The Relationship Between Lateralized Motor Impairment and Verbal/Visuospatial Deficits in Children with Suspected Brain Dysfunction

by

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ABSTRACT

In children with confirmed brain damage, neuropsychological research has established that evidence of lateralized (right or left hand) impairment on fine motor tests can be used to help infer dysfunction of the contralateral (opposite) cerebral hemisphere and its associated cognitive skills (e.g., verbal and visuospatial skills). In neuropsychological assessments of children with suspected brain dysfunction (such as learning disabilities and/or attention-deficit/hyperactivity disorder), fine motor tests are often used for much the same purpose. This constitutes an example of what is referred to in neuropsychology as the "Comparison of the Left and Right Sides of the Body" inferential method. However, its use for children with suspected brain dysfunction is not supported by the existing research literature. Furthermore, a recent series of studies on children with left hand motor impairment ("extreme right-handers") and no confirmed brain damage has produced results which are inconsistent with those that would be predicted based on traditional neuropsychological theory. It appears possible that previous studies found little relationship between lateralized motor impairment and distinctive cognitive deficits in children with suspected brain dysfunction largely due to the specific motor tests that they used (i.e., ones that rely more heavily on visuospatial/right hemisphere skills than verbal/left hemisphere skills). The Name Printing Test (Joschko & Bailey, 1996) was proposed to be a motor test that involves the skills of both cerebral hemispheres. It was therefore hypothesized to account for a significant amount of unique variance in performance on measures of both verbal and visuospatial cognitive skill, above and beyond that accounted for by the Grooved Pegboard and Finger Tapping Tests, in a sample of 77 right-handed children with suspected brain dysfunction. Left hand motor test scores were hypothesized to account for the greatest amount of variance in visuospatial cognitive skill, while right hand scores were hypothesized to account for the greatest amount of variance in verbal cognitive skill. The WISC-III Verbal Comprehension and Perceptual Organization factor scores were used as the measures of verbal and visuospatial cognitive skill, respectively. Hierarchical multiple regression was the primary method of analysis used to test the research hypotheses. The results provided little support for these hypotheses. Specifically, right and left hand motor test scores were found to be about equal in predicting verbal and visuospatial cognitive skills. Furthermore, only Grooved Pegboard scores accounted for a significant amount of unique variance in visuospatial cognitive skill, while no motor test score was a significant predictor of verbal cognitive ability. Little support was found for the use of the "Comparison of the Left and Right Sides of the Body" inferential method in this clinical group, and it was suggested that such methods of inference require more extensive validation. The Name Printing Test and Grooved Pegboard were found to be sensitive indicators of psychomotor impairment in children with suspected brain dysfunction, while the Finger Tapping Test was not.

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1. INTRODUCTION

1.1 Comparison of the left and right sides of the body as a neuropsychological method of inference

Neuropsychology is an inferential science in which well defined, quantifiable behaviours are used to make inferences about brain functioning. Several different methods of neuropsychological inference have been developed (Nussbaum & Bigler, 1989). One of the most well known is the "Comparison of the Left and Right Sides of the Body" method. This is one of four commonly-used methods of neuropsychological inference made popular by Ralph Reitan, and based primarily on research with adults with neurologically-confirmed brain lesions (Reitan, 1967; Reitan and Davison, 1974). Such research has established that impaired sensory or motor performance on one side of the body is typically associated with dysfunction in the contralateral (opposite) cerebral hemisphere, although each hemisphere also exerts a lesser degree of ipsilateral (same-sided) motor control (Reitan and Hom, 1982).

Since Reitan first popularized the "Comparison of the Left and Right Sides of the Body" method of inference, subsequent research has specified groups for which this inferential method may yield inconsistent results. According to Reitan (1994), these groups include: very young children, persons with chronic brain lesions and persons with brain lesions of certain etiologies (i.e., right cerebrovascular lesions tend to produce greater motor impairment than left cerebrovascular lesions, while this differentiation is not so apparent for neoplastic and traumatic lesions; Hom & Reitan, 1982). Despite these findings, there have been few efforts made to determine the validity of the various inferential methods for use in clinical groups other than those for which they were originally validated.

It seems possible that there has been little interest in conducting the necessary validation research for the "Comparison of the Left and Right Sides of the Body" inferential method due to the fact that sensorimotor testing often constitutes only one, small piece of data in a neuropsychological assessment, if used at all. This has created a situation whereby: "The clinical lore regarding the utility of left hand and right hand tactile and motor tests for differential diagnosis of lateralized brain damage in children is strong, although the empirical evidence supporting such conclusions is weak" (Francis, Fletcher & Rourke, 1988, p.780)[1]. However, it is still incumbent upon neuropsychologists to invest the necessary effort to establish the validity of all their procedures.

One clinical group for which there is presently little or no empirical data to support the use of the "Comparison of the Left and Right Sides of the Body" method of inference is children with suspected brain dysfunction. This group includes children who have been diagnosed with a condition such as a learning disability, attention-deficit/hyperactivity disorder, or neuropsychiatric disorder, for whom there is suspected neurological dysfunction, but no hard neurological evidence of such. Despite the lack of adequate validity data for this group, the literature often recommends the use of

[1]It should be noted that Francis et al. (1988) emphasized that the empirical evidence does not rule out the validity of combining left and right hand motor test scores with other types of neuropsychological test scores in order to make a "differential diagnosis of lateralized brain damage in children".

sensorimotor testing in neuropsychological assessments of such children (e.g., Fennell, 1995; Gaddes & Edgell, 1994; Hartlage & Williams, 1990).

There is a need for research that examines the validity of the "Comparison of the Left and Right Sides of the Body" inferential method for children with suspected brain dysfunction. Although there has been some such prior research (to be reviewed below), the number of studies is very small and their methods often seem crude by modern standards. This fact, combined with some recent work by genetic theorists suggesting that a large fine motor skill discrepancy between the two hands can be viewed as a developmental anomaly that is associated with cognitive dysfunction (Gangestad & Yeo, 1994; Markow, 1992a; Yeo & Gangestad, 1993), provides a good rationale for conducting further research in this area. It will therefore be the purpose of the present study to examine the relationship between lateralized motor impairment and performance on measures of verbal and visuospatial cognitive skill (thought to be the primary types of cognitive skill subserved by the left and right cerebral hemispheres, respectively, Kolb & Whishaw, 1990) in children with suspected brain dysfunction.

1.2 Research on fine motor skills in children with suspected brain dysfunction

A number of studies have provided strong evidence suggesting that children with confirmed brain damage tend to score significantly lower than normal children on tests of motor ability (e.g., Klonoff, Low & Clark, 1977; Nici & Reitan, 1986; Reed, Reitan & Klove, 1965; Reitan, 1971a; Reitan & Boll, 1973; Selz & Reitan, 1979). Mentally retarded children also show inferior performance to normal children on motor tests, and the extent of motor impairment is clearly related to the degree of intellectual deficiency (Rarick, 1980). There are, however, few studies that have attempted to determine whether children with suspected brain dysfunction score lower than normal children on motor tests.

Among the studies that have examined this issue, probably the first was conducted by Knights and Moule (1968). They administered Klove's (1963) Motor Steadiness Battery (including the Pencil Maze, Graduated Holes and Grooved Pegboard Tests) to 184 normal school children and 40 children with "school problems" and "suspected neurological dysfunction" who were being assessed for a study on Ritalin. The intent of the investigation was to collect norms for the Motor Steadiness Battery, but in the course of doing so, the researchers found that scores obtained on each of the motor tests significantly distinguished the normal children from the children with suspected brain dysfunction. Significant correlations were also found between several motor test scores and IQ scores, obtained from an unspecified intelligence test.

The next study of this kind was one conducted by Reitan and Boll (1973). They administered a large battery of neuropsychological tests to four groups of children: 25 normal control children, 25 children with confirmed brain damage, 25 children with minimal brain dysfunction (MBD) and learning difficulties and 19 children with MBD and behaviour problems (MBD was defined by impaired performance on neuropsychological tests). On nearly all tests, including the motor skills tests, the four group's scores ranked them in the same order, with the normal control group scoring the highest, followed by the MBD and behaviour problems group, then the MBD and learning problems group and, finally, the brain damaged group. However, the control group and the two MBD groups tended to score very closely and, for the most part, their differences were not statistically significant.

A somewhat similar study was one conducted by Tsushima and Towne (1977). They used a series of t-tests (with no error correction) to contrast the performance of 31 children who had learning problems but no history of illness or trauma that might lead to brain damage (the "normals"), to 31 children with "questionable brain disorders" who had a history of serious illness or trauma but no current neurological symptoms, on 37 neuropsychological test scores. Ten scores were found to significantly distinguish the two groups; five of which were derived from the three motor tests included in the battery (Grip Strength, Finger Tapping and Purdue Pegboard).

Most of the questionable brain disorder subjects in the Tsushima and Towne (1977) study were right handed (26/31), and it was the performance of their nondominant (primarily left) hand that most clearly distinguished them from the normal children on the motor tests. Since four of the ten test scores that significantly discriminated the two groups were the WISC PIQ, Picture Completion, Block Design and Object Assembly scores, a pattern of relatively poor left hand skill combined with deficient performance on measures of visuospatial ability was evident. This pattern can be seen as providing some incidental evidence for the association of lateralized motor test performance to specific cognitive deficits (at least visuospatial deficits).

In yet another study, Brunt, Magill and Eason (1983) administered an alternating tapping task to 30 normal and 30 "learning disabled" 8- and 10-year old boys ("learning disabled" was undefined). They found that the normal boys performed significantly better on the tapping task than did the learning disabled boys. Finally, Gaddes and Edgell (1994) reexamined the sensorimotor performance of 154 8- to 15-year old children classified as "learning disabled with no clear neurological signs" who were assessed at the University of Victoria Neuropsychology Laboratory on three motor tests (Grip Strength, Finger Tapping and Visual-Manual Reaction Time). They found that anywhere from 38.5% to 65.5% of these children performed at least one standard deviation below age norms on the motor tests, with one or both hands. They concluded that "inferiority in a sensory, and/or a motor, and/or a sensorimotor integration task is a sensitive indicator of CNS dysfunction and a reliable correlate of learning disorders" (p. 197).

One dissenting piece of evidence was provided by Selz and Reitan (1979). They administered a battery of neuropsychological tests to three groups of 25 children: one normal control group, one group with verified brain damage and a third group with learning disabilities but no neurological soft signs or history of relevant health problems. They were attempting to determine whether the tests could discriminate between the three groups. Of the 13 scores derived from the tests, only two could successfully distinguish all three groups: the WISC Performance IQ (PIQ) and Full Scale IQ (FSIQ) scores. On the only motor test included in the battery (Finger Tapping), the performance of the learning disabled children was significantly better than that of the brain damaged children, but they did not significantly differ from the normal controls.

1.3 Research on the relationship between lateralized motor impairment and cognitive deficits in children with suspected brain dysfunction

Although there have been a few studies that have attempted to determine whether motor skills impairment is common in children with suspected brain disorders, there have been fewer that sought to ascertain whether right and left hand impairment on such tests is associated with specific cognitive deficits. Likely the first such study was one conducted by Rourke and Telegdy (1971). Their sample consisted of 45 9- to 14-year old children who were referred for neuropsychological assessment due to suspected "learning" and/or "perceptual" problems. The sample was divided into three groups of 15 based on their WISC VIQ and PIQ scores: Group 1 subjects had PIQs that were at least 10 points higher than their VIQs, Group 2 subjects had VIQs that were at least 10 points higher than their PIQs, while Group 3 subjects had VIQs and PIQs that were within 4 points of each other.

Rourke and Telegdy attempted to determine whether their three subject groups could be discriminated based on their left and right hand scores on seven motor tests often used with the Halstead-Reitan batteries: the Hand Dynamometer, the Maze Test, the Graduated Holes Test, the Grooved Pegboard, the Finger Tapping Test, the Foot Tapping Test and the Tactual Performance Test. Using a series of individual comparisons (with no error correction) they found that the group with the low PIQs scored below the low VIQ group on 22 out of 25 motor test scores. The low VIQ group did not score significantly lower than the low PIQ group on <u>any</u> of the 25 scores. Most relevant to the present study, however, was the fact that there was no relationship found between group membership and right versus left hand motor performance. The main conclusion that the authors derived from these results was that an intact right hemisphere is more important than an intact left hemisphere for performing visuomotor tasks, whether performance is with the right or the left hand.

Rourke, Yanni, MacDonald and Young (1973) used almost the exact opposite approach to investigate the relationship between cognitive and lateralized motor impairments. Their sample consisted of 46 right-handed 10- to 14-year olds who had also been referred for neuropsychological assessment due to a suspected learning or perceptual problem. They divided the sample into four groups depending on whether they showed impaired performance on the Grooved Pegboard with one, both, or neither of their hands. Impaired performance was defined as scoring at least one standard deviation below the mean with that hand, based on appropriate age norms. The four groups consisted of children with: 1. normal right- and left-hand performance (n=17), 2. normal right- and impaired left-hand performance (n=10), 3. normal left- and impaired right-hand performance (n=9), and 4. impaired performance with both hands (n=10). Use of a normal control group was considered unnecessary due to the availability of normative data for all tests used.

The authors used a series of one- and two-way analyses of variance to compare the performance of the four groups on a battery of 14 neuropsychological tests (with no error correction). They found that the group with unilateral right hand impairment scored below the group with unilateral left hand impairment on seven out of eight verbal and auditory-perceptual tests, including the WISC VIQ, although only four of these differences were statistically significant (Speech Sounds Perception Test, Aphasia Screening Test, WRAT Reading & WRAT Spelling). Conversely, the left hand impairment group scored below the right hand impairment group on very few of the visual-perceptual tests and none of the differences were statistically significant.

The were no statistically significant differences between the bilateral and no motor impairment groups on any of the tests. The only performance pattern evident for either of these groups was that, in many cases, their test scores fell in between those obtained by the two unilaterally impaired groups. Despite a seeming lack of support for this assertion in their data, the authors concluded that the results of their study closely matched those of previous studies that had revealed a relationship between lateralized brain dysfunction and right versus left hand motor impairment in adults with confirmed brain damage.

The most recent study that has attempted to explicate the meaning of lateralized motor impairment in children with suspected brain dysfunction was one conducted by Francis, Fletcher and Rourke (1988). Their intention was to determine whether the left and right hand sensorimotor test scores derived from the Halstead-Reitan Neuropsychological Battery for Children actually possess discriminant validity. That is, they wanted to ascertain if the left and right hand sensorimotor test scores really measure separate constructs.

In order to evaluate this question, Francis et al. used a sample of 888 right-handed 9- to 14-year old children. All had been referred for neuropsychological assessment, primarily due to suspected learning disabilities. None showed frank evidence of neurological disorder. The total sample was split into an analysis (n=488) and a cross-validation (n=400) sample, and confirmatory factor analyses were conducted using their left and right hand scores on a set of eight sensorimotor tests. The results provided no indication that left and right hand sensorimotor tests possess discriminant validity in a sample such as this, as the left and right hand measures were not found to load on separate factors. Instead, the best-fitting factor model was one that distinguished between simple and complex motor (and tactile) tests (i.e., Finger Tapping and Grip Strength as one factor; Grooved Pegboard and the Maze Test as another).

1.4 Simple versus complex motor tests

One potential reason why previous studies have been unable to find distinct cognitive deficits associated with right versus left hand motor impairment in children with suspected brain dysfunction relates to the specific motor tests that they have used. It is known that persons with obvious brain dysfunction are more likely than persons with only mild or suspected brain dysfunction to show impairment on tests of simple motor functions (O'Donnell, 1983; Reitan & Boll, 1973; Rourke & Telegdy, 1971; Sarazin & Spreen, 1986; Selz & Reitan, 1979; e.g., grip strength, finger tapping, motor steadiness). Persons with mild or suspected brain damage are likely to show a more selective impairment on complex motor tests (Bishop, 1990; Francis, Fletcher & Rourke, 1988; Rourke & Strang, 1978; Rourke & Telegdy, 1971; i.e., those that require the use of additional cognitive skills for successful performance).

In previous studies, the complex motor tasks that have typically been used are ones that appear to primarily involve visuospatial skills, in addition to basic motor proficiency (as seems to be the case for most complex motor tests). The most common examples are the Grooved Pegboard, the Purdue Pegboard and the Mazes test from the Motor Steadiness Battery. Due to the apparent visuospatial demands of these tests, their completion would seem to primarily require input from the right hemisphere, whether performed with the right or the left hand (Hom & Reitan, 1982; Rourke, Bakker, Fisk & Strang, 1983; Rourke & Telegdy, 1971). This is likely why Rourke (1995) has found that one of the primary characteristics of children with nonverbal learning disabilities (thought to be based on right hemisphere dysfunction) is bilateral impairment on complex motor tasks. It could also explain why Francis et al. (1988) discovered that left and right hand motor test scores did not load on separate factors. The optimal complex motor test for making inferences about brain functioning, then, would be one that equally involves the cognitive skills of both cerebral hemispheres.

A complex motor test that appears to involve skills traditionally thought to be subserved by both the left and right cerebral hemispheres is the Name Printing Test (Joschko & Bailey, 1996), which is a modified and renormed version of the Name Writing Test from the Reitan-Klove Lateral Dominance Examination (Reitan & Davison, 1974). Administration of the Name Printing Test requires subjects to print both their first and last names using their dominant hand, then their nondominant hand. Children age eight and under may print only their first name. Completion time is recorded and divided by the number of letters in the subject's name. In the original

Name Writing Test, no consideration was given to differences in name length, as the subject's score was simply the amount of time taken to write his/her first and last names. The rationale for viewing the Name Printing Test as a motor test involving cognitive functions controlled by both cerebral hemispheres derives from the fact that printing is a motor skill that is known to require both visuospatial (right hemisphere) and linguistic (left hemisphere) components (Roeltgen, 1985; Sandler et al., 1992; Spreen, Risser & Edgell, 1995).

1.5 The relationship of "extreme right handedness" to cognitive impairment

A different source of evidence regarding the cognitive correlates of lateralized motor impairment can be found in the work of the British psychologist, Marian Annett. Her research has focused on the cognitive correlates of various handedness subtypes, with "extreme right handedness" being the subtype that she has devoted the most attention to. Extreme right handedness refers to a handedness category composed of people whose right hand skill is clearly superior to their left hand skill (usually determined by the use of a timed peg moving task).

Over the course of Annett's studies, it has become apparent that extreme right-handers do not gain membership in this group due to outstanding right hand skill (their right hand performance is often within the average range), but to left hand impairment. Consequently, Annett appears to be the researcher who has single-handedly accumulated the largest collection of data on the cognitive correlates of left hand motor impairment. Interestingly, the cognitive deficits that she has identified as being associated with left hand impairment are inconsistent with those that would be predicted based on traditional neuropsychological theory.

Some of Annett's earlier work in this area (Annett & Kilshaw, 1984; Annett & Manning, 1990a) actually found extreme right handedness to be associated with impairment in skills typically associated with left hemisphere functioning (i.e., reading, spelling, auditory comprehension). More recently, however, she has put greater emphasis on evidence suggesting that extreme right handedness (due to left hand impairment) is associated with global intellectual impairment (Annett, 1991; Annett & Manning, 1989; Annett & Manning, 1990b). For example, Annett and Manning (1989) administered a number of cognitive and academic skills tests, including Raven's Progressive Matrices, to a normal sample of 169 male and 173 female schoolchildren (age range = 5-11 years). They identified a significant trend for those with the most extreme right hand skill, as measured by a timed peg moving task, to score the lowest on the (Raven's) IQ test.

In a subsequent study, Annett and Manning (1990a) administered Raven's Progressive Matrices and a reading test to a sample of 313 children, aged 6 to 11. They discovered that the poorest readers could be found in both extremes (left and right) of the hand skill distribution. However, the reading weakness manifested by children in the left and extreme right handed groups was based on differing etiologies. Specifically, the left handed poor readers appeared to have a specific reading disability. Conversely, the extremely right handed poor readers manifested their reading impairment as a concomitant of lower overall IQ scores. In both studies, extreme right hand skill was found to be the result of left hand deficiency.

Annett's genetic theory of hand dominance stipulates that it is significant underdevelopment of the right hemisphere that underlies extreme right handedness (Annett, 1985). Accumulating evidence of poor IQ test performance among extremely right handed children has led her to speculate that such right hemisphere underdevelopment leads not only to a deficiency in skills typically thought to be subserved by the right hemisphere, but also to general cognitive/intellectual impairment as a result of lower overall "brain power" (Annett, 1991; Annett & Manning, 1989; Annett & Manning, 1990a). However, this conclusion is inconsistent with traditional neuropsychological theory, which would predict left hand motor impairment to be associated more specifically with a visuospatial (right hemisphere) skills deficiency.

1.6 Summary and purpose

In summary, the use of motor tests has been found to be a valid method for distinguishing children with known brain damage from children with no or suspected brain dysfunction, with the known brain damage group tending to show the greatest motor impairment. Evidence of lateralized impairment on motor tests has also been found to be a valid marker of lateralized hemispheric dysfunction in children with known brain damage. However, in children with suspected brain dysfunction, there is little or no evidence that motor tests can be used to predict deficits in the primary cognitive skills thought to be subserved by the left and right cerebral hemispheres, despite the fact that such tests are commonly used for similar purposes (i.e., for inferring lateralized brain dysfunction; Francis, Fletcher & Rourke, 1988). Furthermore, there is recent evidence that disputes traditional neuropsychological beliefs about the types of cognitive dysfunction that can be predicted based on lateralized motor impairment (Annett, 1991; Annett & Manning, 1989; Annett & Manning, 1990a). It is suggested that the meaning of lateralized motor impairment in children with suspected brain dysfunction requires reexamination, especially since the original studies of this topic were conducted in the early 1970's, with little else since. The purpose of the present study was to conduct a portion of this reexamination. It was believed that, with the use of more sophisticated methods of analysis and a more appropriate means of assessing fine motor impairment, this study would contribute to the empirical knowledge base, and help alleviate some of the present confusion, regarding the relationship of fine motor impairment to cognitive deficits in children with suspected brain dysfunction.

1.7 Hypotheses

Three research hypotheses were devised for this study of children with suspected brain dysfunction:

1. Left hand scores from three motor tests will be better predictors than right hand scores of performance on a measure of visuospatial cognitive skill.
2. Right hand scores from three motor tests will be better predictors than left hand scores of performance on a measure of verbal cognitive skill
3. Scores from the Name Printing Test will account for a significant proportion

of unique variance in measures of both verbal and visuospatial cognitive skill, even after the variance accounted for by another complex motor test, the Grooved Pegboard, and a simple motor test, the Finger Tapping Test, has been partialled out.

2. METHOD

2.1 Subjects

The study sample was comprised of 77 right-handed, 6- to 16-year old children with suspected brain dysfunction. All were referred for neuropsychological assessment to the Neuropsychology Service of Queen Alexandra Centre for Children's Health (QACCH) in Victoria, British Columbia. None had been assessed as exhibiting 'hard' neurological signs (i.e., symptoms or medical test results invariably indicative of brain dysfunction). The research data was obtained retrospectively from a data bank at QACCH that contains several years worth of neuropsychological assessment data. The neuropsychological testing was conducted by a staff neuropsychologist, or by a neuropsychology graduate student supervised by a staff neuropsychologist. Consent had previously been obtained from each child's guardian(s) to use his/her data for scientific research (see Appendix A). The 'cons' of using archival data such as this is are that it is impossible to control the conditions under which the data is collected, there is a need to rely on the written reports of unknown examiners to judge the validity and accuracy of the data, and it is rarely possible to select subjects randomly, as they must be chosen according to whether their files contain all the relevant data for analysis. Conversely, the 'pros' of using archival data are that, since the data is collected from clinical files, it is likely that considerable care was used in ensuring that the assessment data was accurate and valid (as it is often used to make important clinical decisions), and that there is no possibility of expectancy effects influencing the data (the study hypotheses would be unknown to both examiners and subjects).

Descriptive statistics for the study sample are presented in Table 1. Their primary diagnoses (medical or psychological) were: learning disability (29), learning disability and attention-deficit/hyperactivity disorder (18), attention-deficit/hyperactivity disorder (11), neuropsychiatric disorder (10), Tourette syndrome (5), developmental skills disorder (3), borderline I.Q. (1). All subjects had received a prior medical (usually neurological) assessment, and if this did not establish their diagnosis, it was determined via the neuropsychological assessment.

At the time of assessment, six subjects were on a CNS stimulant medication (Ritalin), five were on an antipsychotic (Loxapine, Haldol, Mellaril, Chlorpromazine or Respiridol), four were on an antidepressant (Desipramine, Prozac or Clomipramine), one was on a sympathomimetic (Dexedrine), three were taking a combination of two of these medications, while the medication status of four subjects was unknown. Thus, at least 25% of the sample was taking a psychotropic medication at the time of assessment. Although each of these medications may have either a direct or indirect influence on motor functioning, and thereby lead to an overall improvement or decrement of motor test performance, there is no information to suggest that they should exert a differential influence on right versus left hand motor skill (Canadian Pharmaceutical Association, 1996). Therefore, it was thought to be unlikely that medication effects would alter the nature of the relationship between lateralized motor impairment and cognitive deficits, which was the subject of focus for this study.

Table 1 - Sample Demographics

Variable	Mean	sd	Range
Age (years)	11.05	2.36	6.61 - 16.57
Education (grade)	4.99	2.05	1 - 10
Verbal IQ	93.15	13.43	62 - 129
Performance IQ	93.67	14.61	63 - 132
Full Scale IQ	92.57	13.07	59 - 124
n = 77	Male = 61 (79%)		Female = 16 (21%)

Furthermore, the "Comparison of the Left and Right Sides of the Body" inferential method has been described as being highly resistant to the influences of extraneous variables (Selz, 1981).

Three criteria were used to identify subjects as right-handed: 1. a demonstrated preference for using the right hand to perform at least 4 out of 7 actions on the Reitan-Klove Lateral Dominance Examination (Reitan & Davison, 1974); 2. faster name printing speed with the right hand than with the left hand; and 3. faster completion of the Grooved Pegboard with the right hand than with the left hand. Hand proficiency measures were used along with a hand preference inventory to determine hand dominance, as it has been suggested by several researchers that it is important to use both types of measure for this purpose (Annett, 1985; Bishop, 1990; Peters & Servos, 1989; Strauss & Wada, 1988). Only right-handed subjects were used in the study, because the research literature suggests that their brains may be more strongly lateralized than those of left-handers (Kim et al., 1993; Reynolds, Hartlage & Haak, 1981; Steinmetz, Volkmann, Jancke & Freund, 1991).

2.2 Measures

The Finger Tapping Test - This test was originally part of Halstead's (1947) neuropsychological test battery and was formerly known as the Finger Oscillation Test. It is included in both the Reitan-Indiana Neuropsychological Test Battery for Children (for ages 5-8) and the Halstead-Reitan Neuropsychological Test Battery for Children (ages 9-14). It requires the subject to repeatedly tap a metal key, similar to a telegraph key, as quickly as possible with his/her index finger. The subject taps first with the preferred hand, then with the nonpreferred hand. As administered at QACCH, the score for each hand is calculated as the mean of the best three of four 10 second tapping trials, where the scores on all three trials are within five points of each other. The subject is allowed a maximum of 10 trials in order to obtain three trials within five points.

Numerous studies have been conducted to establish the reliability and validity of the Finger Tapping Test. Spreen and Strauss (1991) have described Finger Tapping performance with either hand as being "quite stable over time, even with lengthy intervals between retest sessions (e.g., two years)" (p.363). They report that reliability coefficients have been found to range from .58 to .93, with both normal and neurologically-impaired subjects.

Evidence of the criterion validity of the Finger Tapping Test has been demonstrated in several studies involving children. These have included investigations that have found it to distinguish normal children from children with confirmed brain damage (Nici & Reitan, 1986; Reitan, 1971a; Reitan & Boll, 1973; Selz & Reitan, 1979), as well as studies that have successfully used it to discriminate children with confirmed versus suspected brain damage (Reitan & Boll, 1973; Selz & Reitan, 1979; Tsushima & Towne, 1977).

Concerning children with learning disabilities, Gaddes and Edgell (1994) reported that 63% of learning disabled children tested in the University of Victoria Neuropsychology Laboratory scored at least one standard deviation below their age mean with their dominant hand on the Finger Tapping Test (none with their nondominant hand). Rourke and Telegdy (1971) found that learning disabled children whose WISC Performance IQs (PIQs) were superior to their Verbal IQs (VIQs) scored significantly better with their left hand on the Finger Tapping Test than did learning disabled children with roughly equal VIQs and PIQs. They also determined that learning disabled children whose VIQs were superior to their PIQs scored significantly better with their right hand on the Finger Tapping Test than did learning disabled children with approximately equal VIQs and PIQs. However, Rourke and Strang (1978) found that the Finger Tapping Test could not be used to distinguish among children with different types of learning disability.

The construct validity of the Finger Tapping Test has been examined in several studies that have included it in factor analyses of neuropsychological test batteries. It has rarely, if ever, been found to load on factors shared with more complex motor tests (e.g., Grooved Pegboard, Purdue Pegboard). Two studies have found it to load most heavily on a factor composed solely of its own left and right hand scores (Ardila, Roselli & Bateman, 1994; Crockett, Klonoff & Bjerring, 1969). Several more have discovered it to load on a factor with one or two other simple motor tests, such as the Hand Dynamometer (Fowler, Richards, Berent & Boll, 1987; Francis, Fletcher & Rourke, 1988; Francis, Fletcher, Rourke & York, 1992; Moehle, Rasmussen & Fitzhugh-Bell, 1990) or the Foot Tapping Test (Klonoff, 1971). Additionally, as Spreen and Strauss (1991) have noted, numerous studies have shown the Finger Tapping Test to be sensitive to both the presence and laterality of brain lesions, and performance is typically worse with the hand contralateral to a lesion.

The Grooved Pegboard - This test was originally part of the Klove-Matthews (or Wisconsin) Motor Steadiness Battery and is included in both the Reitan-Indiana Neuropsychological Test Battery for Children (ages 5-8) and the Halstead-Reitan Neuropsychological Test Battery for Children (ages 9-14). It is designed as a 5" x 5" board with a metal face that contains 5 rows of 5 key-shaped holes. The object of the test is to have the subject fill each hole with a small metal peg as fast as possible, using one hand at a time. The pegs are rounded on one side and have a long metal 'tooth' on the other side, similar to a skeleton key. The pegs are made to match the shape of the holes, but because the slot on the side of each hole is rotated to a different orientation, it is necessary for the subject to rotate the pegs to fit the holes.

Children aged 9-15 are scored according to the time it takes them to fill all 25 holes, first with their dominant hand, then with their nondominant hand. Children aged 5-8 are only required to fill the top two rows of holes (10 pegs), which means that it is necessary to convert each child's raw score to a standard score in order to compare across age groups. For both age groups, timing continues if a peg is dropped.

In a study of children's performance on the Grooved Pegboard, Knights and Moule (1968) reported six-week test-retest reliability coefficients of .80 (dominant hand) and .81 (nondominant hand) for the test. In adult samples, Kelland and Lewis (1994) obtained a one-week test-retest reliability coefficient of .82 (hand unspecified), while Barnsley and Rabinovitch (1970) reported a preferred hand test-retest reliability coefficient of .78 (time interval unspecified). From these reports, it would appear that the Grooved Pegboard has very consistent test-retest reliability, regardless of the subject's age or the hand used for performance.

A number of studies have provided evidence of the Grooved Pegboard's criterion validity. For example, in a five year follow-up study of 100 head-injured children, Klonoff, Low and Clark (1977) found that the Grooved Pegboard could be used to successfully distinguish head-injured from age-and sex-matched control children. Knights and Moule (1968) determined that the test discriminated normal school children from a sample of children with "school problems" and "suspected neurological dysfunction". Rourke and Telegdy (1971) discovered that it was the best of a group of seven psychomotor tests at discriminating among three groups of learning disabled children with different patterns of Verbal and Performance IQ scores. Additionally, Rourke et al. (1973) found that when it was used to place learning disabled children into lateralized motor impairment groups, that the groups exhibited unique and theoretically predictable patterns of Verbal and Performance IQ scores. Finally, Rourke and Strang (1978) determined that the test could be used to distinguish among children with different types of learning disability, while the Finger Tapping and Hand Dynamometer tests could not.

Evidence for the construct validity of the Grooved Pegboard has been established by a number of studies that have included it in factor analyses with other neuropsychological tests. It has commonly been found to load most strongly on factors shared with other complex motor tests, and some more purely cognitive tests. For example, Francis, Fletcher and Rourke (1988) found it to load most highly on a factor shared with the Mazes test from the Motor Steadiness Battery, while Lewis, Kelland and Kupke (1989) determined that its strongest loading was on a factor with the WAIS Digit Symbol subtest, Trails B and a Sentence Writing task. Francis, Fletcher, Rourke and York (1992) discovered that it loaded most strongly on a factor with the WISC Object Assembly, Block Design and Picture Completion subtests, as well as the Tactual Performance test. Conversely, both Klonoff (1971) and Moehle, Rasmussen and Fitzhugh-Bell (1990) found its strongest loading to be on a factor composed solely of its own right and left hand scores.

Another pegboard test that is likely at least as popular as the Grooved Pegboard for use in neuropsychological assessments is the Purdue Pegboard (Tiffin & Asher, 1948). Unfortunately, no research could be found that directly examines the differences and similarities between these two tests. Therefore, it was the greater amount of research suggesting that the Grooved Pegboard contains a notable cognitive (probably visuospatial) component, that led to it being considered as the superior choice for one of the two complex motor tests in the present study.

The Name Printing Test - As explained above, the Name Printing Test (Joschko & Bailey, 1996) is a revised version of the original Name Writing Test (Reitan & Davison, 1974). Revisions include the requirement that subjects print their first and last names rather than writing them, and that completion time is now divided by the number of letters printed. Also, yearly age norms have recently been collected for ages 6-17, in order to evaluate the level of performance with each hand and to convert raw scores to standard scores (see Appendix B). The normative data was obtained from a total of 350 children who volunteered from over 20 schools in the Greater Victoria School District, in British Columbia, Canada.

The Name Printing Test is different from other motor tests in that it involves a skill that is strongly practiced with one hand. Nevertheless, this is a condition that is equal for all subjects and would only be considered a problem if the two hands were compared to each other in order to make a judgement of impairment. Instead, this decision is made by separately comparing each hand to the norms for that hand.

In a large factor analysis of motor skills tests, Barnsley and Rabinovitch (1970) found a name printing task (performed with the preferred hand only) to load most heavily on a motor skills factor that they called Wrist-Finger Speed. They also found it to have high test-retest reliability (r=.98; time interval unspecified). Provins and Cunliffe (1972) found a similar task (alphabet writing) to have high test-retest reliability with the nonpreferred hand (r=.94), but a lower value with the preferred hand (r=.59). Kelland and Lewis (1994) used another similar task, Sentence Writing, and obtained a one-week test-retest reliability value of .93 for the dominant hand (the nondominant hand was not tested). Dodrill and Thoreson (1993) found the Name Writing Test to have 100% 5-year, test-retest reliability when used to determine hand dominance for normal controls and subjects with epilepsy.

Regarding the validity of the Name Printing Test, Eaves, Kendall and Crichton (1972) were successful in using a different name printing task to distinguish normal children from children with suspected brain dysfunction, while Reitan (1971a) found that the original Name Writing Test could be used to discriminate brain damaged from normal control children. Klesges, Fisher, Pheley, Boschee and Vasey (1983) administered the WAIS-R, the Wechsler Memory Scale and the complete Halstead-Reitan Neuropsychological Battery (including the Name Writing Test) to 141 brain damaged subjects and 83 normal controls (all adults). They found that the Name Writing Test was the fifth best test at discriminating the presence versus absence of brain damage, the second best at distinguishing localized versus diffuse brain damage, and the best at discriminating right versus left versus diffuse versus no brain damage.

In a sample of 225 normal 15 to 40-year olds, Yeudall, Reddon, Gill and Stefanyk (1987) found nonpreferred hand name writing speed, but not preferred hand name writing speed, to be significantly correlated with WAIS-R PIQ scores. Since the nonpreferred hand for 86% of the sample was their left hand, it can be stated that this finding implicates a specific association between left hand name writing speed and PIQ scores. No association was found between name writing speed (with either hand) and WAIS-R VIQ scores. Nevertheless, Maxwell and Wise (1984) did find preferred hand name writing speed, but not nonpreferred hand name writing speed, to be significantly correlated with performance on the Peabody Picture-Vocabulary Test (PPVT), in a sample of 84 adults with various neurological and psychiatric disorders. Although the frequency of right versus left hand preference in this sample was not reported, this finding most likely suggests a specific relationship between right hand name writing speed and vocabulary skill (as the majority of the population is right hand dominant).

Therefore, although there is evidence indicating that the Name Printing Test might be used as a predictor of verbal/visuospatial skills deficits in adults, as well as to distinguish children with suspected brain dysfunction from normal children (i.e., Eaves et al., 1972), no previous study has examined its relationship to scores on tests of verbal/visuospatial skills in children with suspected brain dysfunction. Furthermore, although previous name printing tasks have been used by other researchers (i.e., Barnsley & Rabinovitch, 1970; Eaves et al., 1972), none is exactly the same as the Name Printing Test used in the present study. For instance, Barnsley and Rabinovitch (1970) used the same scoring system (time to print first and last names divided by number of letters), but only assessed the preferred hand. Eaves et al. (1972) had children print their names so that they could rate them on a 5-point scale according to their spelling accuracy and pencil control. Finally, Yeudall et al. (1987) used the same scoring system as that used for the Name Printing Test, but had their adolescent and adult subjects write their names instead of printing them. No other researchers are believed to have collected norms for a name printing task.

WISC-III Verbal Comprehension and Perceptual Organization Factors - The measure used to assess cognitive ability was the Wechsler Intelligence Scale for Children, 3rd edition (WISC-III; Wechsler, 1991). The score from the WISC-III Verbal Comprehension Index was used as the measure of verbal cognitive ability, while the WISC-III Perceptual Organization Index score was used to assess visuospatial cognitive skill. Next to tests of lateral sensory and motor functioning, measures requiring the processing of either verbal or visuospatial materials are the most commonly used neuropsychological tests for inferring lateralized brain dysfunction (Ross, Thrasher & Long, 1990).

The Verbal Comprehension and Perceptual Organization factors represent the two strongest factors found in repeated factor analyses of the WISC-R and WISC-III (Wechsler, 1991). These factors include the majority of the subtests comprising the WISC-III Verbal and Performance scales, eliminating the subtests found to have the weakest correlation with these scales (i.e., Arithmetic, Coding and Digit Span). These factors were found to be clearly identifiable across each of the 11 age groups (n=2,200; ages 6-16) included in the WISC-III standardization sample (Wechsler, 1991). They have also been consistently identified in factor analyses of WISC-R and WISC-III data obtained from diverse groups of children, such as in a recent examination of WISC-III data obtained from a sample of 167 6- to 16-year old children with "learning disabilities, reading disorders, or attention-deficit disorders" (Wechsler, 1991, p. 196), which is very similar to the sample used in the present study.

The Verbal Comprehension and Perceptual Organization factors have high reliability (Wechsler, 1991). The Verbal Comprehension factor was found to have an average split-half reliability over the 11 age groups used in the WISC-III standardization sample (n=2,200) of .94, while the Perceptual Organization factor obtained a value of .90. Regarding test-retest reliability, the average value for the Verbal Comprehension factor across three age groups (n=353), tested and retested a median of 23 days apart, was .93, while the value for the Perceptual Organization factor was .87. Parsons and Prigitano (1978) have stated that it is important to use tests that are equivalent in both reliability and item difficulty in order to investigate lateralized brain dysfunction, and added that measures derived from the Wechsler

Intelligence scales seem to fulfil these criteria especially well.

The Verbal Comprehension and Perceptual Organization factors also appear to be highly similar, if not identical, to the two or three strongest factors that have been consistently identified in factor analyses of neuropsychological test batteries. For example, Fowler, Richards, Berent and Boll (1987) administered the Wechsler Adult Intelligence Scale (WAIS) and a modified Halstead-Reitan Neuropsychological Battery (HRNB) to 108 adults with epilepsy. They factor analyzed the 45 subtest scores and arrived at a five-factor solution. The first and third strongest factors were labelled "Verbal Comprehension" and "Perceptual Organization", respectively, and included all of the WAIS subtests normally found to load on these factors, as well as several HRNB subtests considered to measure similar functions. To support the validity of these factors in detecting lateralized epileptic foci (identified by EEGs), subjects with a left hemisphere focus were found to score significantly lower than the three other groups (right, bilateral or generalized foci) on the Verbal Comprehension factor, while subjects with a right hemisphere focus scored significantly lower than the three other groups (left, bilateral or generalized foci) on the Perceptual Organization factor.

Moehle, Rasmussen and Fitzhugh-Bell (1990) factor analyzed the HRNB and WAIS scores obtained by a much larger sample of adults with "confirmed or suspected cerebral dysfunctions" (n=1376). They compared the results obtained from solutions using two to seven factors. Their first factor ("Factor A") consistently contained all of the WAIS Verbal Comprehension subtests, while the second factor ("Factor B") consistently contained all of the WAIS Perceptual Organization subtests, excluding

Picture Completion. Factor A accounted for 16.4% of the total subtest variance, while Factor B accounted for 14.8% of the total variance. Each of these factors also contained several HRNB tests that are considered to measure functions similar to those assessed by the Verbal Comprehension and Perceptual Organization subtests.

Swiercinsky and Howard (1982) performed yet another factor analysis of the WAIS and HRNB subtest scores obtained from a sample of 658 adults with various medical, neurological and psychiatric conditions. They labelled their first factor, which contained all of the WAIS Perceptual Organization subtests and several HRNB subtests believed to measure similar functions, "Spatial Reasoning". It accounted for 19% of the total subtest variance. The second factor, which included all of the WAIS Verbal Comprehension subtests and several HRNB subtests considered to measure similar functions, was named "Verbal Reasoning". It accounted for 14% of the total variance. They concluded that "These two factors emerge as the most consistently defined factors in most neuropsychological analyses reported" and, "These factors also most clearly represent what most neuropsychologists consider right hemisphere functions (Spatial Reasoning factor) and left hemisphere functions (Verbal Reasoning factor)" (p. 150).

Several similar factor analysis studies have been conducted with samples of children. In one of the earliest, Crockett, Klonoff and Bjerring (1969) factor analyzed the subtest scores obtained by 240 "normal" 5- to 8-year old children on both the Wechsler Intelligence Scale for Children (WISC) and a children's version of the HRNB. Block Design and Object Assembly were the WISC subtests that loaded most strongly on Factor I, which the authors noted was similar to the Perceptual Organization factor. The WISC Picture Arrangement (.379) and Picture Completion (.308) subtests had loadings that fell just below the .400 value that was needed to consider a subtest as loading on that factor. This factor accounted for 15.5% of the total variance. Vocabulary, Similarities and Information were the WISC subtests that loaded most highly on Factor III, which accounted for 6.9% of the total variance and was described by the authors as being similar to the Verbal Comprehension factor. The Comprehension subtest obtained a .353 loading on this factor.

Klonoff (1971) conducted another factor analysis of WISC and HRNB data obtained from 200 "normal" 9- to 15-year old children. He obtained one factor ("Verbal Fluency") on which the four WISC Verbal Comprehension subtests obtained loadings greater than .400 (accounting for 8.5 of the total variance) but, surprisingly, no factor on which the usual WISC Perceptual Organization subtests obtained loadings above this value. Sutter, Bishop and Battin (1986) factor analyzed WISC-R and achievement test data collected from 360 7- to 10-year olds who had been referred for psychological assessment due to language, learning or behavioural problems. Of the five factors with eigenvalues greater than one, they labelled the first (accounting for 14.97% of the variance) "Language". Its strongest loadings came from the WISC-R Verbal Comprehension subtests, as well as from most of the "auditory" subtests from the Illinois Test of Psycholinguistic Abilities. The factor accounting for the third most total variance (9.92%) was labelled "Visual Spatial". Its highest loadings came from the WISC-R Block Design and Object Assembly subtests, as well as the Bender

Gestalt, Raven's Progressive Matrices and Draw-A-Person tests.

D'Amato, Gray and Dean (1988) performed a factor analysis on the WISC-R and HRNB subtest scores obtained from 1,181 children with learning disabilities. The factor with the highest eigenvalue (4.83) was labelled "Verbal Achievement" and had the WISC-R Verbal Comprehension subtests as its highest loadings. The factor with the third highest eigenvalue (1.88) was named "Visually Guided Perceptual Organization" and contained the four WISC-R Perceptual Organization subtests as its only subtests with loadings greater than .30. Finally, Chittooran, D'Amato, Lassiter and Dean (1993) factor analyzed scores obtained by 934 learning disabled children on the WISC-R, HRNB, Wide Range Achievement Test (WRAT) and Peabody Picture Vocabulary Test (PPVT). They obtained seven factors with eigenvalues greater than one. The factor accounting for the greatest amount of variance (23%) was labelled "Verbal Reasoning", and its highest loadings came from the four WISC-R Verbal Comprehension subtests and the PPVT. The factor accounting for the third most variance (9.5%) was named "Visual-Perceptual Organization" and included the four WISC-R Perceptual Organization subtests as its only tests with loadings greater than .30.

Despite the potential utility of the Wechsler factor scores, few studies have been conducted to specifically determine how children from different clinical groups tend to score on these measures. Among the rare exceptions are the tables presenting the factor scores obtained by children from various groups in the WISC-III manual (Wechsler, 1991, pp.210-216). These tables do not provide comparisons of how children with suspected right versus left hemisphere dysfunction perform, but some information of this type can still be extracted. Specifically, children with reading disorders (n=34; most likely left hemisphere dysfunction) were found to have a lower mean Verbal Comprehension score (mean=100.4, sd=10) than their mean Perceptual Organization score (mean=104.7, sd=10.3), although the difference was minimal. In a sample of children with speech/language delays (n=44; also presumably left hemisphere dysfunction), the Perceptual Organization score was reported to be the highest factor score (mean=81.5, sd=17.3), although the Verbal Comprehension score was not reported.

One of the very few studies that has examined the performance of children with lateralized brain dysfunction on the Wechsler factor scores was one conducted by Aram and Ekelman (1986). They studied a sample of left-lesioned (n=18) and right-lesioned (n=13) children ranging from 4- to 16-years old. Among the children who were old enough to be administered the WISC-R, the discrepancy between their VIQ and PIQ scores was found to be unrelated to lesion laterality, however, the right-lesioned did group exhibit a significant weakness on the Perceptual Organization factor. Conversely, no significant differences were detected on the Verbal Comprehension factor.

2.3 Analyses

All three research hypotheses[2] were tested with the use of bivariate correlations and hierarchical multiple regression analyses[3]. With the regression analyses, Hypotheses 1 was tested by statistically comparing the multiple correlation coefficients (R) obtained by using the three left versus the three right hand motor test scores as predictors of WISC-III Perceptual Organization scores, in separate regression equations. Hypothesis 2 was tested by statistically comparing the multiple correlation coefficients (R) obtained by using the three right versus the three left hand motor test scores as predictors of WISC-III Verbal Comprehension scores, in separate analyses. Hypothesis 3 was evaluated by determining the amount of unique variance accounted for in Perceptual Organization and Verbal Comprehension scores by left and right hand Name Printing Test scores, respectively, when they were entered into the regression equations following the Grooved Pegboard and Finger Tapping Test scores from the same hand. The results of bivariate correlations between the predictor and criterion variables were used in conjunction with the results of the regression analyses in order to further evaluate the study hypotheses.

In order to remove the confounding effects of age on performance on the motor

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[2]Hypothesis 1: Left hand motor test scores will be better predictors of visuospatial skill than right hand scores; Hypothesis 2: Right hand motor test scores will be better predictors of verbal skill than left hand scores; Hypothesis 3: Name Printing scores will account for a significant proportion of unique variance in verbal and visuospatial test performance even after variance accounted for by Grooved Pegboard and Finger Tapping Test scores has been partialled out.

[3]Hierarchical regression was selected following an initial attempt at analyzing the data using forced entry multiple regression. It was subsequently determined that hierarchical regression would be needed in order to determine the amount of unique variance in the criterion variables that Name Printing scores accounted for after Grooved Pegboard and Finger Tapping scores had been partialled out.

and cognitive tests, the raw scores from each of these tests was standardized based on appropriate norms. The norms used for the Name Printing Test were the previously-described Joschko and Bailey (1996) norms for 5-17 year olds, collected in Victoria, B.C. The norms used for the Grooved Pegboard and Finger Tapping Tests were those compiled by Knights (1966) on schoolchildren in Ontario, Canada, with no history of school failure. These norms are for children in the 5-14 year old range, so it was necessary to compare the performance of 15- and 16-year olds in the present sample to the norms for 14-year olds. Since there were only four children who fell into this age range in the present sample, any confounding effects that this may have had on the data were considered unlikely to have had a significant influence on the study's results. The standard WISC-III norms (Wechsler, 1991) were used for calculation of the Perceptual Organization and Verbal Comprehension scores.

With the exception of the Perceptual Organization and Verbal Comprehension scores, which are already standardized, the study sample's raw scores on the remaining tests were standardized by converting them to z-scores. Z-scores are obtained through a linear transformation of the raw scores, and are set to have a mean of 0 and a standard deviation of 1. When raw scores are transformed to z-scores, all the properties of the original score distribution are retained, and any computations that can be performed with the raw scores can also be performed with the z-scores without altering the results (Anastasi, 1988).

3. RESULTS

3.1 Descriptive statistics

Statistics summarizing the study sample's scores on the three motor and two cognitive test variables are presented in Table 2. It is evident that the majority of the sample scored in the average range on the WISC-III Verbal Comprehension and Perceptual Organization factors (as they did on the WISC-III Full Scale, Performance and Verbal IQs), which would seem to make them representative of most samples of children with learning disabilities and/or ADHD. They also duplicated the pattern of having a Perceptual Organization score that is slightly higher than their Verbal Comprehension score, as was the case for the samples of children with these diagnoses whose scores are presented in the WISC-III manual (Wechsler, 1991).

As can be seen in Table 3, it is further apparent that the Verbal Comprehension and Perceptual Organization factor scores obtained by the study sample, as well as their three IQ scores, were exceptionally close to those obtained by the sample of "Learning-Disabled" children presented in the WISC-III manual, and slightly less close to the samples of children with "Reading-Disorder" and "Attention-Deficit Hyperactivity Disorder". This is consistent with the diagnostic makeup of the study sample, who were primarily diagnosed with learning disabilities.

Initial examination of the descriptive statistics for the three motor tests (Table 2) reveals a trend whereby subjects showed less overall impairment on the one "simple" motor test (Finger Tapping) than they did on the two "complex" motor tests (Name

Table 2 - Study Variables

Variable	Mean	sd	Range
Name Printing Test, right hand z-score	-1.39	2.11	-9.46 to 1.54
Name Printing Test, left hand z-score	-1.35	1.64	-8.68 to 1.35
Grooved Pegboard, left hand z-score	-1.30	1.93	-8.41 to 1.83
Grooved Pegboard, right hand z-score	-.32	1.47	-6.56 to 1.73
Finger Tapping Test, left hand z-score	.29	1.18	-3.16 to 3.13
Finger Tapping Test, right hand z-score	.63	1.37	-2.80 to 4.53
WISC-III Perceptual Organization factor score	97.53	15.08	65 to 131
WISC-III Verbal Comprehension factor score	94.20	13.49	65 to 124

Table 3

Comparison of WISC-III Scores Obtained by Study Sample and Three Clinical Samples Presented in the WISC-III Manual (Wechsler, 1991)

	Study Sample (n=75)		WISC-III Learning Disabled Sample (n=65)		WISC-III Reading Disordered Sample (n=34)		WISC-III ADHD Sample (n=68)	
WISC-III Score	Mean	sd	Mean	sd	Mean	sd	Mean	sd
VIQ	93.1	13.4	92.1	15.6	98.0	9.3	98.0	16.0
PIQ	93.7	14.6	97.2	16.7	101.9	10.2	101.3	15.0
FSIQ	92.6	13.1	93.8	15.9	99.6	8.1	99.4	15.6
VC Index	94.2	13.5	93.8	15.3	100.4	10.0	98.8	15.8
PO Index	97.5	15.1	100.5	16.3	104.7	10.3	105.0	16.3

VIQ = Verbal IQ
PIQ = Performance IQ
FSIQ = Full Scale IQ
VC Index = Verbal Comprehension Index
PO Index = Perceptual Organization Index

Printing and Grooved Pegboard). It was reassuring to see this trend. This is because it was necessary to use two different normative samples in order to calculate the present sample's z-scores on the three motor tests (one for the Name Printing Test and another for the Grooved Pegboard and Finger Tapping Tests). If these normative samples had been somehow very dissimilar, this would have confounded comparisons of the present sample's z-scores on the three motor tests. Fortunately, whatever differences may exist between the two normative samples, they are at least not great enough to produce a theoretically-inconsistent patterning of the present sample's z-scores on the three motor tests.

3.2 Assumptions of regression analysis

In order to conduct regression analysis, there are several assumptions regarding the nature of the data that must be fulfilled. One of these assumptions is that there will be an adequate subjects to variables ratio. The subjects to independent variables ratio in the present study was 25:1, which can be seen to exceed the 20:1 ratio described as optimal by Tabachnick and Fidell (1989). One subject was missing Finger Tapping scores, while two other subjects were missing their Verbal Comprehension and Perceptual Organization scores. Due to the small proportion of missing data that this constituted on each variable, the decision was made to simply eliminate these subjects from analyses involving these variables.

A second assumption important to multiple regression analysis is that there not be multicollinearity among the predictor variables. Multicollinearity occurs when two or more predictor variables are highly correlated and therefore redundant. Multicollinearity was assessed by calculating the Tolerance and Variance Inflation Factor (VIF) of each variable included in the four regression equations. These values can be seen to fall well within conventionally acceptable limits (see Tables 5 &6), which suggests that multicollinearity was not a problem in the present data set.

Normality and homoscedasticity of the residuals constitutes a third, important assumption for regression analysis. These assumptions were evaluated by examination of residuals plots and by calculating values representing the degrees of skewness (symmetry) and kurtosis (peakedness) of the study variables (see Appendix D). These analyses revealed significant negative skews in the left and right hand Name Printing Test and Grooved Pegboard scores. This was a result of a large proportion of subjects showing impaired performance on these tests (z-scores < -1.00), with some scoring several z-scores below the mean. In contrast, there were few subjects who scored above average on these variables (z-scores > 1.00) and no excessively large (>1.8), positive z-scores.

As recommended by Tabachnick and Fidell (1989), a transformation for negative skewness was applied to the variables with significant skews. This involved "reflecting" the original z-scores (using a transformation to reverse the distribution so that the highest scores become the lowest and the lowest scores the highest, all with values above zero), then applying a square-root transformation to the reflected z-scores (which is a transformation normally used for moderate positive skews). These transformations were successful in eliminating the significant skews in all four variables (see Appendix D). However, when regression analyses were performed before and after the variable transformations, it was apparent that the transformations resulted in no meaningful changes in the overall R-squared values, nor in the values or ordering of individual regression coefficients.

Transformations can alter the data to meet the assumptions of regression analysis, but also tend to make interpretation of results less clear (Tabachnick & Fidell, 1989). Since the use of transformations on the present data set made no meaningful difference in the regression results, the decision was made not to transform the two motor variables, in order to maximize the interpretability of the results.

3.3 Bivariate correlations

Bivariate correlations between the predictor and criterion variables are presented in Table 4. Although the significance of various correlations will often be referred to, the large number of correlations calculated makes it possible that some attained statistical significance purely due to chance. Therefore, it will be important to assign more weight to the magnitude of the correlations, and to the r-squared values indicating the amount of shared variance between variables, than to their actual significance levels.

Nevertheless, considering the bivariate correlations between the predictor and criterion variables, significant correlations were found between the WISC-III Perceptual Organization score and the right ($r=.39$) and left hand ($r=.51$) Grooved Pegboard scores, as well as right hand ($r=.28$) Finger Tapping scores. A significant

Table 4 - Bivariate Correlations

	1	2	3	4	5	6	7	8
1	1.00							
2	.47 p=.000	1.00						
3	-.18 p=.13	.01 p=.93	1.00					
4	-.01 p=.90	.08 p=.51	.63 p=.000	1.00				
5	.39 p=.000	.19 p=.10	.17 p=.14	.11 p=.33	1.00			
6	.51 p=.000	.23 p=.04	.05 p=.67	.03 p=.76	.80 p=.000	1.00		
7	.28 p=.01	.10 p=.42	.23 p=.04	.13 p=.24	.17 p=.14	.25 p=.03	1.00	
8	.22 p=.06	.11 p=.35	.27 p=.02	.07 p=.54	.19 p=.10	.24 p=.04	.59 p=.000	1.00

1 = WISC-III Perceptual Organization score
2 = WISC-III Verbal Comprehension score
3 = Name Printing Test, right hand z-score
4 = Name Printing Test, left hand z-score
5 = Grooved Pegboard, right hand z-score
6 = Grooved Pegboard, left hand z-score
7 = Finger Tapping Test, right hand z-score
8 = Finger Tapping Test, left hand z-score

correlation (r=.23) was also obtained between WISC-III Verbal Comprehension scores and left hand Grooved Pegboard scores.

Regarding correlations among the predictor variables, those between the Name Printing Test and Grooved Pegboard were very small and nonsignificant. Conversely, right hand Name Printing Test scores correlated significantly with both right (r=.23) and left (r=.27) hand Finger Tapping scores. Correlations between left hand Grooved Pegboard scores and both right (r=.25) and left (r=.24) hand Finger Tapping Test scores were also statistically significant. Furthermore, as would be expected, there were significant, positive correlations between the left and right hand scores on each motor test.

3.4 Regression analyses

Table 5 provides a summary of the results of the hierarchical multiple regression analyses using WISC-III Perceptual Organization scores as the criterion variable and left hand, then right hand, Name Printing, Grooved Pegboard and Finger Tapping scores as the predictor variables. Contrary to Hypothesis #1, although the R value for predicting the WISC-III Perceptual Organization scores from the three left hand motor test scores (.52) was higher than that obtained by using the three right hand motor test scores (.46), the difference did not attain statistical sigficance (z = .72; see Tabachnick & Fidell, 1989, p. 159 for z formula). Additionally, and counter to Hypothesis #3, Name Printing Test scores did not account for a significant proportion of unique variance in Perceptual Organization scores when they were entered into either

Table 5

Hierarchical Multiple Regression of Left and Right Hand Finger Tapping, Grooved Pegboard and Name Printing Scores on WISC-III Perceptual Organization Scores

Left Hand Scores

Multiple R	.52
R Square	.27
Adjusted R Square	.24
Standard Error	13.17
F	8.66
Sig. F	.0001

Variables in the Equation

Variable	Unstandardized Beta	SE Beta	Standardized Beta	Tol.	VIF	t	Sig t
Finger Tapping	1.32	1.33	0.10	.94	1.06	0.99	.32
Grooved Pegboard	3.74	0.81	0.48	.94	1.06	4.62	.000
Name Printing	-0.33	0.93	-0.03	.99	1.00	-.35	.73
(Constant)	.0000						

Right Hand Scores

Multiple R	.46
R Square	.21
Adjusted R Square	.17
Standard Error	13.70
F	6.23
Sig F	.0008

Variables in the Equation

Variable	Unstandardized Beta	SE Beta	Standardized Beta	Tol.	VIF	t	Sig t
Fnger Tapping	2.52	1.18	.23	.96	1.04	2.13	.04
Grooved Pegboard	3.69	1.09	.36	.96	1.04	3.37	.001
Name Printing	-.77	.97	-.08	.97	1.03	-.79	.43
(Constant)	.0000						

regression equation following Finger Tapping and Grooved Pegboard scores. In fact, only the Grooved Pegboard scores accounted for a significant amount of unique variance in Perceptual Organization scores (when entered following Finger Tapping scores).

Table 6 provides a summary of the hierarchical multiple regression results using WISC-III Verbal Comprehension scores as the criterion variable and right hand, then left hand, Finger Tapping, Grooved Pegboard and Name Printing Test scores as the predictor variables. Contrary to Hypothesis #2, left hand motor test scores (R=.25) were found to be slightly better predictors of WISC-III Verbal Comprehension scores than right hand motor test scores (R=.20), although this difference was also not statistically significant (z = -.33). Also inconsistent with Hypothesis #3, neither left nor right hand Name Printing Test scores were found to account for a significant proportion of unique variance in WISC-III Verbal Comprehension scores when they were entered into either regression equation following Finger Tapping and Grooved Pegboard scores. In fact, none of the motor test scores was a significant multivariate predictor of Verbal Comprehension scores (although the left hand Grooved Pegboard scores nearly attained significance).

As an additional attempt to determine whether Name Printing Test performance might have a unique, nonmotor/cognitive component that might overlap with similar aspects of WISC-III Perceptual Organization and Verbal Comprehension scores, a residualization analysis was conducted. This involved correlating Name Printing Test scores with the residuals left over from the prediction of Perceptual Organization and

Table 6

Hierarchical Multiple Regression of Right and Left Hand Finger Tapping, Grooved Pegboard and Name Printing Scores on WISC-III Verbal Comprehension Scores

Right Hand Scores

Multiple R	.20
R Square	.04
Adjusted R Square	.0006
Standard Error	13.48
F	1.02
Sig. F	.3908

Variables in the Equation

Variable	Unstandardized Beta	SE Beta	Standardized Beta	Tol.	VIF	t	Sig t
Finger Tapping	.71	1.18	.07	.93	1.08	.60	.55
Grooved Pegboard	1.67	1.08	.18	.95	1.05	1.54	.13
Name Printing	-0.24	0.76	-0.04	.93	1.08	-.31	.75
(Constant)	.0000						

Left Hand Scores

Multiple R	.25
R Square	.06
Adjusted R Square	.02
Standard Error	13.34
F	1.56
Sig F	.21

Variables in the Equation

Variable	Unstandardized Beta	SE Beta	Standardized Beta	Tol.	VIF	t	Sig t
Fnger Tapping	.61	1.35	.05	.94	1.06	.45	.65
Grooved Pegboard	1.51	.82	.22	.94	1.06	1.85	.07
Name Printing	.55	.94	.07	.99	1.00	.58	.56
(Constant)	.0000						

Verbal Comprehension scores from the three motor test scores. This procedure produced extremely low correlations between Name Printing Test scores and scores from both the Perceptual Organization ($r=.0000$) and Verbal Comprehension ($r=.0000$) factors. This finding provides further evidence suggesting that Name Printing Test scores do not contain a unique, nonmotor/cognitive component that overlaps with the cognitive constructs measured by either the WISC-III Perceptual Organization or Verbal Comprehension factors.

3.5 Intertest consistency analyses

As the results of the regression analyses indicated that the three motor tests did differ in their ability to predict scores on the verbal and visuospatial cognitive skill measures, an attempt was made to determine the consistency with which the three tests could be used to form a judgement of motor impairment. This question was considered to be of interest due to empirical and theoretical suggestions that, firstly, the three motor tests should vary in their level of complexity (with the Name Printing Test and Grooved Pegboard being more complex than the Finger Tapping Test) and, secondly, that children with suspected brain dysfunction should have more difficulty on the complex motor tests (Name Printing and Grooved Pegboard) than on the simple motor test (Finger Tapping). These questions were evaluated, in part, via kappa interrater (or intertest) reliability analyses (Cohen, 1960; 1968), which allows the consistency with which the three motor tests rate subjects in the same manner, beyond that expected by chance, to be statistically evaluated.

In order to determine the consistency of the three motor tests in forming a judgement of impairment, a decision was made to define "impaired" performance as a score that falls at least one standard deviation below the mean for the subject's age group on that test. Although this criterion would most likely be considered very liberal and inadequate for making a clinical judgement of impairment, it is one that has been used by other researchers to define impaired motor test performance by children (Gaddes & Edgell, 1994; Rourke, Yanni, MacDonald & Young, 1973). Using the one standard deviation criterion, it was possible to determine the proportion of subjects exhibiting either right, left, bilateral or no impairment on each of the three motor tests (see Table 7).

With the use of the kappa statistic, a determination can be made as to the level of agreement between any pairing of motor tests in rating subjects as impaired versus not impaired, after correcting for the amount of agreement expected by chance. The kappa statistic is typically used to evaluate the extent of agreement between two raters using the same rating method, but can also be used to determine the amount of agreement achieved using two different tests. The results of the intertest reliability analysis for the extent of agreement between each pair of tests in making judgements of motor impairment is presented in Table 8.

As can be seen from Table 8, the level of agreement between any pair of tests, when the expected level of chance agreement is controlled, is quite low. A kappa value of at least .70 is typically considered to represent an acceptable level of agreement (Sattler, 1992). The highest kappa value obtained between any pairing of tests was the

Table 7

Number of Subjects Scoring in "Impaired" Range (>1 sd below Mean) on Three Motor Tests

	Right Impairment	Left Impairment	Bilateral Impairment	No Impairment
Name Printing	8	13	31	25
Grooved Pegboard	0	17	21	39
Finger Tapping	2	4	5	65

Table 8

**Intertest Consistency (Kappa) -
"Impaired" vs. "Not Impaired" Ratings**

NPT	PEGS				
		Impaired	Not Impaired	Totals =	observed proportion of agreement = 61%
NPT	Impaired	29	22	51	
	Not Impaired	8	18	26	expected chance agreement = 49%
	Totals =	37	40	n=77	Kappa = .23

TAP	PEGS				
		Impaired	Not Impaired	Totals =	observed proportion of agreement = 59%
TAP	Impaired	8	2	10	
	Not Impaired	29	37	66	expected chance agreement = 51%
	Totals =	37	39	n=76	Kappa = .16

TAP	NPT				
		Impaired	Not Impaired	Totals =	observed proportion of agreement = 39%
TAP	Impaired	7	3	10	
	Not Impaired	43	23	66	expected chance agreement = 38%
	Totals =	50	26	n=76	Kappa = .01

NPT = Name Printing Test
PEGS = Grooved Pegboard
TAP = Finger Tapping Test

23 value between the Name Printing and Grooved Pegboard Tests. This was followed by the .16 kappa value between the Grooved Pegboard and the Finger Tapping Test. The kappa value of .01 obtained between the Name Printing and Finger Tapping Tests indicated that there was basically no agreement between these two tests in making judgements of motor impairment, beyond that expected by chance alone.

The second intertest consistency analysis was conducted to determine the extent to which the three motor tests agreed in rating subjects as having either lateralized (right or left) or nonlateralized (bilateral or none) motor impairment. As can be seen in Table 9, the extent of agreement between each pairing of motor tests in making this decision was actually slightly less than what would be expected by chance alone.

It appeared that the lack of intertest consistency in determining the presence of lateralized versus nonlateralized motor impairment was a result of the small number of subjects classified as having lateralized impairment on any test (see Table 7), and the even smaller number of subjects who were rated as having lateralized impairment on more than one test. Conversely, when the tests were used to simply make judgements of impairment versus no impairment (as was the case for the first intertest consistency analysis), there were relatively large numbers of subjects who fell into each of these two categories (except on the Finger Tapping Test), which made it more likely that any test pairing would rate subjects in a similar manner. It should be noted, however, that the levels of agreement between the motor tests were not necessarily low in an absolute sense (one of six pairings had only a 39% agreement rate, but the other five ranged from 59% to 74% agreement), but were low relative to the extent of agreement

expected by chance.

Table 9

Intertest Consistency (Kappa) -
Lateralized vs. Non-lateralized "Impairment" Ratings

		PEGS			
		Lateralized	Non-lateralized	Totals =	observed proportion of agreement = 61%
NPT	Lateralized	4	17	21	expected chance agreement = 63%
	Non-lateralized	13	43	56	
	Totals =	17	60	n=77	Kappa = -.05

		PEGS			
		Lateralized	Non-lateralized	Totals =	observed proportion of agreement = 74%
TAP	Lateralized	1	4	5	expected chance agreement = 75%
	Non-lateralized	16	55	71	
	Totals =	17	59	n=76	Kappa = -.04

		NPT			
		Lateralized	Non-lateralized	Totals =	observed proportion of agreement = 70%
TAP	Lateralized	1	4	5	expected chance agreement = 71%
	Non-lateralized	19	52	71	
	Totals =	20	56	n=76	Kappa = .03

NPT = Name Printing Test
PEGS = Grooved Pegboard
TAP = Finger Tapping Test

4. DISCUSSION

4.1 Conclusions

The results of the present study can be seen to provide little support for the three research hypotheses[4]. Firstly, although left hand motor tests scores were found to predict visuospatial cognitive skill (as measured by the WISC-III Perceptual Organization factor) marginally better than right hand motor test scores, this difference was not statistically significant. Secondly, left hand motor test scores were actually found to be slightly better predictors of verbal cognitive skill (as measured by the WISC-III Verbal Comprehension factor) than right hand motor test scores, although this difference was also not statistically significant. Finally, the Name Printing Test was not found to account for a significant proportion of unique variance in visuospatial or verbal cognitive skill scores after the variance accounted for by Finger Tapping and Grooved Pegboard scores had been partialled out.

The results of both the bivariate correlations and multiple regression analyses suggested that neither left nor right hand Name Printing Test scores have much in common with WISC-III Perceptual Organization or Verbal Comprehension factors. In fact, the only significant result found in the analyses using the Name Printing Test was the significant correlation between the right hand scores and scores from both hands on

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[4]Hypothesis 1: Left hand motor test scores will be better predictors of visuospatial skill than right hand scores; Hypothesis 2: Right hand motor test scores will be better predictors of verbal skill than left hand scores; H ypothesis 3: Name Printing scores will account for a significant proportion of unique variance in verbal and visuospatial test performance even after variance accounted for by Grooved Pegboard and Finger Tapping Test scores has been partialled out.

the Finger Tapping Test. This would seem to suggest that left and right hand Name Printing Test scores may be measuring slightly different skills (at least to some degree). Since the right hand scores do not correlate exclusively with right hand Finger Tapping scores, it would not seem to be a factor such as left hemisphere functioning that underlies this relationship. Rather, it is likely that right hand Name Printing Test performance is more of a rote motor skill than left hand performance, at least in a sample of right-handed children. This would help explain why right hand Name Printing scores had a significant correlation with a rote, simplistic motor task like Finger Tapping, while left hand scores did not. Unfortunately, the results of this study do little to help determine what is measured by left hand Name Printing Test scores, other than to suggest that it is most likely some aspect of psychomotor skill.

In addition to providing some preliminary research data on the Name Printing Test, the results of this study also yielded new data concerning the more well established Grooved Pegboard and Finger Tapping Tests. Firstly, these results are inconsistent with Gaddes and Edgell's (1994) finding that 63% of learning disabled children tested at the University of Victoria Neuropsychology Laboratory scored at least one standard deviation below their age mean with their dominant hand on the Finger Tapping Test. Only four percent of children with suspected brain dysfunction (most diagnosed with a learning disability) were found to score at least one standard deviation below their age mean with their dominant hand in the present sample (and only 5% with their nondominant hand). The present findings are more consistent with those from the majority of similar studies, which have found no evidence for the ability of the Finger Tapping Test to distinguish among different groups of children with suspected brain dysfunction, or between them and normal controls (Reitan & Boll, 1973; Rourke & Strang, 1978; Selz & Reitan, 1979). It must be noted, however, that some or all of Gaddes and Edgell's data was collected with the use of an electronic finger tapping device (the present study's data was collected using a manual finger tapper), which indicates that surprisingly discrepant results may be expected from the use of different finger tapping devices and/or different norms, as Snow (1987) has previously suggested.

The findings related to the Grooved Pegboard are also consistent with those of most prior research. They supported Francis et al.'s (1992) discovery that the test loaded most highly on a neuropsychological test factor that they called "Complex Visual-Spatial Relations". They were further consistent with Rourke and Strang's (1978) determination that Grooved Pegboard performance could distinguish learning disabled children with the weakest "visual-perceptual and visual-spatial abilities" from those with other types of skill weakness. They fit well with the results of Williams and Dykman's (1994) factor analysis of children's nonverbal neuropsychological tests, from which they concluded that the Grooved Pegboard is "sensitive to more complex information-processing" and that the Finger Tapping Test is "more sensitive to pure motor speed" (p.25). One somewhat unique result, however, was that only this sample's mean <u>left</u> hand Grooved Pegboard z-score fell into the "impaired" range (>1 sd below the mean). In the one study appropriate for comparison, Knights and Moule (1968) found that scores from <u>both</u> hands could be used to distinguish normal children from children with "suspected neurological dysfunction".

The distinction made in the neuropsychology literature between simple and complex motor tests was another topic of focus in the present study. It was suggested that both the Grooved Pegboard and Name Printing tests should be considered complex motor tests, while the Finger Tapping Test should be viewed as a simple motor test. This categorization was supported by the study's results in several ways.

Firstly, based on mean z-scores, the subject sample had the most difficulty with the Name Printing Test, followed by the Grooved Pegboard, then the Finger Tapping Test. Secondly, on the Name Printing and Grooved Pegboard tests, the mean z-scores were negative, but positive on the Finger Tapping Test. Additionally, the results of the intertest consistency analyses indicated very little similarity between these three tests in judging subjects as having lateralized versus nonlateralized motor impairment. However, when used to simply discriminate subjects as being with or without motor impairment, the results were consistent with the three tests' hypothesized complexity levels. In other words, the two most complex tests (Name Printing and Grooved Pegboard) were the most similar in making this discrimination, followed by the second and third most complex tests (Grooved Pegboard and Finger Tapping), and finally the first and third most complex tests (Name Printing and Finger Tapping), which showed basically no similarity beyond that expected by chance. Finally, considering the overall number of subjects who scored in the impaired range on each of these tests, the highest number was found on the Name Printing Test, followed by the Grooved Pegboard, then the Finger Tapping Test.

The results of the present study can also be interpreted in light of the information that they provide regarding the nature of the WISC-III Perceptual Organization factor. There was a statistically significant correlation between Perceptual Organization scores and right hand Finger Tapping scores, and a nearly significant correlation with lef t hand Finger Tapping scores. This finding serves to highlight the importance of simple motor skill in performance on the Perceptual Organization factor, which is most likely due to the fact that three out of four of the WISC-III subtests composing this factor (Object Assembly, Block Design and Picture Arrangement) require some form of motor response.

Both left and right hand Grooved Pegboard scores were found to account for a significant amount of variance in Perceptual Organization scores, even after variance accounted for by Finger Tapping scores had been partialled out. This finding appears to emphasize the additional, complex motor component of Perceptual Organization scores and/or the visuospatial component of Grooved Pegboard performance. It should be added that the regression analyses indicated that one-quarter of the variance in the Perceptual Organization factor was accounted for by performance on the three motor tests. The implication of these findings for the interpretation of Perceptual Organization scores is that undiagnosed motor impairment should always be considered as a possible causative factor when a child obtains a low score on this factor.

The findings regarding both WISC-III factors can be related to those of other researchers who have conducted similar studies using the WISC VIQ and PIQ scores as dependent measures. For example, the present results closely parallel those of

Rourke and Telegdy (1971), who found motor test impairment to be related to low WISC PIQ scores, but not low VIQ scores. They are also similar to Lord and Hulme's (1987) discovery that "motor clumsy" children scored significantly lower than normal children on the WISC-R PIQ score, but not the VIQ score. They match Tramontana, Klee and Boyd's (1983) finding that the presence of lower WISC-R PIQ than VIQ scores in a sample of children with psychiatric disorders was associated with bilateral sensorimotor impairments. Finally, they fit with Reitan's (1970) detection of a "strikingly depressed" Wechsler-Bellevue PIQ score, compared to the VIQ score, in a sample of adults with sensorimotor impairment due to neurological disorder.

The findings of the present study do not support Rourke et al.'s (1973) discovery of an apparent link between right hand motor impairment and weak performance on verbal and auditory- perceptual measures (although the present study did not use the same range of verbal skills measures). However, even their own data can be seen to provide only the weakest evidence for this association. Bornstein (1986) found that motor tests scores were poor at detecting left hemisphere impairment and stressed that it is important to always consider the results of nonmotor tests together with motor test scores in order to make decisions regarding left hemisphere integrity.

Some prior studies (Reitan & Telegdy, 1971; Yeudall et al., 1987) have established a stronger link between left hand motor performance and visuospatial cognitive skill, than between right hand motor performance and verbal cognitive ability. The present study's results also revealed a nonsignificant trend in this direction. One possible explanation for this differential association is that the Wechsler Performance measures (PIQ and Perceptual Organization) provide a stronger estimate of right hemisphere functioning than the Verbal measures (VIQ and Verbal Comprehension) do of left hemisphere functioning (Aram, Ekelman, Rose & Whitaker, 1985). Such a hypothesis is supported by Aram and Ekelman's (1986) finding that WISC-R Perceptual Organization scores, but not Verbal Comprehension scores, could be used to discriminate control children from right hemisphere-lesioned children, while neither score distinguished control children from left hemisphere-lesioned children. It is further supported by Ballantyne, Scarvie and Trauner's (1994) discovery that children with right hemisphere lesions had a Wechsler PIQ score that was significantly lower than their VIQ score, but that children with left hemisphere lesions had no significant VIQ-PIQ discrepancies Furthermore, Maxwell and Wise (1984) were able to find a significant correlation between PPVT scores (i.e., a different measure of verbal cognitive skill) and preferred (mostly right) hand name writing speed, but not nonpreferred (mostly left) hand name writing speed.

Conversely, it might also be argued that the differential relationship described above is simply a result of the fact that the Wechsler Performance measures contain a strong motor component, while the Verbal measures have none. This would help explain why motor test scores from <u>both</u> hands were found to be significant correlates of Perceptual Organization scores in the present study. Nevertheless, Grooved Pegboard scores were found to be significant predictors of Perceptual Organization scores even after some overlapping motor variance (with the Finger Tapping Test) was partialled out. This indicates that there is likely more to their relationship than just a common motor component.

The results of the present study also provide some intriguing information regarding the nature of the study sample; children with suspected brain dysfunction. It seems that the likelihood of detecting motor impairment in such children is highly test dependent. Specifically, the more complex the motor test, the more likely they are to obtain below average scores.

The present study sample scored more than one standard deviation below the mean on the Name Printing Test with both hands, as well as with their left hand on the Grooved Pegboard, but were well within normal limits on the Finger Tapping Test. Consequently, it would seem reasonable to conclude that the Name Printing Test may be a sensitive indicator of psychomotor impairment in children with suspected brain dysfunction, while the Finger Tapping Test is not. This fits with Eaves et al.'s (1972) finding that a name printing task could be used to distinguish normal children from children with suspected brain dysfunction.

Another result of interest in the present study is that the frequency of left hand impairment was greater than that of right hand impairment on each of the motor tests. This finding has also been reported in other samples of children (Reitan, 1971a; Reitan, 1971b; Tsushima & Towne, 1977) and adults (Lewis & Kupke, 1992) with neurological dysfunction. The results of previous research can be applied to explain this phenomenon in at least two ways.

Firstly, based on Annett's studies (Annett, 1991; Annett & Manning, 1989;

Annett & Manning, 1990b), it could be hypothesized that the study sample contained a relatively large number of extreme right handers; children whose right hand skill is much better than their left hand skill due to impaired right hemisphere development. One could expect to find a higher proportion of such children in a group with suspected brain dysfunction than would be found in the normal population. However, the study sample's relatively normal mean Perceptual Organization score might argue against an hypothesis of right hemisphere impairment.

A competing hypothesis is one that derives from studies showing that persons with diffuse neurological impairment are most likely to exhibit motor dysfunction in their nondominant hand (Lewis & Kupke, 1992; Reitan, 1974). These researchers have hypothesized that this finding is related to the fact that neurologically-compromised individuals will find it difficult to perform any unfamiliar motor task, but especially with their less-used hand. The Grooved Pegboard and Finger Tapping Tests can both be seen as unfamiliar motor tasks, and Name Printing Test performance would be quite unfamiliar with the nondominant hand. It would seem that this hypothesis could be used to explain the data more adequately than that derived from Annett's theory, as it would account for the finding that a notable proportion of subjects showed evidence of left hand motor impairment, but with no conspicuous decrement in their Perceptual Organization scores. It might also provide an alternative explanation for why Annett has found that children with global intellectual deficiency (low "total brain power"), seem to manifest unusually weak left hand motor skill (extreme right handedness).

Finally, regarding the utilization of the "Comparison of the Left and Right Side of the Body" inferential method, the results of this study can be seen to provide only limited support for its use with children with suspected brain dysfunction. No measure of right sided motor proficiency was found to be a good predictor of verbal cognitive skill/left hemisphere functioning, although it is possible that more supportive results might have been found with a different verbal cognitive skill measure (e.g., the PPVT). The findings provided only slightly more support for using left hand motor proficiency scores to predict visuospatial cognitive skill/right hemisphere functioning. This is partly due to the fact that this relationship was not found to be specific to left hand motor test scores; right hand scores were also significant correlates of visuospatial cognitive skill. This appeared to be largely the result of overlapping motor variance with the visuospatial cognitive skill measure.

The results of this study also provided little support for basing inferences regarding lateralized hemispheric functioning on individual motor test scores (at least when hemispheric functioning is estimated from performance on tests of verbal and visuospatial cognitive skill). Several other authors have stressed the importance of looking for consistency among different motor tests, as well as combining them with nonmotor tests, in order to make such inferences (e.g., Bornstein, 1986; Francis et al., 1988; Greiffenstein, Baker & Gola, 1996; Lezak, 1995; Spreen & Strauss, 1991; Thompson, Heaton, Mathews & Grant, 1987). The findings from this study would suggest that this process needs to be taken even one step further, because it appears that multiple test scores may need to be entered into regression equations in order to make the most accurate inferences. This is because, as seen in this study, there can be considerable variance present in neuropsychological test scores that is irrelevant to the constructs that neuropsychologists wish to make inferences about (i.e., many neuropsychological tests are not "pure" measures). Only through the use of statistical procedures such as regression analysis can this irrelevant variance be removed. Regression analysis is also probably the most accurate method for determining the amount of weight that should be assigned to different neuropsychological test scores in order to make such inferences.

4.2 Summary

In summary, the results of this study were found to provide little support for the research hypotheses. Left hand motor test scores were only marginally (and nonsignficantly) better predictors of visuospatial cognitive skill than right hand scores. Right hand motor tests scores were not better than left hand scores at predicting verbal cognitive skill, at least as measured by the WISC-III Verbal Comprehension factor. The Name Printing Test did not account for a significant amount of unique variance in verbal or visuospatial cognitive skill scores, when variance accounted for by the Grooved Pegboard and Finger Tapping Tests had been partialled out.

There was some evidence from the present and past studies that the Perceptual Organization factor may provide a better estimate of right hemisphere functioning than the Verbal Comprehension factor does of left hemisphere functioning. If so, then results more consistent with the research hypotheses might have been found if an alternative measure of verbal cognitive skill had been used. It was observed that the

Perceptual Organization factor possesses a marked motor skills component.

The study's results also supported the classification of the Name Printing Test and Grooved Pegboard as complex motor tests, and the Finger Tapping Test as a simple motor test. It was confirmed that children with suspected brain dysfunction are more likely to exhibit impairment on complex motor tests than on simple motor tests. It can be concluded that the Name Printing Test appears to be a sensitive indicator of psychomotor impairment in children with suspected brain dysfunction

Another intriguing finding was that left hand motor impairment was more common in this sample of children with suspected brain dysfunction than right hand impairment. It could be hypothesized that this is a result of deficient right cerebral hemisphere development, but this hypothesis was not supported by the sample's average Perceptual Organization score. A more appropriate explanation seems to be that children with cognitive deficits are likely to have relatively more difficulty than normal children in performing a novel task with their nondominant hand.

Finally, the results of this study provided only minimal support for the use of the "Comparison of the Left and Right Sides of the Body" inferential method for children with suspected brain dysfunction. They would suggest that it is important to conduct validational research before any such inferential method is applied to new clinical groups. Furthermore, there seems to be little basis for using individual motor test scores to make inferences regarding lateralized hemispheric functioning. In fact, it would seem that regression equations incorporating multiple test scores are needed in order to make the most accurate inferences.

4.3 Directions for future research

The results of the present study provide the basis for a number of suggestions for future research. Firstly, as has been stated several times, it would be worthwhile to conduct a similar study with a different measure of verbal cognitive skill. Optimally, this would be one that has been found to be a better measure of left cerebral hemisphere functioning than the WISC-III Verbal Comprehension factor. This would likely provide a more adequate test of the association between Name Printing Test performance and verbal cognitive ability. Furthermore, since the measure of visuospatial cognitive skill utilized in the present study (the WISC-III Perceptual Organization factor) involves a strong motor component, it would also be useful to conduct any future studies of this type by including one or more "motor-free" measures of visuospatial ability.

On a more specific level, it would be interesting to examine the similarities between the Grooved Pegboard and another pegboard test that is used as or more frequently in neuropsychology, the Purdue Pegboard (Tiffin & Asher, 1948). Considering the apparent similarity of these two measures, it is surprising that there have been so few (if any) attempts made to compare them directly. Since a primary difference between the two measures is that the Purdue Pegboard utilizes rounded pegs and holes, it would not seem to have the visuospatial demands that the Grooved Pegboard does, and may therefore be less complex. However, this needs to be determined empirically.

Further validation research is also required for the Name Printing Test. It appears that its left and right hand scores measure slightly different things, but not necessarily right and left hemisphere functioning. It seems that right hand performance, at least for right-handed children, is more of a rote motor skill (although this may not be the case at the lower end of the age distribution). It also seems that children with suspected brain dysfunction tend to score in the below average range on this test, with both hands, but this finding requires replication. It will also be important to establish its test-retest reliability.

Furthermore, although the present study used comparison to age norms to determine the level of performance of the sample on each test, it would still be an improvement to compare them to matched controls. This would be the best way to reach firm conclusions regarding the motor skills development of children with suspected brain dysfunction. Additionally, more validation research is required for the Wechsler factor scores, in order to help determine exactly what they measure. They are potentially quite useful measures, and have been shown to have strong reliability, but there is very little validity data available for many purposes.

Finally, it would seem that neuropsychology could benefit considerably from research designed to develop regression equations that use neuropsychological test scores (and other data) to predict various important constructs or outcomes. For example, neuropsychological regression equations might be developed to aid in the diagnosis of subtle forms of brain dysfunction that are normally difficult to detect or differentially diagnose (e.g., fetal alcohol syndrome, postconcussive syndrome, early-onset dementias, etc.). Additionally, such equations might be used to predict longterm outcomes (educational, vocational, social, etc.) for children with different neurological disorders. Similarly, neuropsychological regression equations could be devloped to help predict response to different types of rehabilitation programs, for persons with various neurological disorders. Such uses of regression equations would be an example of the "actuarial prediction" that Meehl described in 1954, and argued would be an improvement over the clinical "rules of thumb" used by most psychologists at the time, and apparently still used by many neuropsychologists today. A considerable amount of research is still needed in this area in order to explore the possible advantages of such methods for use in neuropsychology, and to develop them to the point where they could potentially become a common aspect of neuropsychological practice.

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APPENDIX A

CONSENT FOR PSYCHOLOGICAL SERVICE:

Please sign below if you agree to the goals for psychological service as they have been outlined above.

Name of Client/Family: ______________________________

Signature(s): ______________________ Date: ____________

____

______________________ Date: ____________

Witness: ______________________ Date: ____________

CONSENT FOR RESEARCH AND TEACHING:

In addition to our clinical work, the Psychology Department is also involved in research and teaching to advance scientific knowledge about children and their families. When data is used for these purposes, the identity of the child and family is never revealed. Please sign below if you agree to have your child's data used for research or educational purposes.

Name of Client/Family: ______________________________

Signature: ______________________ Date: ____________

Witness: ______________________ Date: ____________

Jan 19/94

APPENDIX B

NAME PRINTING TEST - VICTORIA NORMS (time/letters)

Age 6 n = 29	
Preferred Hand	Mean = 1.92; sd = .79; range = .50 - 3.7
Nonpreferred Hand	Mean = 3.26; sd = 1.05; range = 1.0 - 5.5
Age 7 n = 44	
Preferred Hand	Mean = 1.48; sd = .59; range = .80 - 3.4
Nonpreferred Hand	Mean = 3.01; sd = 1.1; range = 1.2 - 7.2
Age 8 n = 37	
Preferred Hand	Mean = 1.36; sd = .41; range = .80 - 2.2
Nonpreferred Hand	Mean = 2.71; sd = .74; range = 1.6 - 4.7
Age 9 n = 25	
Preferred Hand	Mean = 1.02; sd = .43; range = .50 - 2.4
Nonpreferred Hand	Mean = 2.19; sd = .64; range = .90 - 3.4
Age 10 n = 35	
Preferred Hand	Mean = .97; sd = .45; range = .40 - 2.7
Nonpreferred Hand	Mean = 2.04; sd = .79; range = .80 - 4.6
Age 11 n = 38	
Preferred Hand	Mean = .73; sd = .21; range = .40 - 1.3
Nonpreferred Hand	Mean = 1.62; sd = .46; range = .90 - 2.5
Age 12 n = 34	
Preferred Hand	Mean = .75; sd = .22 ; range = .40 - 1.3
Nonpreferred Hand	Mean = 1.65; sd = .56; range = .90 - 3.4
Age 13 n = 27	
Preferred Hand	Mean = .68; sd = .17; range = .40 - 1.1
Nonpreferred Hand	Mean = 1.53; sd = .33; range = 1.0 - 2.2
Age 14 n = 20	
Preferred Hand	Mean = .57; sd = .16; range = .40 - .90
Nonpreferred Hand	Mean = 1.36; sd = .40; range = .80 - 2.2
Age 15 n = 24	
Preferred Hand	Mean = .55; sd = .16; range = .40 - .90
Nonpreferred Hand	Mean = 1.30; sd = .37; range = .70 - 2.1
Age 16 n = 17	
Preferred Hand	Mean = .53; sd = .14; range = .40 - .90
Nonpreferred Hand	Mean = 1.33; sd = .49; range = .60 - 2.3
Age 17 n = 20	
Preferred Hand	Mean = .48 ; sd = .10; range = .30 - .70
Nonpreferred Hand	Mean = 1.13; sd = .30; range = .60 - 1.8

n = 350

APPENDIX C

University of Victoria

Office of Research Administration

Alex McAuley, Ph.D.
Associate Vice-President, Research

Michael Corcoran, Ph.D.
Associate Dean, Research

Certificate of Approval

University of Victoria
Human Research Ethics Committee

Principal Investigator	Department/School	Supervisor
Mark Bailey **Grad student**	**Psychology**	**Dr. M. Joschko**

Title: ***The Relationship of Lateralized Motor and Cognitive Impairments in Children With Suspected Brain Dysfunction***

Project No.	Start Date	End Date	Approval Date
170-96	17 Jun 96	31 Oct 96	17 Jun 96

Certification

This is to certify that the University of Victoria Ethics Review Committee on Research and Other Activities Involving Human Subjects has examined the research proposal and concludes that, in all respects, the proposed research meets appropriate standards of ethics as outlined by the University of Victoria Research Regulation Involving Human Subjects.

Michael Corcoran,
Associate Dean, Research

Alex McAuley,
Associate Vice-President, Research

This Certificate of Approval is valid for the above term provided there is no change in the procedures. Extensions/minor amendments may be granted upon receipt of "Request for Continuing Review or Amendment of an Approved Project" form.

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APPENDIX D

Skewness and Kurtosis of Study Variables, Before and After Transformations

Variable	Skew	S.E. Skew	z	p<[1]	Kurtosis	S.E. Kurt	z	p<[1]
Before Transformations								
NPT-R	-1.22	.274	-4.45	.000	1.98	.541	3.66	.000
NPT-L	-1.27	.274	-4.63	.000	4.13	.541	7.63	.000
PEGS-R	-1.37	.274	-5.00	.000	2.99	.541	5.53	.000
PEGS-L	-1.23	.274	-4.49	.000	2.13	.541	3.94	.000
TAP-R	.17	.276	.61	.27	.29	.545	.53	.30
TAP-L	-.55	.276	-1.99	.02	.65	.545	1.19	.12
WISC3 PO	.16	.277	.58	.28	-.47	.548	-.86	.19
WISC3 VC	-.12	.277	-.43	.33	-.42	.548	-.77	.22
After Transformations								
NPT-R	.52	.274	1.90	.03	.09	.541	.17	.44
NPT-L	.31	.274	1.13	.13	.91	.541	1.68	.05
PEGS-R	.59	.274	2.15	.02	.44	.541	.81	.21
PEGS-L	.49	.274	1.79	.04	.58	.541	1.07	.14

NPT-R = Name Printing Test, right hand z-score
NPT-L = Name Printing Test, left hand z-score
PEGS-R = Grooved Pegboard, right hand z-score
PEGS-L = Grooved Pegboard, left hand z-score
TAP-R = Finger Tapping Test, right hand z-score
TAP-L = Finger Tapping Test, left hand z-score
WISC3 PO = WISC-III Perceptual Organization
WISC3 VC = WISC-III Verbal Comprehension

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[1]Tabachnick and Fidell (1989, p.73) recommend the use of "conventional but conservative" alpha levels of .01 or .001 to evaluate the significance of skewness and kurtosis.