Performance Test				
Dominant Hand	0.022	2	0.00	0.9998
error	145.668	21		
Non-Dominant Hand	50.077	2	0.24	0.7916
error	211.918	21		
Both Hands	349.384	2	1.19	0.3248
error	294.320	21		
Tactile Perception				
Right Hand	62.833	2	0.27	0.7680
error	235.046	21		
Left Hand	33.270	2	0.13	0.8769
error	251.622	21		
Finger Agnosia				
Right Hand	15.500	2	0.03	0.9714
error	533.476	21		
Left Hand	53.463	2	0.11	0.8961
error	485.045	21		
Finger-Tip Number Writing				
Right Hand	29.723	2	0.08	0.9239
error	374.246	21		
Left Hand	61.826	2	0.17	0.8476
error	370.870	21		

Appendix C (cont'd)

Variable	Mean Square	df	F	p
Astereognosis				
Right Hand	490.870	2	4.73	0.0202
error	103.823	21		
Left Hand	753.910	2	7.05	0.0046
error	106.997	21		
MANOVA		38 4	1.66	0.3372

Note: The Hotelling-Lawley Trace was used for the MANOVA F test.

Appendix D

Summary of ANOVA and MANOVA Results for the Concept-Formation Measure (Knights and Norwood Norms)

Variable	Mean Square	df	F	p
Category Test				
Subtest 1	239.932	2	1.21	0.3192
error	198.881	21		
Subtest 2	91.621	2	1.91	0.1730
error	47.976	21		
Subtest 3	95.187	2	1.10	0.3527
error	86.879	21		
Subtest 4	304.411	2	4.44	0.0247
error	68.562	21		
Subtest 5	45.483	2	0.63	0.5406
error	71.798	21		
Subtest 6	216.970	2	3.53	0.0477
error	61.482	21		
Total	133.960	2	1.83	0.1850
error	73.170	21		
MANOVA		14 28	1.80	0.0896

Note: The Hotelling-Lawley Trace was used for the MANOVA F test.

Appendix E

Summary of ANOVA and MANOVA Results for Verbal, Auditory-Perceptual, Visual-Spatial, and Visual-Perceptual Measures (Sample _T_-scores)

Variable		Mean Square	df	_F_	_p_
Information		100.074	2	1.06	0.3662
	error	94.172	18		
Comprehension		5.894	2	0.05	0.9499
	error	114.340	18		
Arithmetic		636.210	2	12.51	0.0004
	error	50.869	18		
Similarities		143.299	2	2.76	0.0904
	error	52.012	18		
Vocabulary		44.323	2	0.51	0.6100
	error	87.220	18		
Digit Span		82.150	2	1.03	0.3783
	error	80.023	18		
PPVT I.Q.		36.826	2	0.40	0.6750
	error	91.664	18		
Aphasia Screening Test		491.710	2	11.40	0.0006
	error	43.137	18		
Speech Sounds Perception Test		578.140	2	12.61	0.0004
	error	45.856	18		

Appendix E (cont'd)

Variable		Mean Square	df	F	p
Auditory Closure		159.836	2	1.71	0.2090
	error	93.474	18		
Sentence Memory		163.802	2	1.76	0.2002
	error	93.007	18		
Picture Completion		137.719	2	1.40	0.2713
	error	98.091	18		
Picture Arrangement		30.394	2	0.26	0.7713
	error	115.370	18		
Block Design		225.295	2	2.73	0.0921
	error	82.508	18		
Object Assembly		25.435	2	0.29	0.7545
	error	88.890	18		
Target Test		223.426	2	2.52	0.1081
	error	100.567	18		
MANOVA			32 4	0.60	0.8151

Note: The Hotelling-Lawley Trace was used for the MANOVA F test.

Appendix F

Summary of ANOVA and MANOVA Results for
Motor, Psychomotor, and Tactile-Perceptual Measures
(Sample T-scores)

Variable	Mean Square	df	F	p
Tapping Test				
Right Hand	21.686	2	0.19	0.8289
error	144.531	21		
Left Hand	59.910	2	0.63	0.5432
error	95.349	21		
Strength of Grip				
Right Hand	177.670	2	1.91	0.1727
error	92.945	21		
Left Hand	371.878	2	5.00	0.0168
error	74.382	21		
Mazes (time)				
Right Hand	59.999	2	0.56	0.5774
error	106.401	21		
Left Hand	67.102	2	0.83	0.4491
error	80.671	21		
Pegboard (time)				
Right Hand	35.355	2	0.32	0.7286
error	110.007	21		
Left Hand	52.767	2	0.51	0.6066
error	103.060	21		

Appendix F (cont'd)

Variable	Mean Square	df	F	p
Tactual Performance Test				
Dominant Hand	40.363	2	0.38	0.6869
error	105.563	21		
Non-Dominant Hand	10.581	2	0.10	0.9078
error	108.919	21		
Both Hands	204.550	2	2.26	0.1291
error	90.497	21		
Tactile Perception				
Right Hand	20.947	2	0.20	0.8235
error	106.873	21		
Left Hand	11.970	2	0.11	0.8954
error	107.728	21		
Finger Agnosia				
Right Hand	6.019	2	0.05	0.9466
error	109.458	21		
Left Hand	9.098	2	0.08	0.9200
error	108.678	21		
Finger-Tip Number Writing				
Right Hand	176.707	2	1.91	0.1736
error	92.731	21		
Left Hand	102.833	2	1.03	0.3730
error	99.464	21		

Appendix F (cont'd)

Variable	Mean Square	df	F	p
Astereognosis				
Right Hand	323.036	2	4.12	0.0309
error	78.404	21		
Left Hand	396.780	2	5.52	0.0118
error	71.832	21		
Composite measure for Tactile-Perceptual Abilities				
Right Hand	156.209	2	1.65	0.2157
error	94.575	21		
Left Hand	152.960	2	1.61	0.2231
error	94.857	21		
MANOVA		40 2	4.68	0.1916

Note: The Hotelling-Lawley Trace was used for the MANOVA F test.

Appendix G

Summary of ANOVA and MANOVA Results for the Concept-Formation Measure (Sample T-scores)

Variable	Mean Square	df	F	p
Category Test				
Subtest 1	118.343	2	1.22	0.3161
error	97.210	21		
Subtest 2	115.420	2	1.17	0.3308
error	98.932	21		
Subtest 3	99.756	2	1.00	0.3849
error	99.813	21		
Subtest 4	383.826	2	5.27	0.0140
error	72.852	21		
Subtest 5	106.413	2	1.07	0.3606
error	99.354	21		
Subtest 6	288.952	2	3.51	0.0484
error	82.303	21		
Total	240.211	2	2.77	0.0853
error	86.607	21		
MANOVA		14 28	1.41	0.2108

Note: The Hotelling-Lawley Trace was used for the MANOVA F test.

Appendix H

Explanation for Abbreviations used on Figures

1. INFO - WISC Subtest - Information
2. COMP - WISC Subtest - Comprehension
3. SIMIL - WISC Subtest - Similarities
4. VOCAB - WISC Subtest - Vocabulary
5. DIGITS - WISC Subtest - Digit Span
6. ARITH - WISC Subtest - Arithmetic
7. PPVT - I.Q. obtained on the Peabody Picture Vocabulary Test
8. AST - Aphasia Screening Test
9. SSPER - Speech Sounds Perception Test
10. AUDCLO - Auditory Closure Test
11. SENMEM - Sentence Memory Test
12. PICCOM - WISC Subtest - Picture Completion
13. PICARR - WISC Subtest - Picture Arrangement
14. BLKDES - WISC Subtest - Block Design
15. OBJASS - WISC Subtest - Object Assembly
16. TARGET - Target Test
17. GRIPR - Strength of Grip with the Right Hand
18. GRIPL - Strength of Grip with the Left Hand
19. TAPR - Tapping Test - Right Hand
20. TAPL - Tapping Test - Left Hand
21. MAZERT - Mazes Test - Time measure for the Right Hand
22. MAZELT - Mazes Test - Time measure for the Left Hand
23. PEGSRT - Grooved Pegboard Test - Time measure for the Right Hand
24. PEGSLT - Grooved Pegboard Test - Time measure for the Left Hand
25. TACR - Right Hand measure for Tactile-Imperception
26. TACL - Left Hand measure for Tactile-Imperception
27. FAGNR - Finger Agnosia - Right Hand
28. FAGNL - Finger Agnosia - Left Hand
29. FTWR - Finger-Tip Number Writing (Dysgraphesthesia) - Right Hand
30. FTWL - Finger-Tip Number Writing (Dysgraphesthesia) - Left Hand
31. ASTR - Astereognosis - Right Hand
32. ASTL - Astereognosis - Left Hand
33. TPTDT - Tactual Performance Test - Time measure for the Dominant Hand
34. TPTNDT - Tactual Performance Test - Time measure for the Non-dominant Hand
35. TPTBT - Tactual Performance Test - Time measure for both Hands

Appendix H (cont'd)

36. PERCD - A composite score for Tactile-perceptual abilities for the Dominant Hand
37. PERCND - A composite score for Tactile-perceptual abilities for the Non-dominant Hand
38. CAT1 - Subtest 1 of the Halstead Category Test
39. CAT2 - Subtest 2 of the Halstead Category Test
40. CAT3 - Subtest 3 of the Halstead Category Test
41. CAT4 - Subtest 4 of the Halstead Category Test
42. CAT5 - Subtest 5 of the Halstead Category Test
43. CAT6 - Subtest 6 of the Halstead Category Test
44. CATTOT - Total number of errors on the Halstead Category Test

Numbers 1 to 16 appear on Figures 2, 5, 8, 9, and 10.
Numbers 17 to 35 appear on Figures 3, 6, 11, 12, and 13.
(Note: On Figures 11, 12, and 13 L and R are replaced with D [Dominant] and ND [Non-dominant], respectively)
Numbers 36 and 37 appear on Figures 11, 12, and 13.
Numbers 38 to 44 appear on Figures 4, 7, 14, and 15.

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VITA AUCTORIS

Joanna M. Hamilton (nee 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 with her Ontario Secondary School Honours Graduation Diploma. In September 1981 she enrolled at Trent University. She graduated with a Bachelor of Science (Honours) Degree in Psychology in May 1985. Since September 1986 she has been enrolled in the Doctoral programme in Clinical Neuropsychology at the University of Windsor. She completed her Master of Arts Degree in December of 1988.

Joanna married Stewart Hamilton in August of 1987.