

**THE DEVELOPMENT OF A NORMATIVE PROFILE TO DETERMINE
THE EXTENT OF HANDEDNESS IN CHILDREN**

Submitted by

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List of Abbreviations

BCT	Bimanual Coordination Test (<i>modified Bimanual Coordination Test</i>)
BDT	Bead Tracing Task (<i>modified hand performance subtest</i>)
BMC	Bilateral Motor Coordination (<i>initial bimanual coordination test, SIPT</i>)
BTT	Bear Tracing Task (<i>modified hand performance subtest of Skill Test</i>)
CI	Confidence interval
EHI	Edinburgh Handedness Inventory (<i>initial hand preference test</i>)
ES	Error score
FHPT	Functional Hand Preference Test (<i>modified hand preference test</i>)
IHD	Interhand difference
LQ	Laterality quotient
MAcc	Motor Accuracy Revised (<i>initial hand performance test</i>)
MCE	Midline crossing extent
MCQ	Midline crossing quotient
MCT	Midline Crossing Test (<i>modified midline crossing test</i>)
PHU	Preferred hand use
PL	Performance level
PR	Parent report
RS	Raw score
SCSIT	Southern California Sensory Integration Tests
SIPT	Sensory Integration and Praxis Tests
SVCU	Space Visualisation and Contralateral Use test (<i>initial midline crossing test</i>)
TMMC	Test of Manual Midline Crossing (<i>basis for modified midline crossing test</i>)

Abstract

Handedness establishment is decisive in the development of manual skill and occupational performance, and unestablished handedness has been associated with developmental delay. Furthermore, evidence exists that motor and learning problems could occur if a child's handedness is misclassified. The accurate assessment of handedness of preschool children by paediatric occupational therapists is therefore important. However, unestablished handedness has received little attention within the occupational therapy literature, and there is a lack of comprehensive handedness assessments designed to investigate unestablished handedness and related neuromotor behaviours. Exploring handedness-related neuromotor behaviours such as unimanual and bimanual hand use executed in midline, ipsilateral and contralateral spaces in addition to hand performance, is likely to inform subsequent treatment approaches and rendered them more effective.

The introduction (Chapter 1) explores neurophysiological evidence and models relating to the origin and dysfunction of handedness within the handedness literature, and the need for a handedness profile is justified. The first study (Chapter 2) assesses the potential of existing tests to evaluate the extent of handedness in a normative sample of 5-year old children, but results indicate skewed and kurtosed distributions. Two of the four initial tests are modified for the second study (Chapter 3), where handedness is assessed in 3, 4 and 5-year old normal children, showing more normal distributions. However, the other two initial tests fail to demonstrate sufficient variability despite the introduction of younger age ranges. These tests are also modified in a third normative study with 5- to 6-year old children (Chapter 4), where initial and modified tests are compared. The modified tests reveal suitable variability and sensitivity to detect degrees of handedness. Using the normative data of the third study as a basis, a handedness profile is developed (Chapter 5). The fourth study (Chapter 6) applies the normative profile to children with minimal dysfunction aged 4 to 7 years to investigate and classify the extent of handedness establishment and performance in children with normal handedness. The usefulness of the handedness profile is explored (Chapter 7), linking identified handedness features in children with uncertain hand use with proposed causes of handedness variability reported in the literature. The application of the handedness profile in paediatric occupational therapy concludes the chapter.

Statement of Authorship

Except where reference is made in the text of the thesis, this thesis contains no material published elsewhere or extracted in whole or in part from a thesis by which I have qualified for or been awarded another degree or diploma.

No other person's work has been used without due acknowledgement in the main text of the thesis.

This thesis has not been submitted for the award of any degree or diploma in any other tertiary institution.

All research procedures reported in the thesis were approved by relevant Safety / Ethics Committees.

Signature: 

Date: 26 / 02 / 03

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CHAPTER 1

INTRODUCTION

The establishment of handedness is critical for successful occupational performance and development of high manual skill levels (Hurlock, 1975; Mandell, Nelson & Cermak, 1984; Subrina, 1969; Vasconcelos, 1993). It is unlikely that a child will be able to develop optimal skill if hands are changed during tasks such as drawing or writing, as the preferred hand will fail to specialise to the required proficiency (Hurlock, 1975). In addition, established handedness is considered to be an important indicator of the hemispheric specialisation and callosal myelination required for development of apt motoric skills, language and cognitive processes (Annett, 1998; Bishop, 1990a, 1990b; Orton, 1925, 1937; Satz, Rardin & Ross, 1971). Conversely, unestablished handedness, associated with developmental delay or even pathological conditions, might reflect inadequate hemispheric specialisation (Coren, 1992; Gazzaniga, 1970). Furthermore, evidence exists that motor and learning problems frequently occur in children who learn to write with the non-preferred hand due to incorrect handedness classification (Ardila, Correa, Zuluaga & Uribe, 1988; Bishop, 1990a; Clark, 1957; Fischer, 1970; Hildreth, 1949a, 1949b; Peters, 1990; Sattler, 1998, 2001, 2002). In this context, the promotion of handedness in children with unestablished handedness as a necessary and important domain of occupational therapy (Mandell, Nelson & Cermak, 1984).

The accurate assessment of handedness in pre-school children is therefore of significance to occupational therapists. However, to date unestablished handedness has received little attention within occupational therapy literature. To understand the complex phenomenon of handedness and the variations in its establishment within the context of occupational performance, greater knowledge is required of both unimanual and bimanual hand preference and hand performance, executed in midline, ipsilateral and contralateral spaces. Exploring the neurophysiological development and the variations in handedness presentation in the context of occupational performance is deemed to increase the understanding of children who present with unestablished handedness in therapy. A better comprehension of handedness variability would also inform treatment approaches and render them more effective.

1.1 Outline of Chapters

This introductory chapter examines neurophysiological evidence for handedness and models relating to its origin and purpose, in addition to theoretical postulates illustrating the need and the importance for handedness establishment. Handedness is discussed in the context of proposed reasons for its existence, its prevalence, definition and classification. Possible causes for handedness variability (hereon referred to as *variable handedness*) and related problems are also presented. The neurophysiological development of callosal and cortical maturation and associated neuromotor behaviours (i.e., handedness, midline crossing and bimanual coordination) are examined in normal and clinical populations. Finally, the need to develop a handedness profile, based on modifications to existing tests, is emphasized, implemented, and its practical application explored.

The first study presented in Chapter 2 assesses the usefulness of existing tests to evaluate the extent of handedness in a sample of normal 5-year old children. Necessary test modifications for midline crossing and bimanual coordination are discussed and implemented in Chapter 3, and the application of these modified tests with a sample of 3-, 4- and 5-year old normal children is reported. In Chapter 4, further modification of the two remaining initial tests for hand preference and hand performance is described, and a third normative study compares initial and modified tests. Based on the normative study of the third study, Chapter 5 constructs a normative handedness profile using percentiles. Chapter 6 presents a fourth study that applies the normative profile to a clinical sample of 4- to 7-year old children presenting with unestablished handedness. A comparative analysis between the normal and clinical populations is performed, and the clinical handedness profiles are explored for typical handedness features, using several case studies for illustration. (See Appendix 1A for an overview of the research designs for Chapters 2, 3, 4, 5 and 6.) Finally, in Chapter 7 reflects on the usefulness of the handedness profile in the context of a conceptual framework and relevant literature. The application of the handedness profile as a tool to guide clinical decision making and occupational therapy treatment, is proposed. (See Appendix 1B for a glossary summarizing the terminology presented in this thesis.)

1.2. The Importance of Handedness Establishment

1.2.1 Factors Influencing the Establishment of Handedness

1.2.1.1 Neuro-Anatomical and Neurophysiological Foundations of Handedness

Findings from scientific research link hemispheric integration and callosal maturation to many higher cognitive activities, such as complex problem solving, visuomotor coordination, language skills, social competence as well as handedness establishment (e.g., Chiarello, 1980; Ettinger, Blakemore, Milner & Wilson, 1972; Rourke, 1987; Temple, Jeeves & Vilarroya, 1990). When neuroscientists became aware of the functional asymmetry of the brain, they regarded the two hemispheres as a left-right dichotomy of ‘two minds, two consciousnesses’ (Gazzaniga, Bogen & Sperry, 1962). It was assumed that the left hemisphere was ‘dominant’ and superior to the right hemisphere, particularly for speech and praxis (Gazzaniga et al., 1962; Gazzaniga & Sperry, 1967; Luria, 1973; Sperry, 1974), while the right (‘lesser’, ‘inferior’) hemisphere provided a general context to function in non-verbal, emotional and visuospatial domains (Hécaen & Sauguett, 1971; Luria, 1973; for a review, see Beaton, 1985).

Currently however, hemispheric ‘dominance’ is viewed as *relative* rather than absolute, whereby one hemisphere is specialised only in relation to the other (Ornstein, 1997). This bilateral concept of ‘asymmetric but integrated’ hemispheric roles assumes that the hemispheres operate collaboratively on all tasks, whilst showing flexibility in acquiring these roles, should the need arise (e.g., after brain damage) (Deacon, 1997; Gazzaniga, 1995; Ornstein, 1997).

In addition to the emphasis on hemispheric role integration, there is continued support in the literature for cortical lateralisation regarding specialised hemispheric function and fundamental differences in information processing (Galín, 1974; Pally, 1998; Tucker, 1981) (see Table 1.1 for more detail).

Table 1.1. Empirical Findings Supporting the Proposed Specialised Roles for the Left and Right Hemispheres

<i>Authors</i>	<i>Left Hemisphere Specialisation (superior right hand performance)</i>	<i>Right Hemisphere Specialisation (superior left hand performance)</i>
Carson, 1989; Gazzaiga & Sperry, 1967; Walch & Blanc- Garin, 1989		Right handers show superior left hand performance in haptic tasks, including 3-D relationships and spatial memory.
Ingram, 1975		Right handers show superior left hand performance in manual gestures.
Holloway & LaCoste- Larey-Mondie, 1982; LeMay, 1976	Language-related cerebral asymmetries (e.g., planum temporale, sylvian fissure and occipital petalia) are larger on the left side in right handed subjects.	
Kolb & Wishaw, 1996	Left hemisphere specialises in fine resolution of temporal stimuli.	Right hemisphere specialises in gross discrimination.
Young, 1990	Left hemisphere shows superior inhibition skill affecting motor behaviour.	
Sergent, 1991	Left hemisphere specialises in detailed operation.	Right hemisphere is involved in preliminary processing.
Springer & Deutsch, 1993	Left hemisphere shows sequential analytic skills.	Right hemisphere demonstrates holistic, parallel processes.
Haaland & Harrington, 1989	Left hemisphere controls open-loop (aiming) movement.	Right hemisphere specialises for closed-loop corrective movement.
Hiscock, Hiscock, Benjamins & Hillman, 1989	Right non-affected hand (i.e., contralateral to the non-affected left hemisphere) in left hemiplegic individuals demonstrated a significantly better performance quality than the left non-affected hand in right hemiplegic individuals with left hemispheric lesions. Suggests a left, hemispheric superiority for certain motor tasks.	
Kim, 1994	Right handers appear to have a greater mean hemispheric asymmetry than left handers.	Left handers show greater variance in hemispheric asymmetry.

Based on this type of neurophysiological and neuro-anatomic research investigating hemispheric lateralisation and specialisation, it has been suggested that the two hands display asymmetrical behaviour because they reflect the controlling contralateral hemispheres (e.g., the left hand is superior in spatial tasks regardless of handedness) (Carson, 1989; Ingram, 1975). However, there is a lack of evidence to determine whether these asymmetries are present since embryogenesis and develop into corresponding

functional asymmetries in later life, or whether anatomical asymmetries develop later as a *result* of learnt hand use and the interaction with the environment (Hopkins & Rönqvist, 1998). Environmental influence appears to be evident in the development of other brain structures associated with handedness establishment, such as the corpus callosum. For example, postnatal maturation of the corpus callosum appears to be significantly influenced by experience, based on great variations in callosal size, irrespective of age and gender (Bleier, Houston & Byne, 1986; Cowell, Allen, Yalalimo & Denenberg, 1992). In addition, there is neuro-anatomical evidence that the corpus callosum differs with handedness presentation, being approximately 11% larger in left handed and 'ambidextrous' individuals compared to well-established right handers (Aboitiz, Scheibel, Fisher & Zaidel, 1992; Bleier, Houston & Byne, 1986; Witelson, 1985).

The corpus callosum is the main structure used for interhemispheric communication (Martin & Jessell, 1991), and since the opposite hemisphere primarily controls the motor cooperation of the two hands (Haaxma & Kuypers, 1974), interhemispheric communication ensues, particularly for activities that are not over-learned (Beaton, Hugdahl & Ray, 2000; Preilowski, 1972; Zaidel & Sperry, 1977). Similarly, visual processing is contralateral during reaching, necessitating interhemispheric communication during manual midline crossing (Bryden & Bulman-Fleming, 1994).

Gazzaniga (1970) accentuated the importance of interhemispheric communication for the establishment of handedness. It has been proposed that the corpus callosum, one of the last neurological structures to complete myelination (Farber & Knyazeva, 1991), is instrumental in manual lateralisation and specialisation. Myelination of the corpus callosum is thought to signal the emergence of hand preference, reflecting hemispheric specialisation of cortical function (Gazzaniga, 1970). In other words, the hand-cortex relationship is considered to be a two-way process: more frequent manipulation with the right hand increases the development of the left hemisphere, which in turn reinforces right contralateral hand use until hand/brain 'dominance' is established (Gazzaniga, 1970).

Whilst it may not be clear to date which parts of the brain are involved in handedness establishment, it seems important not to restrict this process to specific parts of the brain, such as the contralateral cortex. Neuroscientific evidence has emerged indicating that

simple tasks tend to involve one hemisphere, whereas effective solving of more complex tasks requires both hemispheres and interhemispheric communication for comparison (Weissman & Banich, 2000). These findings suggest that neurophysiological involvement might be task dependent. More specifically, some authors have proposed that the task may *determine* handedness (Steenhuis & Bryden, 1989). As proposed in systems theory (Kelso, Holt, Kugler & Turvey, 1980), handedness could be viewed as one aspect of the neuromotor system interacting with the environment. It is therefore important to review possible influences and origins of handedness in relation to its establishment.

1.2.1.2 Genetic Influence on Handedness

Studies investigating familial handedness across generations have found support for a genetic aspect to handedness. Hicks and Kinsbourne (1976) discovered that there was a significant correlation between the handedness of college students and their parents, but only if the relationship was biological. A meta-analysis demonstrated a one in ten chance of having a left handed offspring if both parents were right handed (Porac & Coren, 1981). If one parent was left handed, particularly the mother, this ratio doubled to 2:10, and if both parents were left handed, the chance of left handedness further increased to 4:10 (Bryden, Roy, McManus & Bulman-Fleming, 1997; McManus & Bryden, 1992; Porac & Coren, 1981). Other studies have found an even higher ratio of left handers from left handed parents. For example, Annett (1978, 1985, 1995) assessed the difference in skill level between the hands rather than preferred hand use, excluding parents who might have been pathological left handers (see Section 1.2.1.3 on pathological influences). She found a 50% prevalence of left handed offspring from two left handed parents.

Several genetic theories have attempted to explain the incidence of left handedness. Annett's (1972, 1985, 1994, 1995) well known right shift theory postulates that handedness is influenced by an inherited *factor* rather than being inherited directly. A single gene is thought to be responsible for displacing handedness, assumed to be a random or chance phenomenon, towards the right (i.e., right shift). One allele causes right handedness, and another allele results in the independent and random lateralisation of manual praxis. Those individuals homozygous for the random factor would have a 50% chance of being left or right handed. Two factors influence the handedness outcome

and hemispheric specialisation for speech: a genetic right shift (RS+) factor, and a random congenital, but non-genetic factor which codes for speech representation in the left hemisphere. Right handedness is linked to left hemispheric speech representation, and thereby determined by the genetic RS+ factor, while the random factor implies that left handedness and left hemispheric speech representation are not inherited.

According to Annett's model, approximately 25% of individuals presenting with atypical patterns of hemispheric specialisation (i.e., right and bilateral cerebral speech representation) would become left handers. However, Annett argued that the right-biased cultural and environmental influences increase the development of right handedness, so that the incidence of left handers is reduced to approximately 16%, which is congruent with her prevalence studies based on hand skill (Annett, 1998). Furthermore, Annett has proposed that the strength of handedness is inheritable, since some individuals may be homozygous for the RS factor (i.e., RS++), displaying a stronger handedness than individuals who are heterozygous (i.e., RS+-). Annett's model has been criticised for lack of empirical support for the 50% frequency of both dominant and recessive alleles, and the assumption that hand performance and hand preference co-vary (Hopkins & Rönnqvist, 1998; Porac & Coren, 1981).

Similarly to Annett, the authors McManus and Bryden (1992) argued for a single gene with two alleles indirectly determining handedness, namely Dextral (D) and Chance (C). Individuals with a Dextral-Dextral (DD) genotype would be right handed, whereas persons with a Chance-Chance (CC) genotype would have an equal chance of being left or right handed. Heterozygous individuals (DC) received proposed 'additivity', having a 25% chance of being left handed as opposed to a 75% chance of becoming right handed. Unlike Annett, the authors proposed that handedness and hemispheric specialisation are coded independently of one another, and the presence of a sex-linked moderator gene accounts for the increased incidence of left handedness in males. Several other genetic models have been proposed, which have been summarised in Appendix 1C.

The central idea of the genetic models appears to be similar. Approximately half of the population inherits the *potential* to become either left or right handed, but only a proportion of these individuals eventually present as left handers. The genetic models could possibly explain the variation in strength of handedness since variable handers

might include those individuals who have an equal chance of being left or right handed. However, twin studies have compounded the complexities involved in the inheritance of handedness, since monozygotic twins sharing identical genetic make up, do not necessarily present with the same handedness (Oberleke, 1996), and the incidence of handedness discordance being as high as 25% (Carter-Saltzman, Scarr-Salapatek, Barker & Katz, 1976). Thus, current genetic models do not convincingly explain the reduced handedness concordance in monozygotic twins (Stein, 1994), nor is there certainty as to what proportion of people should 'genetically' be left handed, particularly if the socio-cultural and environmental factors reduce the phenotypical presentation of left handers to an unknown extent.

Nevertheless, the increase in ratios of left handed offspring from left handed parents, including the handedness concordance in 75% of identical twins, suggests at least a genetic *component* to the handedness phenomenon (Bryden, Roy, McManus & Bulman-Fleming, 1997). Recent findings also suggest that there is an X-linked pattern of genetic influence on handedness (McKeever, 2000). However, to date no handedness gene or allele has been identified that could ascertain the direction and extent of handedness, and genetic theories thus remain inconclusive. The assumption that a genetic composition is responsible for the direction of handedness permits left handedness to be a 'normal' inherited trait in a minority of people. At the same time, most genetic theorists do not account for prenatal, perinatal and postnatal influences which may increase the incidence of left handedness.

1.2.1.3 The Impact of Pathological Influences on Handedness

Models linking intrauterine influences and birth stress with handedness appear to be based on a genetically predetermined right handedness in humans. Generally, these models propose that left handedness is a failure to become right handed and is thereby rendered abnormal, 'anomalous' (Geschwind & Galaburda, 1985, 1987), or pathological (see Harris and Carlson, 1988, for a review on existing theories relating to pathological left handedness). The Geschwind-Galaburda theory is the most prevalent and controversial intra-uterine model for the cause of left handedness. It is based on the premise that anatomical asymmetries, evidently already present in utero, result in functional asymmetries (Geschwind & Levitsky, 1968). Geschwind and Galaburda

(1987) suggested that growth-retarding influences of chemicals and hormones, particularly testosterone, are most likely to affect the more vulnerable left hemisphere due to its slower rate of development. As a result, the anatomical brain asymmetries are reduced and the hemispheres become more symmetrical, which leads to anomalous dominance with equal chances of becoming left or right handed. The authors proposed that left handedness results if the right hemisphere becomes more specialised. In addition, variations in the chemical environment may cause the variability typical of left handedness.

The testosterone hypothesis has been extensively reviewed and questioned. Brain imaging studies have supported the link between anatomical asymmetries in language related brain areas and hand preference (Foundas, Leonard & Heilman, 1995; Steinmetz, Volkman, Jäncke & Freund, 1991; see Beaton, 1997 for a review). However, there are no longitudinal studies to indicate if the observed anatomical asymmetries in utero are related to corresponding functional asymmetries in later life. Recent evidence also suggests that brain symmetry appears to be triggered by trophic changes in the right hemisphere rather than growth retardation in the left hemisphere (Galaburda, Corsiglia, Rosen & Sherman, 1987; Habib, Touze & Galaburda, 1990). Moreover, if hormonal imbalances do exist, twins subjected to identical intrauterine factors should present with identical handedness, which is not necessarily the case (Oberleke, 1996; Stein, 1994). In addition, males are subjected to greater testosterone levels than females, which, according to Geschwind and Galaburda (1987) should result in a significantly higher incidence of 'atypical' handedness in males. However, significant gender differences were only found in some prevalence studies (McManus, 1991; Seddon & McManus, 1993) but not in others (Ashton, 1982; Beaton & Moseley, 1984; Bishop, 1989; Bryden, 1977; Salmaso & Longoni, 1985). (See also Section 1.2.2.1 on the prevalence of left, right and variable handedness.)

More recently, an increased incidence in left handedness was revealed in male individuals who were exposed to ultrasound in utero, which has been considered as another factor responsible for shifting inherent right handedness to left handedness (Kieler, Axelsson, Haglund, Nilsson & Salvesen, 1998). However, intrauterine conditions do not appear to be the only early influence on handedness development. Just as abnormal prenatal intrauterine conditions may impact on the development of hemispheric

specialisation, unfavourable perinatal and postnatal circumstances, including birth-related stress, seem to have a similar or an even more prevailing effect (Coren, 1992).

Birth-related stress has been cited as one of the most potent acquired influences on handedness outcome (Bakan, Dibb & Reed, 1973). It has been proposed that the 'dominant' hemisphere, which may not necessarily be the left, is most likely to be affected by early brain damage (Best, 1988). Goodman (1994) tested the hypothesis of corresponding hemispheric and manual dominance by investigating 463 children with hemiplegia in relation to familial handedness. Unexpectedly, he found a highly significant correlation between *right* hemiplegia and familial left handedness. Goodman interpreted the results as evidence against the notion of a more vulnerable 'dominant' hemisphere, and rather in support of a more vulnerable *left* hemisphere.

Other evidence exists to support greater vulnerability of the left hemisphere, based on a higher ratio of children with right hemiplegia (Uvebrant, 1988). Several reasons for the increased vulnerability of the left hemisphere have been proposed. Firstly, the blood supply to the left hemisphere has less volume (Raichle, 1987). Secondly, the right hemisphere matures more quickly and earlier than the left hemisphere, thus the latter is more likely to be damaged (Jacobson, 1978), being particularly vulnerable to intracranial focal lesions and intracranial haemorrhage (Schuhmacher, Barks, Johnstone, Down, Sher, Roloff & Barlett, 1988). Thirdly, the left hemisphere requires more blood for metabolism and burns oxygen more quickly (Bakan, 1977), and fourthly, the hormonal imbalances, especially testosterone, appear to affect the left hemisphere more strongly (Geschwind & Galaburda, 1987). In the case of early neural insult affecting the left hemisphere, the right hemisphere is thought to compensate by assuming a more active role, resulting in pathological left handedness (Orsini & Satz, 1986; Rasmussen & Miller, 1977; Soper & Satz, 1984). (See also Section 1.4.6 on pathological handedness.)

Several pre-, peri- and postnatal factors related to the birth process have been associated with an increased incidence of pathological left handedness. These factors include birth weight, prematurity, difficult delivery, induced birth, the mother's age, and smoking during pregnancy (see Appendix 1D for a summary). It has been suggested that these factors might later result in associated disorders such as dyslexia (e.g., Eglington & Annett, 1994), attention deficit disorder (ADD) (e.g., Gillberg & Rasmussen, 1982),

learning disability (e.g., Geschwind & Galaburda, 1984) and intellectual disability (e.g., Fein, Humes, Kaplan, Lucci & Waterhouse, 1984) (see Appendix 1E for more detail). However, some studies have failed to find support for an association between left handedness and pathological conditions (see again Appendix 1E). It has been argued that the proposed elevated incidence of 'pathological' left handedness is based almost exclusively on clinical groups, which consist of twice as many left handers as the normal population (Perelle & Ehrmann, 1982; Satz, 1972), and there is little evidence of an association between left handedness and pathology in the general population (Annett, 1992b; Hardyck & Petrinovich, 1977; Satz, Soper & Orsini, 1988).

Considering the evidence for a genetic versus intrauterine/birth-related stress basis for handedness, it is generally accepted that left handedness consists of two subgroups: *familial* (genetically based) and *pathological* (caused by brain damage) left handedness. Distinguishing between these two subgroups may produce very different research outcomes regarding comparisons between left and right handers (e.g., Annett, 1985; Hècaen & Sauguet, 1971; McKeever, 1981; Orsini & Satz, 1986). To date, there is no agreement on the definition of pathological left handedness. There are those researchers who suggest that pathological left handedness appears to develop only with substantial damage to the left hemisphere (Annett, 1985; McManus & Bryden, 1992; Satz, Orsini, Saslow & Henry, 1985), in which case the incidence of pathological left handedness is relatively low. Conversely, other researchers propose that pathological left handedness is a result of relatively minor neurological trauma. In the latter case, at least half of all left handers (Coren, 1992) or even all left handers (Bakan, 1990) are thought to demonstrate left handed behaviour with a pathological origin.

Hopkins and Rönnqvist (1998) emphasised that very strongly lateralised and unusually consistent hand preference during infancy, rather than fluctuating asymmetry, may be indicative of underlying neuropathology. It has been specifically suggested that poor performance of the non-preferred hand might be suggestive of early brain damage (Bishop, 1984; Gillberg, Waldenström & Rasmussen, 1984). This may affect the left or the right hand. There is indeed evidence for the existence of 'pathological right handers' (Kim, Yi, Son & Kim, 2001), referring to a group of familial left handers who experience early right brain injury and consequently develop right hand preference. However, the

incidence of pathological right handers has been estimated to be very low due to the restricted number of familial left handers (Satz, 1972, 1973).

Finally, if handedness is a manifestation of the extent of interhemispheric communication via the corpus callosum, clinical research should reflect a link between variable handedness and *callosal dysfunction*. There is evidence that dyslexia, which has also been linked with a greater incidence of unestablished handedness (Satz & Fletcher, 1987; Zeman, 1967), appears to be related to poor hemispheric lateralisation (Galaburda, 1993; Satz, 1991), and poor interhemispheric communication (Gladstone, Best & Davidson, 1989; Kerschner, 1983). However, other studies have failed to find support for an association between learning disabilities and unestablished handedness (Bishop, 1990a, 1990b). Also, Magnetic Resonance Imaging (MRI) of the corpus callosum did not reveal differences in callosal size between dyslexic and normal children (Larsen, Höien & Ödegaard, 1992).

In summary, the proposition that unusual pre-, peri- and postnatal conditions influence the cerebral lateralisation process of the immature brain, is supported by empirical evidence. Although many of the findings remain inconclusive, the impact of early unfavourable conditions on hemispheric specialisation has not been disputed to date. However, intrauterine models do not account for the increased incidence of familial left handedness suggesting a genetic component. Furthermore, these models fail to consider socio-cultural influences that are likely to cause an increased occurrence of right handedness.

1.2.1.4 Socio-Cultural and Environmental Influences

Genetic, intrauterine and birth-related stress theories have concentrated on predispositions and very early factors that could determine, influence and change the handedness outcome. However, handedness is undeveloped at birth, and becomes established within the first 5 to 6 years of life (Tan, 1985). While the *direction* of handedness may be already apparent in infancy and is considered to be stable by 5 years (McManus, Sik, Cole, Mellon, Wong & Kloss, 1988), the *degree* and consistency of handedness is subject to change, particularly up to the age of 9 years (McManus et al., 1988; Goodall, 1984), 11 years (Whittington & Richards, 1987), or even across the entire

life span (Porac & Coren, 1981). There is also some evidence that handedness establishment takes place earlier in right handers (i.e., by 5 years of age) than left handers (i.e., by 9 years) (Mandell, Nelson & Cermak, 1984; see also Section 1.4.3 on developmental delay). Environmental and cultural influences are likely to have a significant effect on handedness, although there is little empirical support for handedness as a sole product of cultural influences. For example, children of left handed foster parents do not exhibit an increased use of the left hand (Carter-Saltzman, 1980). Furthermore, in many societies it is far more likely that socio-cultural influences restrain left handedness, forcing, or at best encouraging, left handers to use their right hand (Harris, 1990). One of the more extreme examples is the account of Chinese children at Taiwanese schools, where the incidence of left handed writing is only 0.7% (Teng, Lee, Yang & Chang, 1976). No evidence was found, however, that forced right-handed writing also resulted in increased right hand use in other activities.

There is empirical support that the number of left handers is significantly higher in younger individuals than in older ones, both in cross-sectional and longitudinal studies (Coren, 1992; Hughdal, Satz, Mitrushina, & Miller, 1993; Porac & Coren, 1981; Porac, Coren & Searleman, 1986). Stricter socio-cultural pressures to use the right hand for socially important tasks were imposed particularly on previous generations, a phenomenon that has been described in the 'modification hypothesis' (Coren 1992). This hypothesis asserts that the existing right handed bias in the socio-cultural and physical environments coerces left handers to 'switch' handedness to the right (Coren, 1992; Sakano, 1982) (see Section 1.4.5 on switched handedness for more information). However, the modification theory has only addressed switching of well-established left handers. It is plausible that individuals with a *mild* left handed predisposition would be most vulnerable to right-biased socio-cultural pressures. It would therefore be possible that inherently mildly established left handers constitute a proportion of unidentified switched handers within the right handed population.

In summary, hand preference can be perceived as a multicausal behaviour that is influenced by a variety of mechanisms, including genetic and non-genetic factors. As Provins (1997) contended,

"what is genetically determined is a neural substrate that has significantly increased its functional plasticity in the course of evolution...What is fine-tuned is the relative motor proficiency or skills

achieved by the two sides in any given task according to the use and the demands made on them as a result of social pressure, other environmental influences or habit” (p.556).

Although the origin and cause of manual lateralisation is still debatable, the prevalence of left and right handedness appears to have existed fairly constantly since prehistoric times (Bradshaw & Rogers, 1996; Calvin, 1983; Corballis, 1983; Steele & Mays, 1995; Toth, 1985) and across most human societies (Hardyck & Petronovich, 1977; Harris, 1980, 1990; Peters, 1995). It could be concluded that handedness is a unique human trait, displaying a wide variety of degrees of presentation, which are not yet well understood.

1.2.2 Presentation and Definition of Handedness

1.2.2.1 Prevalence of Left, Right and Variable Handedness

There is a lack of coherent definitions, standard assessments and universal classification procedures for handedness (Annett, 1998; Bishop, 1990a). This renders accurate estimation of the incidence of left, right and variable handedness difficult. Nevertheless, findings of demographic studies have considered handedness as a trinomial phenomenon in terms of left, right and ‘mixed’ (or variable) handers. One of the more conservative estimates states that approximately 85% of the adult population are right handed, about 10% are left handed, and 5% show variable handedness (Coren & Porac, 1977). Other studies have provided more specific distinctions between different handedness groups. Coren (1992) differentiated between ‘strong’ and ‘weak’ left/right handers, suggesting that 5% present as strong left handers, 72% of people are strong right handers, and the remaining 23% demonstrate ambiguous hand use. Annett (1998) made a distinction between ‘ambidextrous’ and ‘mixed’ handers, where ambidextrous handers by definition have the same level of skill in either hand, while ‘mixed’ handers use their left hand for some activities and their right hand for other tasks. Annett (1998) reported only 0.3% of ambidextrous handers, but as many as 30% of mixed handers, a figure supported by Amunts, Jäncke, Muhlberg, Steinmetz and Zilles (2000).

Furthermore, the prevalence of left handedness has been estimated to be 25% higher in males than females (Heim & Watts, 1976; Seddon & McManus, 1993; Thomson & Marsh, 1976). This gender difference may be due to complex factors leading to a

differential expression of laterality in females (McManus, 1991), greater testosterone levels in utero (Geschwind & Galaburda, 1987), or a possible genetic influence on handedness (McKeever, 2000). However, other studies failed to find a significant gender difference (Ashton, 1982; Beaton & Moseley, 1984; Bishop, 1989; Bryden, 1977; Salmaso & Longoni, 1985). The general consensus is that amongst more 'liberal' societies, including most westernised and Caucasian-based populations, 10% to 12% of individuals are left handed (Ardila, Ardila, Bryden, Ostrosky, Rosselli, & Steenhuis, 1989; Connolly & Bishop, 1992; Coren & Porac, 1977; Ellis, Ellis & Marshall, 1988; Harris, 1990; Nicholls, 1998).

1.2.2.2 Definition of Handedness

Difficulties in estimating the prevalence of handedness appear to be directly linked to problems with definition. Sometimes handedness is referred to as hand *preference* and sometimes hand *performance*. *Hand preference* has been defined as the tendency to perform the majority of tasks with one hand rather than the other (Nalçai, Kalayçioğlu, Çiçek & Genç, 2001). This does not necessarily mean that the chosen hand is more efficient (Porac & Coren, 1981). Moreover, hand preference has been stipulated to be the spontaneous *untrained* hand use as a measure of the inherent predisposition to handedness (McManus & Bryden, 1992; Olsson & Rett, 1989; Sakano, 1982; Sattler, 1998; Steenhuis & Bryden, 1989; Steenhuis, Bryden, Schwartz & Lawson, 1990). *Hand performance* is most aptly defined as the superior proficiency of one hand over the other in tasks requiring skill (Annett, 1970a). The innate motor ability interacts with environmental demands and develops with practice to varying extents of skill acquisition, which may be independent of hand preference (Porac & Coren, 1981).

The distinction between hand preference and hand performance has been explored extensively (Annett, 1985; McManus & Bryden, 1992; Peters, 1996; Todor & Doane, 1977). According to Annett (1985), the more skilful hand also becomes the preferred one, whereas McManus and Bryden (1992) conclude that preference precedes performance. It is important to note that different assessments were used in studies supporting the above conclusions, which may be responsible for the contradictory findings. A cause-effect relationship between preference and performance is far from clear, as Peters (1996) suggested:

“is it the predominance of inherent biases interacting with environmental chance events, or is it the predominant environmental influence interacting with weak inherent biases which determines the final pattern of behaviour?” (p.118).

To date there is no clear answer to this question. The literature exploring hand preference and performance/proficiency distributions displays a variety of results, where some performance and preference tasks yield large differences between the hands (bimodal) and others do not (unimodal) (Annett, 1992a; Borod, Caron & Koff, 1984; Steenhuis, 1996). For example, there is greater discrepancy between the hands in handwriting proficiency than grip strength (Provins & Magliaro, 1989). In addition, factors such as practice or task nature may influence the magnitude of the interhand performance differences (Annett, 1992b).

It might be assumed that hand preference and hand performance/proficiency should be virtually interchangeable, (i.e., the preferred hand is also the more skilled and proficient one and vice versa). However, the correlation between hand preference and performance has been shown to be weaker than expected (see Appendix 1F for examples of empirical studies).

Porac and Coren (1981) suggested that preference and performance have a common underlying factor, since their correlation, whilst not always strong, is still significant. Furthermore, the correlations between preference and performance appear to be task dependent (see Porac & Coren, 1981, for a review). Interestingly, in some studies the correlation between preference and performance became significantly weaker when the sample was divided into left and right handers (Bryden, Singh, Steenhuis and Clarkson, 1994; Lake & Bryden, 1976; Tapley and Bryden, 1985). Furthermore, Peters (1996) found that hand preference correlated more strongly with performance in consistent handers than inconsistent handers (see Section 1.2.2.3 on a classification of consistency). The discrepancy between preference and performance is also likely to be compounded by incompatible assessments where hand preference is often assessed subjectively, based on self report or inventories, while hand performance is evaluated more objectively through task execution (Guiard & Ferrand, 1996).

The relatively low correlation between hand preference and hand performance indicates that hand function is multi-faceted and multi-dimensional (Steenhuis, 1996). Several authors have attempted to identify the factors determining hand preference and hand

performance, but no consensus on these factors has been reached. Bryden (1982) proposed four 'types' of hand preference: actions that require *skill* such as using a tool, *reaching* actions that do not require any skill, *power* actions such as carrying a suitcase, (where one is inclined to change hands due to fatigue), and *bimanual* actions where both hands are involved. He found that hand preference is most significant for tool use and bimanual actions, and least significant for power actions and reaching (Bryden, 1982).

Healy, Liederman and Geschwind (1986), and Geschwind and Galaburda (1987) suggested that one significant dimension of hand preference was determined by the musculature involved in task execution. There is physiological evidence that both the contralateral and ipsilateral hemispheres control proximal arm muscles via multisynaptic pathways, whereas distal control of the hand and fingers is executed by the contralateral hemisphere via the corticospinal tract (Brinkman & Kuypers, 1973; Glickstein & Buchbinder, 1998; Haaxma & Kuypers, 1974; Peters, 1995). Support for the distal-proximal distinction was found by several authors who observed that fine manipulations performed by distal musculature appear to be more lateralised than gross motor tasks involving mainly proximal musculature (Bryden, Bulman-Fleming & McDonald, 1996; Peters & Pang, 1992). Other studies only partially supported these findings, suggesting that the musculature used seems to be task-dependent (Case-Smith, Fisher & Bauer, 1989; Steenhuis & Bryden, 1989). Whether and to what extent hand preference is influenced by proximal and distal musculature is yet to be empirically established.

Steenhuis & Bryden (1989) proposed that the position of an object in space (i.e., ipsilateral or contralateral) would influence preferred hand use. In addition, they argued that hand preference consists of two dimensions relating to *skilled* and *unskilled* tasks (see also Section 4.2.3.1 for a more detailed discussion). It has been postulated that when the two hands are equally skilled for a task, either hand may be selected. As skill level differences increases, so does the extent of preferred hand use (Bishop, 1990a).

As with hand *preference*, various dimensions of hand *performance* have been proposed. Some researcher propose hand performance to consist of two main factors: strength, and a combination of speed and accuracy/dexterity (Borod, Coron & Koff, 1984; Porac and Coren, 1981). However, several authors found that hand strength correlated only weakly with hand preference (Johnstone, Galin & Herron, 1979; Provins & Cunliffe, 1972; Satz,

Achenbach & Fennel, 1967). Different hand performance factors identified by other researchers through component analysis (e.g., Barnsley & Rabinovitch, 1970) included reaction time, speed of arm and finger movement, arm-hand steadiness, arm movement steadiness, and aiming. All factors except reaction time, revealed a significant correlation with hand preference (Barnsley & Rabinovitch, 1970).

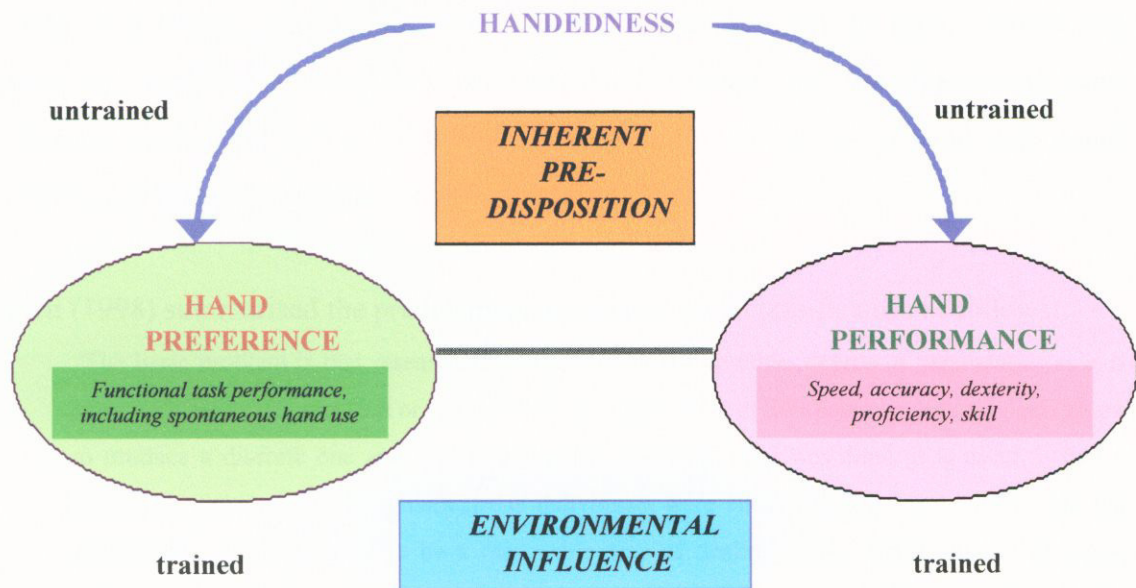
The divergent opinion in the literature demonstrates the complex nature of handedness as a multidimensional variable. Furthermore, while the multidimensional concept of hand preference and hand performance enables a more detailed understanding of handedness, no consensus has been reached on the type, parameters and nature of the dimensions. This renders comparison between studies difficult. To overcome this problem of poor inter-study comparability, *hand preference* has frequently been treated as a unidimensional variable (Porac & Coren, 1981), where all assessment items are equally weighted and, in combination, reflect a single dimension of preferred hand use.

Based on the assumption of unidimensionality, one hand preference inventory in particular has been widely used in a standardised or adapted form over several decades (Oldfield, 1971), allowing for improved comparability between studies (see Section 2.1.1 for test description of Oldfield's Edinburgh Handedness Inventory). Furthermore, unidimensional hand preference assessments appear accurate in determining the *direction* of hand preference (i.e., left or right), which can be obtained more reliably than its *degree* (McMeekan & Lishman, 1975). Similar to Provins (1997), McManus (1984) advocated that the direction of hand preference has a genetic basis while the extent or degree of hand preference is subjected to developmental and environmental factors. Furthermore, it has been argued that the degree of handedness is a more important determinant of ability than the direction of handedness, particularly when studying individuals who lack a distinct hand preference (Annett, 1970b, 1998; Bradshaw & Nettleton, 1983; Swanson, Kinsbourne & Horn, 1980).

To date, most researchers have defined handedness dimensions in relation to their particular study (Bishop, 1990a). For the purpose of this study, handedness will comprise both hand preference and hand performance as two of its dimensions, both subjected to different levels of training. Contextually, handedness is subject to genetic predisposition

and environmental factors (see Figure 1.1 for the researcher's illustration of the dimensions of handedness).

Figure 1.1. Hand Preference and Hand Performance as Two Dimensions of Handedness



1.2.2.3 Classifications of Handedness

It has been proposed that the 'strength' of handedness is inherited, with some individuals presenting with strong left and right handedness, while others show greater variation in their preferred hand use (Bryden, 1982; Coren, 1992; Coren & Porac, 1980). Strength or the *degree* of preferred hand use has frequently been measured on a continuum or as a percentage. Other studies have employed multiple categories instead of a continuum, ranging from three to five or more handedness groups, where strong or explicit handers are distinguished from weak or moderate handers (e.g., Annett, 1985; Peters, 1996; Schachter, 2000).

Classification of handedness in the literature appears to generally entail a non-specific process. Rigal (1992) classified children into left, right and mixed handers, using a score of 70% or above for established handers. These thresholds were selected arbitrarily, as no natural limits exist for the 'mixed' category, and the range for mixed subjects is often varied to meet the researcher's goals (Rigal, 1992). Others have defined left or right handedness as being 100% consistent across all tasks, and any variations from this standard was classified as mixed (Annett, 1970b). Clearly, the classification method

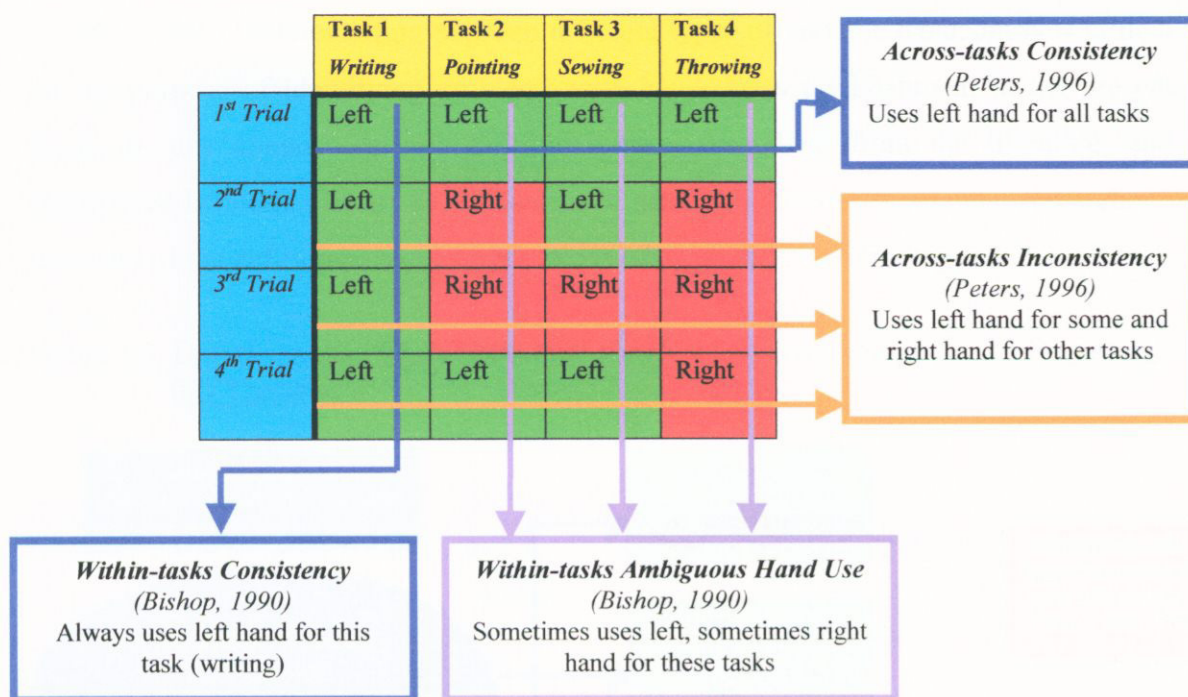
influences the incidence of left, right and mixed handers (Gudmundsson, 1993; see Bishop, 1990a, for a review). Annett (1970b) derived a subgroup classification to assess if meaningful distinctions could be made among mixed handers. She defined eight classes of hand preference, with classes one and eight consisting of 'pure' right and left handers respectively, classes two, three, four and five were mixed right handers and classes six and seven mixed left handers. Annett found that the degrees of hand preference represented by the subgroups related reliably to degrees of hand skill (hand performance) that was assessed using a pegboard task.

Annett (1998) summarised the predicament associated with classification as follows:

“The basic problem is that researchers treat a continuous variable, degree of handedness, as if it were a simple binary one (left or right). There are many ways of dividing a continuous distribution to produce a discrete one and it is often unclear precisely what was done. It is usual to find a statement of the effect that ambidextrous individuals were either discarded or counted with the left-handers, which appears to be a reasonable way of dealing with a small number of cases. However, the authors are usually confusing ambidexterity with mixed handedness and the true size of the problem of mixed handedness is simply not acknowledged. If some 33 percent of a sample can be treated arbitrarily, inconsistency of findings is not surprising” (p.68).

The left/right/mixed classification, however, has not been the only criteria for grouping a sample population. Consistency in hand use is another important means of categorisation. Whilst several studies have investigated consistency in relation to performance domains (e.g., consistence and intelligence, Kee, 1991), the definition of consistency differs between the studies. Bishop (1990a) stressed the importance of measuring consistency *within-tasks* as a separate variable. She argued that inconsistent or 'ambiguous' hand use within a single task (e.g., alternating right or left hand use for throwing) might be more reflective of dysfunction than a hand preference score. Consistency can also be measured *across-tasks* whereby high consistency reflects exclusive left or right hand performance (Peters, 1996, 1990; Peters & Servos, 1989). Thus, an individual might display inconsistency by using the left hand for certain tasks and the right hand for others, resulting in a low overall hand preference score, but concurrently show consistency *within-tasks* by always using the same hand for the same tasks. The across task inconsistency and within-task consistency corresponds with Bishop's (1990a) 'mixed' handedness described earlier. Figure 1.2 has been designed by the researcher to summarise both types of consistency.

Figure 1.2. Summary of Definitions for Consistency



Peters (1996) found that right handers showed greater strength in their preferred hand, but only consistent (across-tasks) left handers showed superior strength in their left hand, whilst inconsistent left handers demonstrated a stronger right hand. Peters proposed that the increased variability in left handers compared to right handers might be substantially influenced by inconsistent handers in the left handed group. More specifically,

“consistent left handers and right handers form extremes on the performance spectrum, with inconsistent left handers being intermediate in their performance. This suggests to us that the distinction between consistent and inconsistent left handers is not merely a matter of manual motor control and reaches deeper into interhemispheric communication arrangements” (p.118).

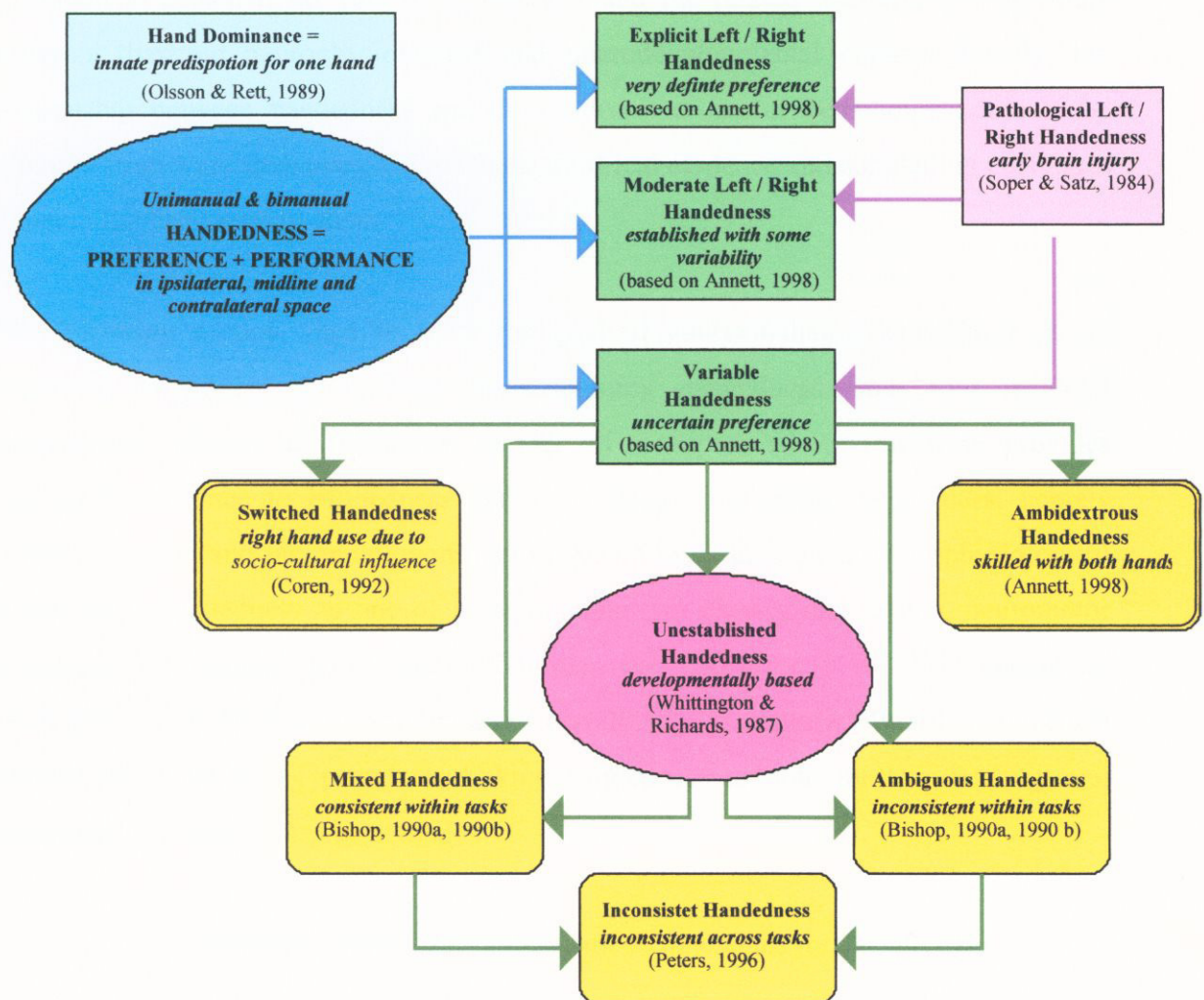
Unfortunately, research studies frequently do not differentiate between consistent and inconsistent handers within- or across-tasks. This might be an important classification in identifying problems associated with variable handedness.

1.2.2.4 Definition of Variable Handedness

The definition of handedness is closely related to its method of classification. There is no consistent terminology for variable handedness across studies. Frequently used terms are ‘ambilateral’ (Flowers, 1975; Olsson & Rett, 1989; Schachter, Ransil & Geschwind, 1987) ‘mixed’ (Bishop, 1990a, 1990b), ‘inconsistent’ (Peters, 1996), ‘ambiguous’ (Bishop, 1990a; Hauck & Dewey, 2001; Molfese & Segalowitz, 1988), ‘adextral’

(Witelson, 1985), ‘anomalous’ (Geschwind & Galaburda, 1987), or ‘ambidextrous’ (Annett, 1998). Differentiating between different types of variable handedness is critical for the purpose of identifying problems with handedness establishment in the present thesis. In this context, several definitions were assembled from the literature, and distinctions between various definitions were made (see Figure 1.3 for the researcher’s summary of the definitions and classifications of handedness terminology).

Figure 1.3. Definitions and Classification of Handedness Terminology for the Purpose of this Thesis



Note. Variable handedness is used as a neutral umbrella term embracing all forms of ‘non-right’ and ‘non-left’ handedness. Those definitions pertaining to specific types of handedness summarised in this diagram will be discussed in more detail in Section 1.4 on proposed causes for variable handedness. (See also Appendix 1B for Glossary.)

1.3 Exploring Handedness and Related Neuromotor Behaviours Within the Context of Occupational Performance

The reviewed literature in the previous sections strongly suggests that handedness is a variable, complex, interactive and multidimensional phenomenon subject to hereditary, environmental and social influences. In order to understand and assess handedness in this context, those neuromotor behaviours that appear to be closely linked to both handedness, function and environment need to be identified and explored. In addition, it is critical to establish the role of handedness and the related neuromotor behaviours within a dynamic neurophysiological and neurodevelopmental context. Finally, the relationship between handedness and the related neuromotor behaviours needs to be explored from a research perspective where empirical evidence and concluding postulates augment the link between them.

The following section aims to meet the goal of contextualising handedness as an important component to function by examining handedness from four different perspectives. Firstly, a conceptual model of occupational performance provides functional relevance to handedness and two related neuromotor behaviours, namely midline crossing and bimanual coordination. Secondly, a theoretical neurophysiological model maps handedness as one of three separate, yet closely interrelated, neuromotor behaviours of manual lateralisation. Thirdly, the concurrency of development of handedness, midline crossing and bimanual coordination is explored. Fourthly, empirical research and concluding postulates linking handedness to both midline crossing and bimanual coordination are investigated.

1.3.1 Conceptual Model of Occupational Performance for Handedness

When handedness is examined within the function-related context of occupational performance, a purposeful association emerges between handedness, midline crossing and bimanual function. There is increased use of the preferred hand in both ipsilateral and contralateral spaces as the child matures. Furthermore, activities requiring higher levels of bimanual coordination, or *bimanual role differentiation* (Fagard, 1998), usually involve a leading (usually the preferred) hand, and a more supportive or assistive (usually the non-preferred) hand.

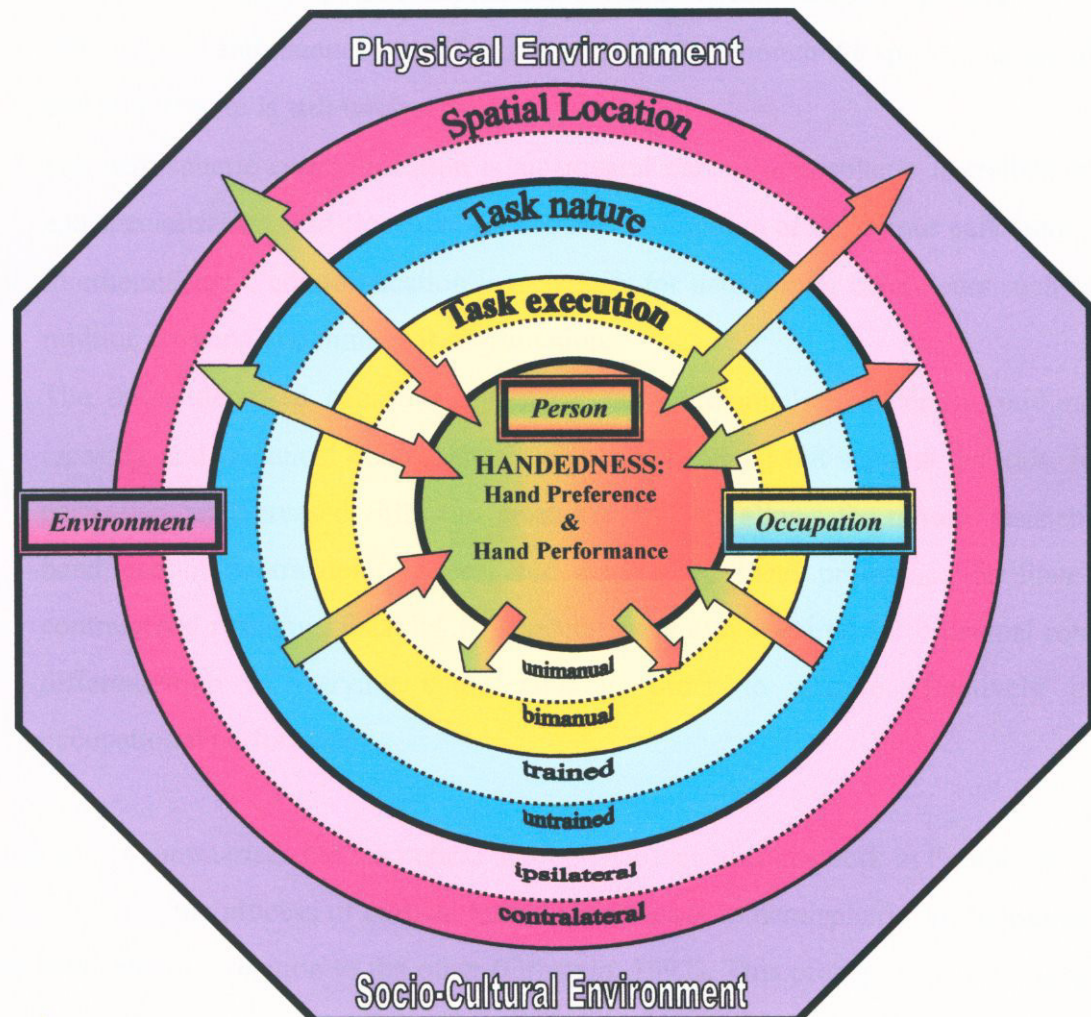
Occupational performance has been defined as a dynamic relationship between a *person* (including various *performance components*), relevant *occupations* and the *environment* (Law, Cooper, Strong, Stewart, Rigby & Letts, 1996). This definition of occupational performance applies to handedness in that a given individual (*person*) presents with an inherent predisposition for a specific handedness presentation (*performance component*), which is also subject to external influences throughout its development (Provins, 1997). The person executes tasks (*occupation*) either unimanually or bimanually, whereby the tasks may be trained or untrained in nature (McManus & Bryden, 1992). In this context it can be argued that handedness is a critical component of occupational performance.

As discussed earlier, it has been proposed that the nature of the task determines hand preference during task execution (Annett, 1992; Porac & Coren, 1981; Steenhuis & Bryden, 1989). *Occupation* in the context of handedness can thus be translated into both task execution and task nature. More specifically, not only does a person's handedness impact on occupation (i.e., task execution), but occupation (i.e., task nature) also influences preferred hand use. Similarly, there is a dynamic interrelationship between the *environment* (i.e., spatial positioning, physical and socio-cultural aspects), and handedness. For example, the positioning of a task in relation to the person (immediate environment) might influence hand use when reaching with the nearest hand (e.g., Stilwell, 1987a). In addition, to a yet unknown extent, handedness is a determinant of culture and society (general environment) (Harris, 1990). For example, the predominance of right handed equipment in the physical environment (e.g., scissors and sharpeners), can influence right rather than left hand use, particularly when the perception of 'right being right' persists in the wider socio-cultural sphere (Harris, 1990).

In the context of handedness-related components of occupational performance, it would be important to incorporate those interactive aspects pertaining to occupation and environment into a handedness assessment (see summary in Figure 1.4). Whilst handedness and midline crossing are not functional behaviours themselves but rather influencing factors on function or performance components, unimanual and particularly bimanual function is fundamental to successful mastery of daily activities and specialised skills (Exner, 1995). Different degrees of lateralised bimanual coordination are observed in many of the daily occupational performance tasks, such as opening a jar, using a dust pan and brush, or cutting with scissors. Although the relationship between unimanual

hand preference and bimanual role differentiation is not clear (Fagard, 1998; Hammond, 1990), it is likely that more complex bimanual performance can only be achieved if handedness is fully and consistently established.

Figure 1.4: Handedness as a Critical Component of Occupational Performance in Relation to the Person, Occupation and the Environment



Note. This model is based on the interpretation of occupational performance as a dynamic relationship between three key aspects: a **person** (including various performance components unique to the person), relevant **occupations** and the **environment** (Law, Cooper, Strong, Stewart, Rigby & Letts, 1996). These key aspects have been adapted to fit handedness in the following way: 'Person' refers to the individual's handedness presentation as a performance component. 'Occupation' consists of both task execution and task nature, the first primarily influencing and the second being influenced by handedness. 'Environment' comprises the immediate spatial, and the broader physical and socio-cultural aspects relevant to handedness.

In order to further understand the process of handedness establishment in relation to midline crossing and bimanual coordination, it is important to review both the neurophysiological relationship and the neurodevelopmental process of the three neuromotor behaviours, handedness, midline crossing and bimanual coordination.

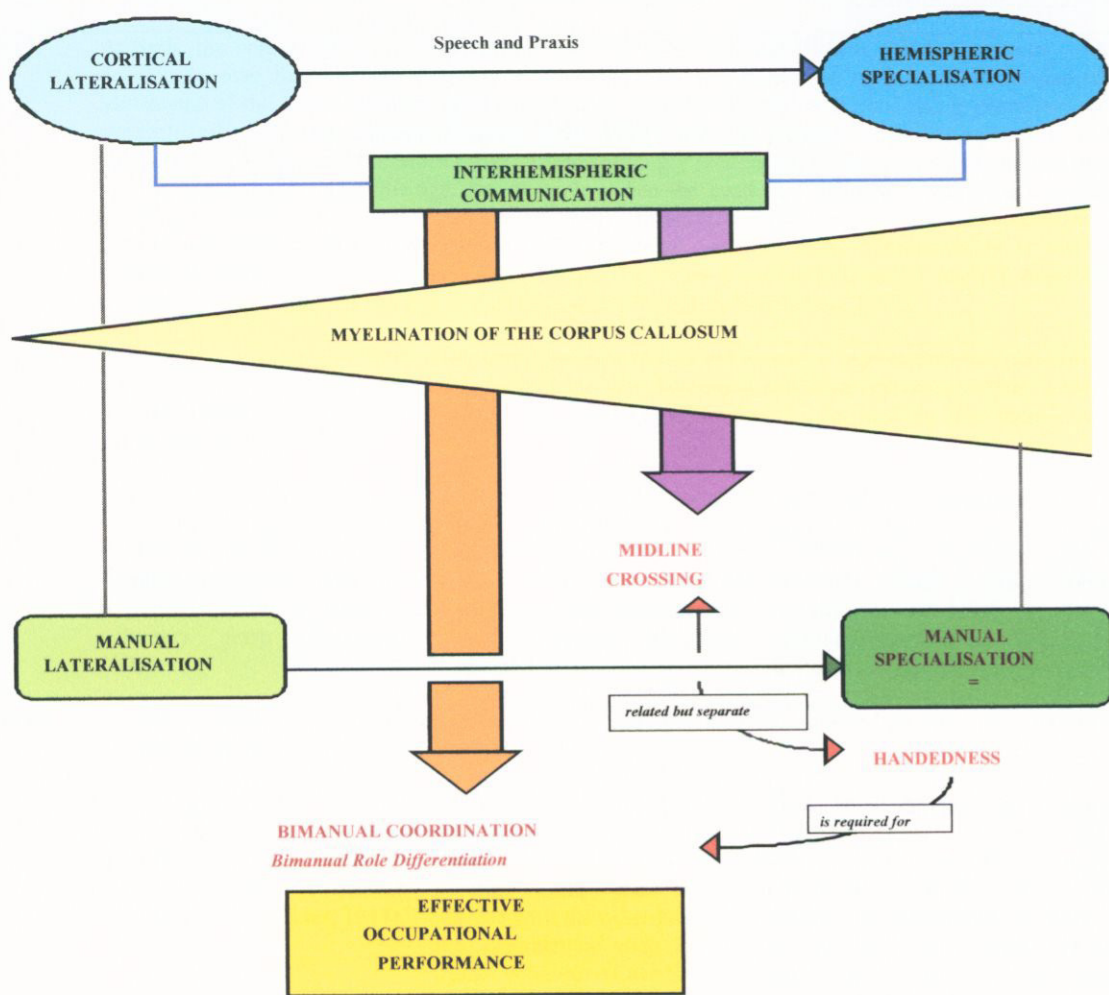
1.3.2 Neurophysiological Model for Handedness and Related Neuromotor Behaviours

The neurophysiological model for handedness is based on some of the neuroscientific evidence, developmental models, and/or theoretical assumptions discussed so far.

- Cortical and manual lateralisation processes both take place during normal development, resulting in hemispheric and manual specialisation respectively.
- Hemispheric and manual specialisation are related, although the specific nature of this relationship is still unclear.
- Interhemispheric communication is an integral part of hemispheric lateralisation and specialisation, and closely related to the myelination of the corpus callosum.
- Interhemispheric communication is necessary for neuromotor behaviours such as midline crossing and bimanual coordination.
- The three identified neuromotor behaviours, (unimanual) handedness, midline crossing and bimanual coordination, are closely related but separate entities. In particular, an increased ability to cross the midline allows for more consistent hand use in contralateral spaces, and established hand preference facilitates contralateral reaching. Established handedness is also required for bimanual role differentiation of varying complexity, in order to engage effectively in occupational performance.

The researcher summarises the theoretical neurophysiological framework in Figure 1.5. It is postulated that the process of cortical lateralisation leads to hemispheric specialisation of one hemisphere in relation to the other (Ornstein, 1997). This process is paralleled by manual lateralisation and specialisation respectively (Carson, 1989), resulting in handedness establishment. The increasing myelination of the corpus callosum appears to play a major role in this process of increased interhemispheric communication, whereby handedness is the outcome of the specialisation process (Farber & Knyazeva, 1991). Midline crossing (Gazzaniga, 1970) and bimanual coordination (Weissman & Banich, 2000) are also considered to demonstrate the extent of interhemispheric communication and integration. Whilst midline crossing and handedness in themselves are not functional behaviours, they influence both unimanual and bimanual coordination, which, in turn, are fundamental to effective occupational performance (see Figure 1.5).

Figure 1.5. Theoretical Framework Illustrating the Neurophysiological Relationship Between Handedness, Midline Crossing and Bimanual Coordination



1.3.3 Normal Neurodevelopment of Handedness, Midline Crossing and Bimanual Coordination

The development of handedness is a neuromotor process that is expressed unimanually and bimanually (Hopkins & Rönqvist, 1998), whereby the hands tend to be used initially in the ipsilateral hemisphere (Provine & Westerman, 1979; Pryde, Bryden & Roy, 1999). Fagard (1998) argued that stabilisation

“of unimanual handedness might be one of the factors influencing the emergence of the capacity to use both hands in cooperation...Bimanual complementary movements often consist of more than one step or action, in which each hand plays a different role. The flexibility in shifting attention between hands might therefore be one prerequisite for bimanual success” (p.125).

In a neurodevelopmental context, the emergence of handedness, midline crossing and bimanual coordination, seem intricately linked (see Table 1.2).

Table 1.2. An Approximate Timeline of the Development of Handedness, Midline Crossing, and Bimanual Coordination

AGE	HAND PREFERENCE	MIDLINE CROSSING	BIMANUAL COORDINATION
BIRTH	At birth, the corpus callosum is underdeveloped and non-functional (Hewitt, 1962; Gazzaniga, 1970), developing over the next ten years at an unprecedented rate compared with its later development. Movement of the upper limb has been described as uncontrolled and reflexive, and is performed both symmetrically and asymmetrically (Fagard, 1990, 1998), with the presence of the Asymmetrical Tonic Neck Reflex (ATNR) and the Moro reflex. These seemingly random movements are closely linked to the lack of postural control at this age. For example, when the head of a neonate is stabilised externally, reaching is possible (Amiel-Tison & Grenier, 1980). However, adequate postural control is necessary to enable independent reaching by the infant, so reaching does not occur spontaneously at this age (Shumway-Cook & Woolacott, 2001). Furthermore, the infant is unable to cross the midline, even when the body is fully supported and one limb is restrained (Provine & Westerman, 1979).		
4 MTHS	According to Gazzaniga (1980), each hemisphere processes sensorimotor information independently of the contralateral side. This activity might indicate that the corpus callosum is starting to play a role in relaying information from one hemisphere (e.g., visual field) to the other (controlling contralateral motor performance).		
	Hand preference coincides with unilateral swiping of either hand (Gesell & Ames, 1947) and a decrease in the grasp reflex which is replaced with a crude but voluntary grasp (Case-Smith, 1995).	Provine and Westerman (1979) found that this is the earliest time that infants are able to cross the midline when one hand is restrained. (See also Murray, 1995, for a review.)	Bimanual movements are symmetrical/mirror-like and simultaneous, resulting soon in bilateral body and object exploration, and hand interplay in midline (Fagard, 1990, 1998; Fagard & Pez�, 1997).
6 MTHS	Gazzaniga (1980) proposed that the corpus callosum first demonstrates increased myelination, reflected in the emergence of unilateral reach.		
	Alternating with the bilateral development, a first (transient) preference for unilateral (usually) right hand use becomes apparent (Gesell & Ames, 1947).	As the infants postural control develops in sitting, weight is borne on one arm for pivoting, and the infant reaches with the other hand to the contralateral side using trunk rotation (Case-Smith, 1995; Gilfoyle, Grady & Moore, 1990). No active contralateral reaching has been recorded at this stage.	There is a definite shift towards bilaterality (Gesell & Ames, 1947) from simultaneous to successive movement (Castner, 1932). For example, the infant holds an object in the one hand and reaches with the other (White, Castle & Held, 1964), or movement is initiated with one hand and completed with the other (Castner, 1932).
8 MTHS	The emergence of a more radial palmar and then digital grasp (Gesell & Amatruda, 1947) precedes a unilateral phase, whereby there is increased left hand use, followed by a greater persistence of right hand use.		
		Further refinement of postural control is now evident (Case-Smith, 1995; Gilfoyle, Grady & Moore, 1990), but no active contralateral reaching has been recorded at this stage.	Infants start to hold two objects simultaneously in each hand and combine this with a bimanual symmetrical action, such as banging (DeSchonen, 1977; Fagard, 1990, 1998; Fagard & Pez�, 1997).
12 MTHS	As the corpus callosum continues to develop, the emerging pincer grasp coincides with another phase of more unilateral left hand performance, followed by a phase of using either hand (Gesell & Ames, 1947).		
	Having achieved good postural control in sitting, the infant is now able to reach into either contralateral space using trunk rotation but with-out employing arm support. However, this midline crossing occurs mainly when one hand is occupied, not yet reflecting a preferred hand. Ipsilateral reaching is still preferred (Carlson & Harris, 1985; Case-Smith, 1995; Knobloch & Pasamanick, 1974), although Bruner (1969) suggests a diminished 'midline barrier' at this stage.		The hands begin to work together in an increasingly complementary fashion and coordinated asymmetrical roles (Goldfield & Michel, 1986), where one hand is more active, the other more passive. Bimanual hand preference emerges after 9-10 months of age, involving temporal and spatial coordination and complementary action. Sequential rather than simultaneous bimanual activity is performed (Fagard, 1998; Fagard & Pez�, 1997).

(table continues)

Table 1.2. (continued)

AGE	HAND PREFERENCE	MIDLINE CROSSING	BIMANUAL COORDINATION
18 MTHS	<p>Around this age, the left hemisphere develops more rapidly than the right (Jacobson, 1978). The clear shift towards unilateral hand use continues, alternating with much bilateral activity, and inconsistent hand use is still apparent (Gesell & Ames, 1947). Other researchers have observed a clear hand preference in bimanual tasks after 14 months (Michael, Ovrut & Harkins, 1985; Ramsay, Campos & Fenson, 1979), concluding that unimanual hand preference precedes bimanual hand preference.</p> <p>More recently, Fagard and Marks (2000) compared unimanual and bimanual tasks in relation to hand preference in babies aged 18 to 36 months. They found that bimanual tasks elicited a stronger role differentiation than unimanual tasks even at 18 months. They deduced that hand preference is task related, and that certain bimanual tasks might display greater asymmetry than unimanual tasks in infancy.</p>	<p>At this stage, the first active contralateral reaching across the body is observed (White, Castle & Held, 1964), without one hand being occupied or used for support.</p>	<p>Children are now able to combine stabilising the object with one hand and manipulating it with the other in an alternating manner (Gilfoyle, Grady & Moore, 1990), which leads to more mature bimanual coordination (Corbetta & Thelen, 1996; White, Castle & Held, 1964).</p>
24 MTHS	<p>The corpus callosum appears to be functioning at a basic level and inhibitory function is emerging (Farber & Knyazeva, 1991). There appears to be a preference for bimanual activity where the preferred hand is more active and the non-preferred hand has a stabilising/assistive role (Fagard & Marks, 2000).</p> <p>At this stage, most young children show a more definite preference for the right hand (Gesell & Ames, 1967), as the fingers and arms are increasingly dissociated for a large variety of functional skills (Case-Smith, 1995).</p>	<p>Stilwell (1987b) found that 2-year old children actively cross the midline, more so with their preferred hand. The hands can now be used in all planes with good control (Gilfoyle, Grady & Moore, 1990).</p>	<p>Two-year old children can also perform a sequence of bimanual movements whereby the arm/hand stabilisation and movement are controlled simultaneously (Knobloch & Pasamanick, 1974), such as holding a crayon and drawing, or threading beads.</p>
2 to 6 YRS	<p>MRI studies have supported age-related increases in cerebral white matter and myelination of the corpus callosum in children and adolescents (DeBellis, Keshaven, Beers, Hall, Frustaci, Masalehdan, Noll & Boring, 2001; Giedd, Blumenthal, Jeffries, Castellanos, Liu, Zijdenbos, Pans, Evans & Rapoport, 1999; Giedd, Blumenthal, Jeffries, Rajapakse, Vaituzis, Liu, Berry, Tobun, Nelson & Castellanos, 1999; Thompson, Giedd, Woods, MacDonald, Evans & Toga, 2000). There is evidence that callosal transfer is not optimal until approximately 10 to 12 years (Yakovlev & Lecours, 1967), and that subsequent sensori-motor and cognitive development further increase the callosal interconnections between the hemispheres up to adulthood (Pujol, Vendrell, Junque, Marti-Vilalta & Capdevila, 1993).</p> <p>By the third and fourth year, the direction of hand preference is evident (McManus, Sik, Cole, Mellan, Wong & Kloss, 1988) and there is a tendency towards unilateral activity (Gesell & Ames, 1947). This stage appears to be followed by another period of well differentiated bilaterality between the ages 5 and 7 years. Hand preference becomes fully established between 6 and 9 years (Gesell & Ames, 1947; Tan, 1985).</p>	<p>At the age of 6 years children use the preferred hand consistently to cross the body midline (Stilwell, 1987b). However, more complex tactile tasks requiring crossed localisation conditions demand a higher level of interhemispheric transfer via the corpus callosum (Fabbro, Libera & Tavano, 2002). Children aged 5 to 6 years make significantly more errors than 10 year olds (Quinn & Geffen, 1986).</p>	<p>Children are increasingly able to execute complex activities requiring differentiated hand performance, where the asymmetrical and functional role differentiation becomes more refined throughout childhood (Fagard, 1990, 1998). Symmetrical in-phase coordination between the hands is evident at 5 years (Fagard, 1987; Southard, 1985), but inconsistent coordination patterns are still observed in children between the ages of 6 and 10 years (Haken, Kelso & Bunz, 1985).</p>

Note. The three neuromotor behaviours appear to develop in parallel, overlapping with each other whilst also being subject to individual variability, and it is thus not possible to determine definite age-related developmental stages. Nevertheless, for the sake of clarity, this summary according to an approximate timeline of the development of handedness, midline crossing and bimanual coordination was deemed useful, and it is based on numerous developmental studies and current knowledge.

Unimanual action such as grasping might strengthen the contralateral unilateral control system during infancy (Fagard, 1998). This allows one hand to take responsibility and lead, which in turn influences hand preference and the dissociation between the hands. Bimanual action, on the other hand, allows the infant to use both hands in succession until infants are able to coordinate their hands in an asymmetrical and simultaneous manner (Fagard, 1998). With maturation, reaching and grasp extend to midline and then to the contralateral space, possibly indicating a shift in interhemispheric communication from extracallosal to callosal control (Liederman, 1983). This contralateral reaching or midline crossing has been defined as

“hand movements that approach and/or cross the centre longitudinal axis of the body (the body midline)” (Stillwell, 1994).

In summary, the development of handedness appears to fluctuate between unimanual and bimanual preferences that seem to be individually paced. Hand function initially takes place only in ipsilateral and midline spaces, and later extends to the contralateral space. This developmental process supports the neurophysiological basis for an intricate relationship between hand preference, midline crossing and bimanual coordination. The next section will explicate how midline crossing and bimanual coordination are developmentally and functionally intertwined with handedness, whilst concomitantly remaining separate entities.

1.3.4 Empirical Research and Postulates Linking Handedness to Midline Crossing and Bimanual Coordination

1.3.4.1 Midline Crossing and Handedness

Several explanations for the emergence of midline crossing have been proposed, including maturation of bilateral (including bimanual) coordination (Ayres, 1972; Provins & Westerman, 1979), establishment of body scheme and left-right integration/directionality (Ayres, 1972; Cermak, Quintero & Cohen, 1980; Kephardt, 1971), development of body righting reactions/trunk rotation (Koomar & Bundy, 1991, 2002; Stilwell, 1981), and the maturation of attention-intention (Bradshaw, Spataro, Harris & Nettleton, 1988).

Provine and Westerman (1979) described midline crossing as gradually developing with skill acquisition from ipsilateral, to midline, and finally to contralateral movement. Thus,

as is evident from the developmental summary, spontaneous midline crossing emerges with age, possibly being constrained by the biomechanical limitations due to neurophysiological immaturity and lack of motor control characteristic of infants (Atwood & Cermak, 1986; Benton, 1959; Provine & Westerman, 1979). Midline crossing becomes fully established with the maturation of contralateral pathways around the age of nine years (Auxter, Pyfer, Huettig, 1993; Cermak, Quintero & Cohen, 1980; Stilwell, 1981). For this reason, midline crossing has been used as a neurological index of development (Benton, 1955, 1959; Giotakos, 2001; Sherrick, Greenman & Legg, 1976; Surburg & Eason, 1999), or a developmental milestone of 'cross-lateral integration' (Cermak, Quintero & Cohen, 1980). However, to date the precise role and significance of midline crossing has not been empirically established. It has been proposed that midline crossing may parallel primitive reflex inhibition (Eason & Surburg, 1993). Even in adults contralateral reaching is slower and less accurate than ipsilateral reaching (Fisk & Goodale, 1988). Eason and Surburg (1993) recommended that temporal aspects should be considered during midline crossing. They suggested that:

“the greater the differences between chronological age and maturational age, the greater the likelihood of increased information-processing time for movements that require crossing the body's midline” (p.278).

In another study, interhemispheric cooperation was assessed using perceptual tasks in midline, ipsilateral and contralateral spaces with varying task demands (Weissman & Banich, 2000). The authors concluded that the extent of *interhemispheric* integration was related to task complexity. When the task was complex, contralateral reaching and inferred interhemispheric processing seemed preferred, while simple tasks appeared to rely on ipsilateral and thereby *intrahemispheric* processing (Weissman & Banich, 2000).

The process of midline crossing appears multifaceted. Not only does the hand crossing the midline require control of the contralateral motor cortex, but visual attention has to be regulated in the contralateral hemispace as well (Bowers & Heilman, 1980). Several studies have emphasised this visuo-spatial aspect of manual midline crossing. Jakobson, Servos, Goodale and Lassoode (1994) tested contralateral reach in four acallosal subjects. The authors fixated the subjects' gaze centrally and visually stimulated the hemisphere contralateral to the reaching hand by positioning objects to the left, right and centre. Results indicated that

“in uncrossed reaches the visually stimulated hemisphere is contralateral to the hand being used while in crossed reaches it is ipsilateral to the hand being used. With central reaches, presumably both hemispheres would be visually stimulated” (p.1109).

Midline crossing and hand preference have traditionally been investigated as a functional unit, with contralateral reaching as an indicator of the extent of hand preference (Ayres, 1989; Schofield, 1976a, 1976b). According to Liederman (1983), the development of midline crossing indicates the inhibition of ipsilateral reaches, which in turn allows for the emergence of hand preference. Within the developmental process midline crossing thus appears to parallel the emerging rotation around the body axis.

More recently, several studies have employed midline crossing as a ‘novel’ and ‘independent’ approach to measure hand preference (Bryden, Bulman-Fleming & MacDonald, 1996; Bryden & Edmonds, 1995; Gabbard, Hart & Gentry, 1995; Harris & Carlson, 1993; Hill & Bishop, 1998; Steenhuis, 1996; Surburg & Eason, 1999; Weissman & Banich, 2000), although others have linked contralateral reaching to manual lateralisation more than two decades prior (e.g., Ayres, 1972). Some authors combined hand performance (i.e., how well a task is performed) rather than hand preference (i.e., with which hand the task is performed) with midline crossing, conceiving this to be a ‘behavioural measure of hand preference’ (Bryden, Singh, Steenhuis & Clarkson, 1994). However, consensus between midline crossing studies is lacking and no standard measure of midline crossing has been used, making comparison of these studies difficult.

As with handedness, there are two aspects to midline crossing that have been the focus of various studies. First, *spontaneous* contralateral reaching which may illustrate preferred hand use as well as the ability to cross the body midline (e.g., Ayres, 1972, 1989), and second, the level of midline crossing performance, based on response speed and accuracy, such as during line bisection (e.g., Bradshaw, Spataro, Harris & Nettleton, 1988) and visual processing (Jakobson, Servos, Goodale & Lassonde, 1994). In this thesis, only the first aspect of midline crossing will be investigated. Whilst the temporal aspect of contralateral reaching appears to be particularly useful for individuals with a fully myelinated corpus callosum, spontaneous midline crossing was deemed to be a more appropriate and important developmental factor for assessing younger age. Timing the response was felt to interfere with the spontaneous response and draw attention to the process.

There is some evidence that avoidance of midline crossing (sometimes referred to as ‘midline crossing inhibition’ [MCI], e.g., Eason & Surburg, 1993) is associated with dysfunction, including brain injury (Benton, 1955), learning disabilities (Cermak & Ayres, 1984; Stilwell, 1981), specific language delay and developmental coordination disorder (Hill & Bishop, 1998), and non-age specific developmental delay (Woodard & Surburg, 1999). Midline crossing problems have also been noted in pre-adolescent and adolescent individuals with mild intellectual delay (Eason & Surburg, 1993) and intellectually challenged adults (Surburg & Eason, 1999; Surburg, Johnston & Eason, 1994).

It is interesting to note that Bishop (1990a), using contralateral engagement as ‘pure’ functional hand preference and performance measures, failed to find a difference between the level of hand preference establishment in reading impaired and normal children. However, individuals with specific language delays and poor motor performance were found to have difficulties with midline crossing (Hill & Bishop, 1998). These findings seem to indicate that specific language delays may be related to the ability to cross the midline rather than handedness establishment. Hill and Bishop (1998) concluded that:

“reaching across the body midline requires more complex programming than an ipsilateral reach, and when confronted with the option of making a difficult movement with the preferred hand versus an easy movement with the non-preferred hand, children with poor motor skills will adopt the latter course” (p.306).

However, the same effect was found in children with language delays only, indicating that difficulties with midline crossing may not entirely be a motor-based phenomenon.

It is possible that a lack of clear definition and specification of aspects of midline crossing contributes to the inconclusive and perplexing results found in empirical research and its conceptual conclusions. There appear to be three variants of midline crossing that are not well distinguished but appear to be very different. Firstly, *manual midline crossing* is mainly concerned with reaching, placing and retrieving objects in and from the contralateral spaces, particularly with the preferred hand. In manual midline crossing, head movements and the visual fields are not controlled (e.g., Ayres, 1989). Secondly, *visual-manual midline crossing* is assessed by controlling head movements and visual fields to investigate hand-hemisphere spatial compatibility and the neurophysiological and neuropsychological aspects of spatial neglect. (e.g., Bradshaw,

Willmott, Umilta, Philips, Bradshaw & Mattingley, 1994). Finally, *body midline crossing* involves the rotation of the upper body against the lower body (e.g., Provine & Westerman, 1979). Body midline crossing most often does not incorporate visual and manual midline crossing, since the upper extremities operate in the ipsilateral visual fields and hemispaces. More research is required to clearly differentiate and determine the relationship between these variants of midline crossing by controlling irrelevant factors.

In addition to midline crossing being an ill-defined behaviour with an unclear underlying mechanism, its relationship to handedness also remains speculative. Cermak and Ayres (1984) suggested that midline crossing might consist of two different neural mechanisms:

“one that, when interrupted, results in avoidance of midline crossing; and the second, less an avoidance of crossing than an inclination to use the hands ipsilaterally because each works equally well” (p.39).

The authors conclude that a greater understanding of the processes underlying contralateral reaching is required to determine whether avoidance of midline crossing is due to poorly established hand preference, or whether a deficit in midline crossing retards hand preference development. It is possible that both options coexist within normal development. According to systems theory, all developmental processes are interrelated and occur at a relatively unique rate in each individual within the context of continuously changing environmental and task demands (Kelso, Holt, Kugler & Turvey, 1980; Rose, 1997). Thus, within the systems theory approach, the quest for a causal relationship between hand preference and midline crossing is not important in normal development. However, exploring the relationship between hand preference and midline crossing and the impact each may have on the other, might be of clinical value and would require further investigation in an impaired population. According to the present knowledge based, hand preference and midline crossing appear to be both closely related as well as independent.

1.3.4.2 Bimanual Coordination and Handedness

There are few truly *unimanual* tasks that humans perform, most being bimanual (Hopkins & Rönnqvist, 1998). The association between handedness and bimanual coordination has been emphasised by some authors. Peters (1994) contended that handedness is an

important feature of bimanual coordination, and Guiard (1985) argued that handedness should be reformulated to include bimanual action. Many tasks demand bimanual cooperation between the hands with very different but complementary task-specific roles assigned to each hand. For example, there may be conditions when performance of the non-preferred hand surpasses that of the preferred hand, such as a right handed person playing the violin (Peters, 1985).

Given the great variety of bimanual performance, numerous aspects of bimanual coordination have been identified, and various attempts have been made to classify its components. Fagard (1991) asserted that bimanual hand use is

“unique in the relationship of the movements between the two hands. Different temporal and spatial relationships between the movements can be distinguished: movements can be simultaneous, alternating, or sequential.” (p.306).

In functional terms, Fagard (1991) identified three kinds of bimanual tasks, *dual tasks*, *bimanual single symmetric tasks*, and *bimanual single asymmetric tasks*. Dual tasks involve the simultaneous performance of different tasks with each hand, such as playing a string instrument. Certain bimanual single tasks require the engagement of both hands in a *symmetrical* complementary task towards a single goal with a similar output, such as kneading dough or catching a large ball. In other bimanual single tasks, the two hands contribute to a single goal with an *asymmetrical* output, such as adjusting the paper with one hand while cutting with the other (Fagard, 1991).

Similar to Fagard, other authors have specified several roles that could be assigned to each hand in terms of sequencing, organisation, spatial and temporal factors, using a mechanical frame of reference rather than functional terms to describe bimanual coordination (Guiard, 1985; Guiard & Ferrand, 1996). Unlike Fagard and Pezé (1997), who found support in their infant studies for bimanual activity as a more reliable indicator of preferred hand use than unimanual tasks, Hammond (1990) failed to find a significant correlation between bimanual coordination and hand preference in adults. Considering the fluctuations between unimanual and bimanual behaviour in normal development, it appears likely that hand preference and bimanual coordination have a complementary rather than a causal relationship, representing different aspects of hand function.

Since fine motor movement of each hand is controlled predominantly by the opposite hemisphere (Gazzaniga, Bogen & Sperry, 1967; Haaxma & Kuypers, 1974; Tanji, Okano & Sato, 1988; Zaidel & Sperry, 1977), the coordinated use of the two hands involves interhemispheric integration, particularly for more novel, non-routine tasks (Beaton, Hudgahl & Ray, 2000; Fagard, Hardy-Léger, Kervella & Marks, 2001). In particular, there is evidence that an intact and functional corpus callosum is fundamental to fast, coordinated and highly skilled bimanual performance (Jeeves, Silver & Jacobson, 1988; Moes, Jeeves & Cook, 1995). Callosotomised patients find smooth coordinated bimanual action impossible during simultaneous bimanual tasks (Kreuter, Kinsbourne & Trevarthen, 1972; Preilowski, 1972; Zaidel & Sperry, 1977). This indicates that the corpus callosum not only enables interhemispheric integration but also interhemispheric inhibition for independent functioning of both hemispheres and hands (Rueckert & Levy, 1996).

Due to its link with agenesis of the corpus callosum (Jeeves, 1986; Jeeves, Silver & Jacobson, 1988; Preilowski, 1972, 1975) and with developmental immaturity (Fagard, Morioka & Wolff, 1985; Jeeves et al., 1988), bimanual coordination has been repeatedly used as a differentiating measure and sensitive indicator of neurological development in impaired populations, including dyslexia (Gladstone, Best & Davidson, 1989; Njiokiktjien & Raemaekers, 1999; Rousselle & Wolff, 1991; Steese-Seda, Brown & Caetano, 1995; Wolff, Michel, Drake & Ovrut, 1990). Moreover, Fagard, Hardy-Léger, Kervella & Marks (2001) found that improved interhemispheric communication enhances bimanual coordination development, particularly in heterologous movement.

A well-established phenomenon displayed in the upper extremities of normal subjects is a strong, natural tendency to perform the same movement at the same speed during simultaneous bimanual action (Kelso, 1984; 1994; Swinnen, 1991; Swinnen, Walter, Lee & Serrien, 1993; Kelso, Putnam & Goodman, 1983). This inherent tendency for the hands to act as a unit of coordinative structures is seen in the context of environmental and task constraints (Kelso, Holt, Kugler & Turvey, 1980), also known as *entrainment* (Carson, Thomas, Summers, Walters & Semjen, 1997). Entrainment between the two arms or hands has been investigated in numerous studies in which distinctions were made between *in-phase* (synchrony comprising same timing and movement patterns), *anti-phase* (asynchrony involving same timing but opposite movement patterns), and *out-of-*

phase actions (asynchrony involving different timing and different movement patterns) (Schmidt & Lee, 1999). When out-of-phase patterns are performed at high speed, the hands will inadvertently change back to an in-phase synchrony, as observed during bimanual finger tapping (Kelso, 1981, 1984; Tuller & Kelso, 1989), and wrist rotations (Lee, Blandin & Proteceau, 1996).

According to Peters (1985), during repetitive bimanual simultaneous rhythmical action the non-preferred hand usually entrains to the other, although this might depend on the nature of the task. Other researchers have also found that the transition from anti-phase coordination to in-phase coordination is most often achieved by the non-preferred hand adjusting to the phase of the preferred hand (Carson, Byblow & Goodman, 1994). However, it is not clear whether the observed asymmetric effect is due to manual lateralisation or to left-hemispheric specialisation of the temporal aspects of high-level coordination (Hammond, 1990). In addition, the non-preferred hand usually shows greater variability in spatial and temporal constraints (Hammond, 1990).

Amazeen, Amazeen, Treffner and Turvey (1997) contended that there are two independent aspects of bimanual coordination: one that focuses on the roles assigned to the hand during functional everyday tasks, and one that emphasises temporal and spatial synchrony between the hands. In everyday tasks the hands need to be uncoupled, whereby the tendency of one hand to entrain to the other has to be inhibited (Beaton, Hugdahl & Ray, 2000), enabling the hands to perform separate roles in cooperation for successful task completion. According to Fagard, Morioka and Wolff (1985),

“the movement routines performed by the two limbs must be uncoupled before they can be re-integrated in a more complex pattern” (p.535).

Most manual tasks require both hands, and the role assigned to the hands depends on the task requirements and complexity (Provins, 1997). Even activities that are usually considered to be unimanual (e.g., cutting with a knife) require at least elementary or temporary assistance of the other hand for stabilisation and adjustment of the object. Motor control and motor learning approaches emphasise the importance of the whole human system interfacing with the environment for successful goal outcome (Schmidt & Fitzpatrick, 1996).

Complementary role differentiation of the hands is obvious in everyday tasks, involving the sequential process of separate acts in which the non-preferred hand will usually precede the action of the preferred hand (Peters, 1994). Peters identified four aspects of role differentiation. First, the preferred hand executes the coordinated movement more directly, with the support of the non-preferred hand. Second, precise timing is required to coordinate preparatory action of the non-preferred hand, usually preceding the movement of the preferred hand. Third, the preferred hand specialises in continuous precision of speed and force adjustment, whereas the non-preferred hand tends to intermittently assume hand positions and postures. Finally, more focused and continuous attention is usually given to the preferred hand during bimanual task execution, while the non-preferred hand receives subsidiary attention (Peters, 1994).

In summary, bimanual coordination has been analysed in various ways to clarify its principal components. However, although it is useful to differentiate between bimanual tasks that elicit coupled versus uncoupled responses and measure interhand differences in speed and accuracy, these assessment procedures may not reflect or correspond to the asymmetry in functional bimanual handedness tasks.

Whilst the association between handedness, midline crossing and bimanual coordination appears strong from functional, neurophysiological, neurodevelopmental and research perspectives, contextualising handedness in terms of occupational performance does not explain the reasons for variable handedness, associated factors and problems. The literature provides a variety of possible causes for handedness variability, which are discussed in the following section.

1.4 Proposed Causes for Variable Handedness, Associated Factors and Problems

Variable handedness might have a variety of origins that are important to consider for assessment and treatment purposes. Numerous authors have claimed that a certain degree of variable handedness is normal, based on the prevalence of non-right/left handedness in society (Annett, 1985; Belmont & Birch, 1963; Dimond, 1972; Kretz, Suchenwirth & Ferner, 1970; Subrina, 1969). Conversely, there is sufficient evidence to support a link between variable hand use and pathological conditions such as autism (e.g., Bryson, 1990; McManus, Murray, Doyle, & Baron-Cohen, 1992), and developmental delay (e.g., Satz, Soper & Orsini, 1988) (see Appendix 1G for a summary of studies investigating 'non-right' handedness and pathological conditions). The researcher identified a range of different reasons for variable handedness from the literature, which are discussed below in more detail.

1.4.1 Severe Trauma to an Upper Extremity or Severe Hemispheric Lesions

The most obvious cause for a change in hand preference is injury to the preferred arm or hand, resulting in a 'forced' change of hand preference (Ardila, Correa, Zuluaga & Uribe, 1988). It is therefore important to investigate a possible history of trauma in the assessment procedures. If injury is permanent, as is the case with amputation or mutilation/burns of the upper extremity, a change in preferred hand use is inevitable. Similarly, severe birth-related trauma, causing congenital hemiplegia forces an alteration in preferred hand use, if the inherently dominant side is affected (Dellatoals, Luciani, Castresana, Rémy, Jallon, Lapalane & Bancaud, 1993).

1.4.2 Normal Variability of Left Handedness

Left handers have obscured the postulate of handedness as a predictor of cerebral specialisation (Bradshaw & Nettleton, 1983; Bryden, Bulman-Fleming & MacDonald, 1996). Whilst *consistent* left handers tend to perform much like right handers (Amazeen, Amazeen, Treffner & Turvey, 1997; Peters, 1994), *inconsistent* left handers, or left handers in general as an undifferentiated group, are not the mirror image of right handers and show different and more heterogenous behaviour as a group (Bryden, Bulman-Fleming & MacDonald, 1996; Dunaif-Harris, 1984).

Evidence suggests that left handers are less strongly lateralised than right handers, and for this reason they are more likely to present with variable hand use (Bryden, 1982; Herron, 1980). Steenhuis and Bryden (1989) proposed that in comparison to right handers, left handers do not obtain lower laterality scores from lacking strength of hand preference in certain tasks (i.e., within-consistency), but because they display greater across-tasks inconsistency of preference and perform some activities with the non-preferred hand.

Furthermore, left handers appear to reflect less asymmetry and greater homogeneity of function between the hemispheres (Butler, 1997; Kim, 1994; Peters, 1985, 1987). For example, Peters (1985, 1987) used a bimanual tapping task with adults to investigate constraints in simultaneous bimanual task performance related to handedness. He found that right handers performed the bimanual tapping task better when the preferred, rather than the non-preferred hand, tapped the more complex patterns. This lateralisation effect was not seen in left handers, who tapped the complex pattern equally well with either hand. Other authors have found a substantial number of left handers, who performed certain motor tasks better with their non-preferred hand (Satz, Achenbach & Fennell, 1967).

Some authors suggested that the obvious behavioural differences in left handers might be a result of different neural and hemispheric organisation (Beaumont, 1974; Hammond, 1990; Perelle & Ehrman, 1982; Peters, 1990; Satz, 1980). Others have argued that differences between left and right handers might also be related to the influencing factors, such as physical environment and socio-cultural milieu with a right handed bias (Coren, 1992; Harris, 1990; Porac, Coren & Searlman, 1986; Sattler, 1998). It can be assumed that variability in left handers is probably due to a combination of these two factors.

1.4.3 Developmental Delay Impacting on Handedness Establishment (Unestablished Handedness)

As alluded to previously, well established handedness is seen as an important developmental milestone indicative of neurological maturation, and the absence of a preferred hand is suggestive of severe dysfunction in neural systems (Kinsbourne, 1988). Whilst Annett (1970a) proposed that mixed handedness appears to be a normal feature of learning a new task at all ages, several studies have presented evidence for increasingly

stable handedness with age in normative samples (Gudmundson, 1993; Kaufman, Zalma & Kaufman, 1978). DeAgostini, Paré, Goudot and Dellatolas (1992) found more handedness variability in children aged three years than at the age of six, and this percentage decreased solely because of an increasing number of right handed children. A study by Stilwell (1987b) indicated similar results, and it was concluded that variable handedness usually develops into right handedness. However, some authors caution against the assumption that variable handedness necessarily leads to right hand preference, since the right bias factor remained unaccounted for in those studies (Harris, 1990; Olsson & Rett, 1989; Porac, Coren & Searlman, 1986; Stutte, Schilling & Weber, 1977).

Mandell, Nelson and Cermak (1984) conducted a study comparing manual lateralisation of left-handed and right-handed boys aged five, seven and nine years. They found that left handers showed significantly less manual lateralisation at age five and seven years than their right handed counterparts. However, by the age of nine years no significant difference was found between the two groups. The authors proposed that left-handers undergo a different neurological development and acquire stable manual laterality at a later stage, thus presenting as unestablished handers before the age of nine (Mandell et al., 1984), supporting the conclusion drawn from other studies (e.g., Beaumont, 1974; Hammond, 1990; Perelle & Ehrman, 1982; Peters, 1990). Other longitudinal studies on the development of handedness between infancy and childhood report similar findings (Fennell, Satz & Morris, 1983; Gaillard & Satz, 1989; Satz, 1980). Overall, it appears that unestablished handedness is a typical feature in early stages of normal development in right, and left handed children.

The cause of frequent change in hand use during preschool years has been ascribed to cortical and callosal immaturity (Gazzaniga, 1970; Liederman, 1983) (see again Table 1.2 under Section 1.3.3 on normal development). It appears necessary that each hemisphere receives, processes and stores sufficient sensorimotor information from the contralateral side first, before effective interhemispheric communication can take place (Gazzaniga, 1980; Saul & Gott, 1973). In a study on children with developmental disorders and learning disabilities, Njiokiktjien and Ramaekers (1999) found that they resembled acallosal and split-brain individuals. Findings of this study supported an association between developmental dysphasia and dyslexia, learning disability and bimanual motor

coordination deficiencies, and impaired midline crossing. However, the authors concluded that despite an increase in ‘non-lefthandedness’, hand preference did not appear to be *established* by callosal function. Instead,

“interhemispheric dysfunction...might destabilise manual laterality, which in turn makes bimanual coordination less optimal” (Njokiktjien & Ramaekers, 1999, p.215).

Focussing predominantly on learning disabled children, Ayres (1972, 1989) has specifically associated poorly established hand preference with deficiencies in midline crossing and bilateral integration characteristic of a sensory integration disorder, now referred to as the *Bilateral Integration and Sequencing (BIS)* deficit. Ayres (1972, 1982) originally hypothesised that poorly established handedness results when a child is unable to integrate both sides of the body effectively in contralateral and bilateral activities. More recent sensory integration literature based on research of the SIPT and clinical observations has confirmed the coexistence of poor bilateral motor coordination with midline crossing and unestablished hand preference (Dahl Reeves, 2002; Fisher, 1991; Kimball, 1993, 1999).

Other authors have suggested developmental delay and immaturity as a cause for unestablished handedness (Annett, 1970a; Fein, Humes, Kaplan, Lucci & Waterhouse, 1984). Another hypothesis states that the principle of minimal effort retards the development of hand preference (Harris & Carlson, 1993). For example, less effort is required to retrieve an object ipsilaterally than employing contralateral reaching, and this may be related to limited trunk rotation and short upper limbs of the infant (Koomar & Bundy, 1991; Stilwell, 1987b). More recently, a study related developmental instability (i.e., minor physical anomalies caused by environmental determinants such as mutations, toxins, maternal stress and pathogens) to atypical lateralisation (Yeo, Gangestad, Thoma, Shaw & Repa, 1997). The results of their study indicate that developmental instability impacts on the variations in handedness. Overall, it can be concluded that certain groups of developmental disabilities feature more left or ambiguous hand use, but results are not conclusive (see Dewey, 1996, for a review). One major obstacle to this type of research is the heterogenous nature of children with developmental disabilities, exacerbated by the poor definition of ambiguous hand use. (See again Appendix 1G for the association between non-right handedness in relation to pathological conditions.)

1.4.4 Motor-Based Problems and Handedness Establishment

Some authors proposed that *poor motor functioning* is responsible for unestablished handedness, since motor dysfunction might delay the specialisation of the hemispheres (Bishop, 1990a, 1990c; Cornish & McManus, 1996). Alternatively, delays in handedness establishment could delay motor function. An association between variable handedness and delays in motor coordination was suggested in two studies in particular. Kaufman, Zalma and Kaufman (1978) studied the relationship between hand preference and motor coordination in a sample of 1032 subjects aged two and a half to eight and a half years. These authors used the motor index of the McCarthy scales (McCarthy, 1972) to assess hand preference. Measurement involved one trial of four items, namely drawing, bouncing a ball, catching a beanbag, and aiming a beanbag at a target. The authors found no significant relationship between hand preference and motor coordination with children aged 5 to 8 years. However, those children younger than five years with unestablished hand preference scored significantly lower on the motor index than those with established preference. Kaufman et al. (1978) concluded that children who establish hand preference early tend to have better motor co-ordination than unestablished handed children (Kaufman et al., 1978). A second study conducted by Tan (1985) also investigated the relationship between handedness and motor difficulties in 512 four-year olds, using the same measures as Kaufman et al. (1978) Again, results showed that those children with unestablished handedness scored significantly lower in motor coordination than left or right handers (Tan, 1985).

While the findings of these two studies appear congruent, other research failed to support a significant correlation between motor coordination and unestablished handedness. Gabbard, Hart and Kanipe (1993) studied hand preference 'consistency' over two trials, using three items (i.e., writing, throwing and stacking cubes). They related hand preference to fine motor performance using a finger tapping task in 160 children aged 4 to 6 years. These authors did not find a significant difference in fine motor tasks of children with inconsistent hand preference compared to their consistent counterparts (Gabbard et al., 1993). In another study, O'Collaghan Burn, Mohay, Rogers and Tudehope (1993b) investigated handedness in relation to intellectual abilities and motor performance in 4- to 6-year old children (N = 67) who had presented with extremely low birth weight in infancy. A parent questionnaire was used to establish the overall hand

preference of the child, while hand performance was assessed by two trials of hammering, writing and rapid tapping. Furthermore, a detailed neuro-sensorimotor assessment was administered. Although the authors found left and ‘mixed’ handers to have a lower mean motor score, the differences were not statistically significant (O’Callaghan et al., 1993b).

The apparent discrepancy between the two sets of studies needs to be seen in context. The measures used to assess hand preference and motor coordination differed across the studies, and it is possible that different aspects of motor behaviour were assessed. Furthermore, ‘unestablished’ hand preference, as defined by Kaufman et al. (1978) and Tan (1985), may not necessarily be synonymous with a lack of handedness ‘consistency’ (Gabbard et al., 1993b) or ‘mixed’ handedness (O’Callaghan et al., 1993a, 1993b). Thus, conclusions regarding the association between motor coordination problems and unestablished handedness based on these studies have yet to be unequivocally established. Moreover, to what extent motor-based delays in handedness establishment might overlap and coexist with developmental delay and/or pathological handedness remains uncertain.

1.4.5 Switched Left Handedness

For the purpose of this thesis, switching will exclusively refer to *left* handers who have learnt to use their right hand for tasks influenced by the right-biased socio-cultural environment, since it would seem very rare to find right handers experiencing pressure to use the left hand.

The concept of switched left handedness has received attention from several modification theorists (Collins, 1975, 1985; Olsson & Rett, 1989; Peters, 1990; Porac, Rees & Buller, 1990; Sakano, 1982; Sattler, 1998, 2000; Steenhuis, 1996; Zuckrigl, 1995). Several studies have investigated the *incidence* of switched handedness (Galobardes, Bernstein & Morabia, 1999; Leiber & Axelrod, 1981; Payne, 1987; Porac, Rees & Buller, 1990; Salmaso & Longoni, 1985). One study estimated that 8% of 19-year old left handers changed their hand preference to the right (Porac, Coren & Searleman, 1986). These findings were supported in a meta-analysis, where 8.9% of left handed individuals were pressurised by persons in authority before the age of nine years to change their preferred

hand (Porac, Rees & Buller, 1990). Unfortunately, no side effects of switching were assessed.

Payne (1987) investigated older individuals and reported the incidence of switched left handers to be 46%, whilst another study found that 89% of innate left handers in the age group between 65 and 74 years had been switched, compared to 26.6% aged 35 to 44 years (Galobardes, Bernstein & Morabia, 1999). The authors assigned the elevated percentage of switched handedness to increased socio-cultural pressure in previous generations. However, it has been proposed that switched handers are not easily detected with the conventional handedness measures (Peters & Murphy, 1992; Sakano, 1982), so the prevalence may well be higher than 8% as proposed by Porac, Coren and Searleman (1986), particularly if switched left handers presenting with moderate handedness are included.

Individuals with an innate predisposition for explicit left handedness are likely to present with a notable left handed preference during their early childhood years (Fischl, 1986; Olsson & Rett, 1989; Sakano, 1982; Sattler, 1998; Stutte, Schilling & Weber, 1977). Parents, other family members and teachers may exert social pressure on children to use their right hand for certain unimanual tasks that are culturally and socially important. Although there has been an increased acceptance for left handedness over the last decades, there is still evidence of existing right-biased social pressures in Western societies reflected in language and social customs (Collins, 1985; Harris, 1990; Porac, Rees & Buller, 1990; Sattler, 1998). Olsson and Rett (1989) suggest that some less strongly lateralised left handed individuals are likely to succumb even to subtle pressures for right hand use, eventually resulting in switched handedness for socially important tasks (e.g., drawing, eating with cutlery, cutting with right handed scissors). *Untrained* tasks, on the other hand, do not receive the same amount of attention and thus tend to be more resistant to environmental influence (Ida, Mandal & Bryden, 2000; Olsson & Rett, 1989). With repetition and practice of task execution, the right non-dominant hand can become the preferred hand for these untrained tasks (Fischl, 1976; Harris, 1990; Richberg, 1987; Sakano, 1982; Sattler, 1998; Stutte et al., 1977). However, switched handers are likely to continue preferring their left hand for many untrained tasks and for the leading role in bimanual actions, resulting in an incomplete shift of handedness (Olsson & Rett, 1989; Porac, Rees & Buller, 1990).

Only few studies have addressed the consequences of switched handedness, finding decreased academic performance (Ardila, Corea, Zuluaga & Uribe, 1988; Bryngelson & Clark, 1933; Clark, 1957), inferior bimanual coordination performance (Vaughn & Webster, 1989), and psychological abnormalities (Young & Knapp, 1966). Based on a large number of case studies, Sattler (1985, 1998, 1999, 2001, 2002) identified primary and secondary problems following switched handedness. *Primary* problems included memory deficit (i.e., recalling learnt material), concentration difficulty (i.e., tiring quickly, poor endurance), learning difficulties (i.e., reading and spelling), position in space problems (including poor left-right concept), speech deficit (especially stammering), and fine motor problems (e.g., hand writing). Interestingly, in numerous cases, these problems decreased or even disappeared when individuals started to write with the inherently preferred left hand, even as adults (Sattler, 1998, 1999, 2001, 2002). *Secondary* problems associated with switching comprised of poor self esteem, insecurity, social withdrawal, overcompensation with increased effort, oppositional and provocative behaviour (e.g. playing the clown, temper tantrums), bed wetting and nail biting, or generally coexist with socio-emotional difficulties (Sattler, 1998, 1999, 2001, 2002).

Other authors have reported similar psychological problems as Sattler (Friedman, 1987; Richberg, 1987; Young & Knapp, 1966). These findings appear to indicate that switching to the non-dominant hand might have an unfavourable effect on cortical functioning (Sattler, 1998, 2001, 2002). Furthermore, it has been speculated that functional specialisation of the hemispheres may be altered through switching handedness, which in turn, might interfere with interhemispheric communication processes (Olsson & Rett, 1989; Sattler, 1985, 1998, 2001).

Initially, many children with switched handedness compensate effectively and their problems may not arise until their performance is challenged as school pressure and demands increase (Fischl, 1986; Olsson & Rett, 1989; Richberg, 1987; Sattler, 2001, 2002; Stutte, Schilling & Weber, 1977). The nature and extent of switching effects also seem to vary greatly between individuals, whereby some appear to adapt more easily to right handedness with minimal problems, compared to others who experience great difficulties (Friedman, 1987; Harris, 1990; Hildreth, 1949a, 1949b; Sakano, 1982; Sattler, 1998, 2001, 2002; Zuckrigl, 1995). The enormous range of variation in the presenting problems (from minimal to multiple) observed in switched handers poses a

challenge in researching and understanding the handedness behaviour of these individuals.

Today it is generally accepted that forcing or converting left handers to become 'right handers' should be avoided (e.g., Richberg, 1987; Sattler, 2002). Even Coren (1996), who appeared to favour pathological causes as an explanation for left handedness, argued convincingly that forcing right handedness is not the answer:

“Left-handedness is not a simple movement preference that has developed into a habit. It probably reflects differences in the patterns of neural circuitry in the brain” (p.261).

Coren (1992) suggested that right hand training only produces mixed handedness or modified left handedness. It can be concluded that there is a general consensus in the literature that switched handedness is undesirable, and the importance of correct handedness classification is evident. However, the lack of specific empirical research into switched handedness and the underlying neuropsychological processes to date, limits the conclusions that can be drawn on this group of variable handers.

1.4.6 Pathological Handedness

As discussed earlier, it is thought that hand preference can be altered due to neural insult, depending on the locus, extent of lesion, as well as the timing (Harris & Carlson, 1988; Liederman, 1983; Satz, 1972; see also Section 1.2.1.3 on the impact of pathological influence on handedness). Liederman (1983) identified three kinds of less severe forms of neural insult, based on their location, (i) perinatal damage, restricted mainly to the right hemisphere temporal lobe; (ii) motor strip lesion of the left hemisphere, where the switch from the right to the left hand is delayed until the second or third year of life when tasks require sufficient motor control; and (iii) temporary disruption of function in the left, more vulnerable hemisphere. Liederman (1983) concluded that

“... even though minimal birth complications may have no permanent effect on neurological organization, they may still serve to temporarily depress functioning of the left side of the brain and may transiently interfere with right-ward biased turning” (p.85).

In addition to these causes, Dellatolas, Tubert-Bitter, Curt and DeAgostini (1997) suggest two further reasons for neurological re-organisation. A 'learning or implicit memory deficit' might cause reduced learning through practice which is thought to increase the degree of hand preference over time, and the interaction between environmental and

pathological factors might also modify hand preference. It is not certain to what extent these hypothetical mechanisms of handedness modification coexist with the other proposed causes for variable handedness.

1.4.7 Diagnostic Base to Variable Handedness

Certain pathological conditions have been found to typically include ‘non-right’ handedness. For example, individuals presenting with diagnosed disorders such as autism were significantly more likely to present with ‘ambiguous handedness’ (Soper & Satz, 1984), and a high number (approximately 40%) of institutionalised adults with intellectual disability and autism presented were found to be ‘ambiguous’ in their hand use (Soper, Nelson, & Green, 1989). Less severe conditions have also been associated with ambiguous hand use, although it is not always clear whether these conditions cause variable handedness or vice versa. For instance, a higher incidence of ‘mixed’ handedness was found in a sample of learning disabled children (Kinsbourne, 1988), stutterers were twice as likely to present with variable handedness compared to an unimpaired control group (Dellatolas, Annesi, Jallon, Chavance & Lellouch, 1990), and an association was found between clumsy children and ‘unestablished’ handedness (Armitage & Larkin, 1993). (See again Appendices 1E and 1G for detail.)

1.4.8 Ambidexterity

According to Annett (1998), ambidextrous individuals demonstrate high levels of skill in *both* hands, so their general level of motor performance is likely to be high average or above. Based on her prevalence studies, Annett (1998) concluded that the incidence of truly ambidextrous individuals is very small (0.3%). Despite its rarity, ambidexterity is likely to present as a form of variable handedness and has thus been included. Reports exist of individuals who deliberately train their non-preferred hand for skilled tasks, such as writing and drawing (e.g., Sattler, 1998). Striving for ambidexterity arises from a belief that ambidexterity is associated with very high intelligence and giftedness, originally proposed by Jackson (1905), founder of the Ambidextral Cultural Society for ‘two-handedness and two-brainedness’. Promotion for ambidexterity continues to the present day (e.g., see *Ambidexterity: Memory, Power and Mindfulness*, a course offered on the Internet to promote ‘ambidexterity’). It appears that some evidence does exist

concerning the motor, psycho-social and cognitive-emotional implications of writing with the non-dominant hand (Olsson & Rett, 1989; Sattler, 1998, 2001, 2002; Vaughn & Webster, 1989), however, this evidence does not appear to have disseminated into the wider scientific community.

1.4.9 Idiopathic

As with most diagnostic measures, it is not possible to identify or classify all presenting features and related causes that result in variable handedness according to the possible causes outlined above. In such cases, variable handedness can be said to have an idiopathic cause.

1.4.10 Summary

In the research studies reviewed, left handers have frequently been confined to one group without coherently distinguishing between the identified subgroups. Variable handers as a group remain even more undefined without a comprehensive classification system. There is a lack of conclusive literature investigating the different possible causes and related clinical presentations. Furthermore, the different proposed causes for variable handedness identified in this literature review may not be mutually exclusive. For example, a child with a history of birth stress (pathological cause) is also more likely to be delayed in handedness establishment, in addition to being exposed to socio-cultural and environmental influences. The challenge remains to establish a child's innate predisposition as a left or right hander (hereon referred to as *hand dominance*), and/or the child's best hand for writing. For example, even if the inherent hand dominance is known, this hand may not be the best one for writing if there is evidence of significantly poorer motor performance on that hand. For this purpose it is critical to understand the developmental process of handedness and related neuromotor behaviours within the functional context of occupational performance. Whilst handedness variability appears to be normal to a yet undefined extent, it is necessary to determine whether an individual is a left or right hander for successful acquisition of functional skills such as writing. In addition, conceptualising the different possible underlying causes for variable handedness appears to be crucial to the correct identification of handedness and clinical decision making on therapeutic intervention.

1.5 Occupational Therapy and Variable Handedness

Occupational therapy is a discipline which identifies

“the performance areas, performance components and performance contexts that enable the individual to engage in meaningful occupation” (Hinojosa & Kramer, 1999, p.10).

Occupation, or occupational performance, in turn, has been defined as

“the ability to choose, organise, and satisfactorily perform meaningful occupations that are culturally defined and age appropriate for looking after one’s self, enjoying life, and contributing to the social and economic fabric of the community” (Law, Polatajko, Baptise & Townsend, 1997, p.30).

In the context of this thesis, handedness, midline crossing and bimanual coordination constitute performance components in relation to occupational performance (see again Section 1.3.1 on the conceptual model of handedness as a critical component of occupational performance). Hinojosa and Kramer (1999) suggested that laterality and midline crossing are performance components at ‘foundational level’, while bilateral integration and fine motor coordination present at the ‘highly integrated skill level’. Within the holistic definition of occupational performance, handedness should not be perceived as an isolated unit within a hierarchy, but rather in relation to other skills relating to occupational performance in the wider sense. As discussed earlier, unestablished handedness in the developmental context is considered to be an indicator of neuro-maturational delay (e.g., Bishop, 1990a), and the degree to which handedness is established may indicate other forms of dysfunction or pathology. Unestablished handedness may also coexist with avoidance of midline crossing and poor bimanual motor coordination, which together impact on functional hand use (e.g., Ayres, 1972; Cermak, Quintero & Cohen, 1980; Koomar, 1999; Dahl Reeves & Cermak, 2002). In addition, it is possible that one hand might be suppressed from gaining sufficient practice to become adequately skilled in drawing and writing tasks. Consequently, unestablished handedness would be likely to retard the development of highly integrated manual skill and fine motor coordination that refine occupational performance.

Children with unestablished handedness are frequently referred to paediatric occupational therapy for other reasons, and their inconsistent hand use is usually noted informally during the process of assessment and treatment. In a survey interviewing 51 occupational therapists it was reported that overall 73% of children between 4 and 7 years presented

with ambiguous hand use (Riedel, Künnemann & Kling, 2002). However, there is a lack of specific test procedures in occupational therapy to assess handedness. One test, the 'Mesker Test' was designed specifically to assess writing handedness for children at school entry (Mesker, 1972). This test was used by occupational therapists in Britain and involves simultaneous drawing with both hands. However, findings from an evaluative study indicate that hand preference could not be confirmed unanimously using the Mesker test (Warren & McKinlay, 1993).

Two assessments that include aspects of handedness in children: the Southern California Sensory Integration Tests (SCSIT) (Ayres, 1980) and the Sensory Integration and Praxis Tests (SIPT) battery (Ayres, 1989). In both test batteries, the *preferred hand use* (i.e., the measure of hand preference) is obtained by first recording the hand that initially uses the pen to draw. Subsequently the therapist observes to what extent the preferred hand is used for contralateral reaching (see Section 2.2.2.3 for more detail on this test). In addition, hand performance is assessed in both hands by means of a tracing task, with scores incorporating both time and accuracy. Whilst the inclusion of handedness-related information was initially aimed at detecting the extent of hemispheric specialisation (Ayres, 1980, 1989; Murray, 1991), contemporary sensory integration is primarily concerned with deficits in the central processing of tactile, proprioceptive and vestibular sensations and the integration of these into adaptive responses (Bundy & Murray, 2002, Windsor, Smith, Roley & Szklut, 2001). Thus, the SCSIT and SIPT test batteries still contain and use measures of preferred hand use, a tracing task for both left and right hands and a midline crossing measure for the purpose of obtaining information on laterality establishment, considered to be an important component for detecting bilateral integration and sequencing deficits (BIS).

Occupational therapy intervention for unestablished handedness has its roots in perceptual motor theory (Kephardt, 1971; Keogh & Sugden, 1985; Lerch, Becker & Nelson, 1974; Williams 1983), sensorimotor principles (Knickerbocker, 1980) and sensory integration (Ayres, 1972, 1989). Laterality has been defined by early perceptual motor theorists as

“the internal awareness of the two sides of the body and their difference” (Kephardt, 1971, p.88).

In this context, the development of laterality was thought to underlie the establishment of handedness: when a child is able to differentiate the two sides from each other, one side

becomes more 'dominant'. The emphasis in the perceptual motor approach is on the establishment of laterality, and handedness is considered to be a by-product (Kephardt, 1971). While some early sensorimotor training programs aimed at improving body image and laterality have resulted in increased contralateral reaching (Ball & Edgar, 1967; Maloney, Ball & Edgar, 1970), the broad definition of laterality fails to specifically address handedness.

Traditionally, clinicians have considered laterality to be a sensorimotor-based phenomenon that establishes independently of the child's knowledge of left and right, and is stabilised when the child has acquired the left-right concept (Williams, 1983). This concept of laterality assumes hierarchical functioning of the central nervous system, where laterality is deemed necessary for higher level movement efficiency, symbol recognition, and directionality (Knickerbocker, 1980). Therapy promoting the establishment of handedness within the perceptual framework aims to improved general body awareness, body image, crossing the midline and directionality (Knickerbocker, 1980).

Adopting a similar bottom-up approach within a sensory integrative frame of reference, Ayres (1972) initially suggested that integration of proprioceptive and vestibular sensations as well as efficiency of interhemispheric connections were fundamental to good bilateral integration. Since then, sensory integration theory has refined these concepts and/or expanded on Ayres' propositions by linking theoretical postulates to clinical practice and sensory integrative therapy using case examples (Dahl Reeves & Cermak, 2002; Kimball, 1993; Koomar & Bundy, 1991, 2002; Kimball 1993, 1999; Murray, 1991; Windsor, Roley & Szklut, 2001). More specifically, some authors suggested that the inclusion of trunk rotation is important in developing bilateral integration and crossing of the midline (Kimball, 1993, 1999; Koomar & Bundy, 1991, 2002). These authors proposed that employing these behaviours together in therapy might assist in promoting the cerebral specialisation necessary for developing a skilled preferred hand.

Moreover, several authors have suggested the inclusion of bilateral coordination and midline crossing activities when treating unestablished handedness in paediatric occupational therapy practice (Clancy & Clark, 1990; Knickerbocker, 1980; Levine,

1991; Stephens & Pratt, 1989; Whitehead, 1978; Wilson, 1994). In some instances mention is made to 'remind' a child to use the preferred hand when hand use is inconsistent (Koomar & Bundy, 1991), although this would presuppose a certainty about the child's 'correct' handedness or hand dominance. Unfortunately, empirical evidence is lacking to support the therapeutic effectiveness using any of these treatment strategies in promoting handedness establishment.

1.6 Purpose of the Thesis

1.6.1 The Need for Developing a Normative Handedness Profile

Since no empirically tested paediatric handedness assessments were found to assess different levels, categories and types of handedness, there appears to be no standard guideline for identifying handedness, and thus an increased risk that occupational therapists are unable to assess handedness sensitively and accurately. This might mean that therapists inadvertently promote handedness establishment of the non-dominant hand or fail to select suitable or effective treatment approaches. Some authors have proposed a need for research in this field. As Stilwell (1994) contended,

“The determination of how the acquisition of manual midline crossing, hand preference interhemispheric control of attention and bilateral motor coordination interrelate in development and dysfunction, would likely assist occupational therapists to refine the treatment strategies used in the management of children with deficits in manual midline crossing” (p.5).

In addition, Hopkins and Rönnqvist (1998) suggested that future studies should address hand preference in terms of bimanual coordination within a developmental framework.

There is a need to develop a comprehensive normative handedness profile that will sensitively reflect the degree and direction of hand preference, the level of both unimanual and bimanual hand performance, the extent of midline crossing and subsequent interhand differences. The primary aim of this thesis was to address this need and develop a normative profile of handedness, based on normal children aged five to six years, since this is the age at which children enter school and handedness needs to be established for writing. The handedness presentation of impaired children could then be measured against the normative profile. The careful analysis of such an ‘impaired’ handedness profile, in the context of sufficient background information on specific delays and weaknesses, would provide a comprehensive basis for clinical decision making and effective treatment implementation.

Since the literature review has demonstrated that handedness appears to be a complex as well as fluid phenomenon in all age groups, this should be reflected in normal variations of handedness. A sufficient variety of responses within a normative sample was thus

deemed important. Only if the normal variability of handedness is known, can it be determined whether, and to what extent, a child demonstrates *unestablished* handedness.

1.6.2 Central Hypotheses to the Thesis

Three central hypotheses were formulated as guidelines for the thesis:

Hypothesis 1: A normative profile addressing handedness in the context of occupational performance (i.e., hand preference and hand performance in both unimanual and bimanual tasks with the inclusion of midline crossing) could be constructed to identify a range of normal handedness variations and provide a standard measure for identifying handedness establishment for school entry children.

Hypothesis 2: Such a normative handedness profile would identify differences in degrees of handedness (i.e., between explicit left/right handers, moderate left/right handers and variable handers) as well as the direction of handedness (i.e., left and right handers).

Hypothesis 3: Children of a clinical sample presenting with variable handedness in occupational therapy would present with handedness profiles that differed significantly from those of established handers. Furthermore, a clinical sample might yield different predictive factors and specific characteristics or features relating to handedness establishment.

In order to achieve these three central hypotheses, specific hypotheses were identified for each study. The first hypothesis of establishing a normative handedness profile was addressed by selecting and implementing existing tests. Chapter 2 investigates the suitability of existing tests for inclusion in a normative profile for handedness.

CHAPTER 2

STUDY I: INVESTIGATING THE POTENTIAL OF EXISTING TESTS TO REVEAL THE EXTENT OF HANDEDNESS, MIDLINE CROSSING AND BIMANUAL COORDINATION IN NORMAL 5-YEAR OLD CHILDREN

2.1 Introduction

2.1.1 Review and Selection of Existing Tests Relating to Handedness

The ability to accurately quantify handedness and its associated neuromotor behaviours (midline crossing and bimanual coordination) is fundamental to a handedness profile. Most of the standardised and normative paediatric test batteries reviewed neither specifically assessed hand preference, hand performance with interhand differences, midline crossing or bimanual coordination, nor did they address the identified behaviours together as a unit (e.g., Bruininks Osertsky Test of Motor Performance: Bruininks, 1978; McCarthy Scales: McCarthy, 1972; Motor Assessment for Preschoolers: Miller, 1982), and some lacked sufficient reliability and validity studies to substantiate test construction (e.g., Test of Sensory Integration, Berk & DeGangi, 1983).

The Southern California Sensory Integration Tests (SCSIT, Ayres, 1980) and Sensory Integration and Praxis Tests (SIPT, Ayres, 1989) appeared to be the only standardised paediatric test batteries available that combined the assessment of preferred hand use, hand performance, midline crossing and bilateral motor coordination, in addition to other behaviours related to sensory integrative dysfunction. There is some evidence that

“limitations in development of unilateral hand preference may be associated with poor functional integration of the two sides of the body... [and] with diminished preferred-hand visuo-motor coordination” (Ayres & Marr, 1991, p.233).

This proposed relationship between hand performance, midline crossing and bimanual coordination is reflected in the test designs of both the SCSIT and SIPT: the subtest *Motor Accuracy (MAcc)* assesses the level of hand performance of both hands; *Preferred Hand Use (PHU)* identifies the preferred hand for drawing; *Space Visualisation Contralateral Use (SVCU)* reflects the frequency of midline crossing, and *Bilateral Motor Coordination (BMC)* evaluates the level of bilateral integration. The SIPT is a later version of the SCSIT with increased test reliability and validity, as well as revised and computerised scoring of the subtests, including the MAcc, PHU and SVCU (Ayres,

1989). However, the administration and the basic test construction of the MAcc, PHU and SVCU remained the same. In addition to the computerised scoring, more items for arms and feet were added to the BMC test (Ayles, 1989). Using a *combination* of these three SIPT tests thus appeared an appropriate basis for a handedness profile.

The SCSIT and particularly the SIPT successfully identify children with sensory integration and praxis disorders in clinical populations (Ayles, 1989; Ayles & Marr, 1991; Brasic, Royeen, Koomar, Cromack, Fortune & Domkey, 1991; see also Appendix 2F), which are likely to contain children with unestablished handedness. However, no studies were found that solely assessed handedness establishment using the PHU, MAcc, SVCU and BMC of the either the SCSIT or the SIPT tests.

Although it has been argued that the SIPT should be interpreted as an entity, since

“patterns of scores across a number of SIPT [tests] can support meaningful inferences [whilst] inferences based on only a single test are subject to error” (Ayles, 1989, p. 234),

it might also be necessary at times to draw inferences from a few subtests (Ayles & Marr, 1991). For research purposes, several studies have used the SVCU test (Atwood & Cermak, 1986; Cermak & Ayles, 1984) and the revised Motor Accuracy (MAcc) test (Mandell, Nelson & Cermak, 1984; Smith, 1983) of the SCSIT as isolated measures to assess midline crossing and hand performance respectively. In particular, Cermak and Ayles (1984) examined midline crossing using the SVCU observations. Scores of 179 learning disabled children were compared with those of 120 normal children, aged between 5 and 8 years. The authors found that the SVCU discriminated clearly between disabled and normal children, which further suggested its suitability for use in this study.

The first study was thus designed to investigate the potential of the three SIPT subtests to reveal the extent of handedness, midline crossing and bimanual coordination in normal 5-year old children. Implementing three related tests appeared to be more appropriate than compiling a set of unrelated measures.

Hand preference, measured by the *Preferred Hand Use* in the SIPT, is based on the initial hand selected for a tracing task (Ayles, 1989). However, it has been cautioned against assuming a highly trained task (e.g., drawing and writing), to provide an accurate reflection of hand preference, since it is subject to socio-cultural influences (Ida, Mandal

& Bryden, 2000). The inclusion of an additional test with more opportunity to demonstrate hand preference across a range of *functional* tasks was thus deemed necessary.

Hand preference assessments typically consist of observing preferred hand use across a variety of every day tasks, some of which are more skilled tasks (e.g., writing and throwing) and less skilled ones (e.g., picking up items, opening containers) (Ida, Mandal & Bryden, 2000; Steenhuis & Bryden, 1989). Some authors state that only items with the highest test-retest reliability should be included (e.g., Chapman & Chapman, 1987; Raczkowski, Kalat & Nebes, 1974), while others question the validity of such items because of the high training element involved in most of the tasks included (e.g., Annett, 1998; Olsson & Rett, 1989; Steenhuis & Bryden, 1989; Stutte, Schilling & Weber, 1977). In general, there appears to be no consensus on superior test items for assessing hand preference.

Hand preference assessments that have been used with children were explored for their ability to provide the variety necessary for a handedness profile, and discarded for reasons listed in Appendix 2A. The test that appeared most suitable for a normative handedness profile was the standardised and widely used Edinburgh Handedness Inventory (EHI) (Oldfield, 1971). Its unidimensional nature was deemed unproblematic since for the purpose of the thesis, hand preference was considered to be one dimension of handedness. Section 2.2 outlines the research method for this study, where the selected tests are described and explored with reference to reliability and validity studies, and related literature.

2.1.2 Experimental Hypotheses

The underlying assumption for the experimental hypotheses is based on the reviewed literature suggesting that handedness is a highly complex and multifaceted interaction phenomenon developed both through inherited neurophysiological, as well as external task related and environmental factors. Handedness is primarily established over the first nine years of life, and degrees of handedness vary widely between individuals. Based on these assumptions, the following experimental hypotheses were established for the purpose of the first study.

Experimental Hypothesis 1: The Edinburgh Handedness Inventory (EHI), and the three tests of the SIPT (i.e., MAcc, SVCU and BMC), would satisfactorily display a wide range of hand preference, hand performance, midline crossing and bimanual coordination behaviour expected in normal developing 5-year old children. In combination, these tests would thus demonstrate a continuum of normal handedness variability at school entry.

Experimental Hypothesis 2: Congruent with studies that have found support for gender differences, significant differences would be revealed in handedness between girls and boys.

If the experimental hypotheses were met, the selected tests would form the basis of a normative handedness profile. If the experimental hypotheses were not supported, the findings would indicate how these tests might need to be adapted in order to provide sufficient information for the basis of a normative profile.

2.2 Method

2.2.1 Participants

The sample for this first study consisted of 122 normal children (61 boys and 61 girls), aged 5 years 0 months to 5 years 11 months. For a moderate effect size of 0.40 (power of 0.96 alpha 0.05), 20 children were required for each of the six cells (i.e., two groups and four variables), resulting in 120 children. A further two children were included to replace dropouts. This sample size was deemed adequate to represent the typical responses in left and right handers of the 5-year old population. The sample was a convenience sample drawn from local kindergartens and prep-schools in Melbourne. Children were excluded in the study if they attended occupational therapy, physiotherapy or speech therapy, or if there was a history of mental or physical disability, evidence of developmental delay, behavioural or attention problems, as determined from a parent questionnaire (see Appendix 2B). Sample selection was dependent on subjects meeting the inclusion criteria, permission of principals, teachers and parents (see Appendix 2C for an example of the Informed Consent Form used throughout this research, with minor adaptations to suit the specific aims and particulars of each study), and availability of the children. Ethics approval was obtained from La Trobe University (see Appendix 2D).

Five-year old children were considered suitable for this study for three reasons. Firstly, while the *direction* of hand preference should be well apparent by the age of five (Tan, 1985), its *degree* is not fully developed until the age of seven years (Ross, Lipper, & Auld, 1992), or nine years (McManus, Sik, Cole, Mellon, Wong & Kloss, 1988). Since the children were either in the second half of kindergarten, or the first half of prep-school, they would not have had much formal schooling where the preferred hand would have been excessively 'trained' through writing. In other words, it could be expected that more children would present with degrees of unestablished hand preference at the age of five years than in older age groups (McManus et al., 1988). Secondly, 5-year old children should have developed a sufficient degree of bimanual coordination and crossing of the midline to perform the SIPT subtests, which are standardised on children aged four to eight years (Ayres, 1989). Finally, unestablished handedness on the verge of school entry raises much concern from parents and teachers since a decision on the writing hand has to be made, and referrals to occupational therapy for handedness delays are most

prevalent at this stage. It is thus important to have an understanding of the normal variability in handedness at school going age.

2.2.2 Tests and Instruments

Whilst the researcher's initial intention was to implement all tests using the standardised administration and scoring procedures, closer investigation of the tests in relation to the aims of the study revealed that rigid adherence to the standardized methods would have serious disadvantages (see Sections 2.2.2.1 to 2.2.2.4). To compound matters, it was not possible to obtain computer scoring for an *incomplete* SIPT battery of 3 subtests to compare the results with a standardised population. After careful consideration it was decided to administer the tests as stipulated by the SIPT but to score them manually according to the SCSIT. Only those adaptations to the administration and scoring that were deemed to improve the overall quality and accuracy of the data were incorporated, whilst the remaining aspects of the tests were administered and scored as stipulated by the SIPT/SCSIT.

2.2.2.1 Handedness: Hand Preference

The Edinburgh Handedness Inventory (EHI) consists of ten items (see Table 2.1) which include highly skilled and trained activities such as writing and drawing as well as less trained/skilled ones, such as opening the lid of a box.

Table 2.1. Summary of Test-Retest Reliability of the Edinburgh Handedness Inventory (EHI) (McFarland & Anderson, 1980)

<i>Item</i>	<i>Pearson's r</i> <i>(p < 0.05)</i>	<i>Item</i>	<i>Pearson's r</i> <i>(p < 0.05)</i>
1. Writing	0.95	6. Eating with a spoon	0.84
2. Drawing	0.94	7. Striking a match	0.79
3. Throwing a ball	0.90	8. Sweeping with a broom	0.62
4. Using a toothbrush	0.87	9. Using a knife for cutting	0.81
5. Cutting with scissors	0.85	10. Opening the lid of a box	0.69

The extensive use of the EHI (Annett, 1998; Schachter 2000), including its application with children (Brito, Lins, Paumgarten & Brito, 1992; Ross, Lipper & Auld, 1992), and its generally high reliability, confirmed the decision to include it as an alternative hand

preference assessment to the 'preferred hand use' of the SIPT. The EHI has been standardised on several populations (e.g., McMeekan & Lishman, 1975; Williams, 1986). In addition, the EHI displays a high factor stability and is thus valid in terms of test-retest performance, age and sex factor loading (McFarland & Anderson, 1980). Recently, Ransil and Schachter (1994) re-confirmed the high reliability of eight of the ten EHI items ($N = 735$, overall Spearman's $r = 0.715$, Kendall's tau = 0.616; right handers Spearman's $r = 0.75$, $p < 0.01$; left handers Spearman's $r = 0.86$, $p < 0.01$). Pearson's r for test-retest correlations of the remaining two items, using a knife without fork and opening a box, were obtained from the study by McFarland and Anderson (1980). (See again Table 2.1 for summary of EHI test-retest reliability for individual items.)

2.2.2.2 Handedness: Hand Performance

Hand performance was assessed using the *Motor Accuracy (MAcc) Revised* test of the SIPT. The MAcc

“emphasises accuracy or ‘steadiness’ of the visually directed hand use of a pen and is specifically designed for comparison between the more- and less-accurate hands” (Mandell, Nelson & Cermak, 1984, p.115).

The MAcc requires timed tracing of a butterfly shaped line on an A3 paper, first with the preferred hand and then with the non-preferred hand (see Appendix 2E for example of MAcc test). As the original MAcc test yielded 'extremely low scores' (Smith, 1983), the administration and scoring procedures were changed for the purpose of the SCSIT and the SIPT whilst the structure of the test was maintained, comprising the present MAcc (Revised). This modification raised the standard scores and thereby appeared to improve the validity of the test in clinical populations (Ayres, 1980; Smith, 1983).

The test-retest reliability of the MAcc (adjusted score) and the interrater reliability (Ayres & Marr, 1991) are summarised in Table 2.2 together with the other two tests. Available validity data has also included correlations and factor analyses between the subtests in addition to factor and cluster analysis of the entire test battery (see Appendix 2F for a summary of validity-related evidence for the three selected SIPT subtests).

Table 2.2. Summary of Test-Retest and Interrater Reliability of the Motor Accuracy (MAcc) Test, Space Visualisation Contralateral Use (SVCU) Test, Preferred Hand Use (PHU) and Bilateral Motor Coordination (BMC) Test for Arms

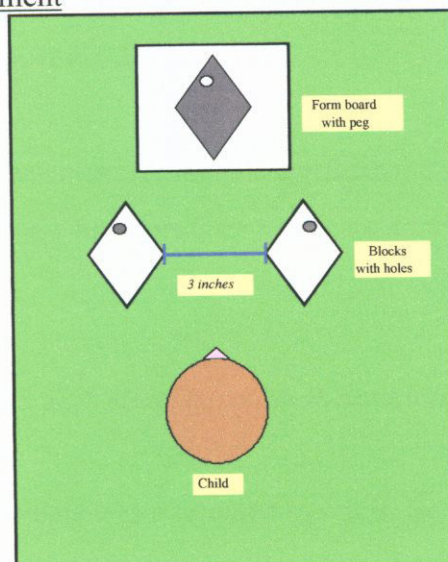
<i>SIPT Test</i>	<i>Test-retest Reliability: Combined sample (N = 10 normal, N = 41 dysfunctional)</i>	<i>Test-retest Reliability: Learning disabled sample (N = 41)</i>	<i>Interrater Reliabilities</i>
SVCU score	r = 0.61	r = 0.49	r = 0.94 (N = 63)
PHU	r = 0.64	r = 0.66	-
BMC (arms)	r = 0.82	r = 0.77	r = 0.96 (N = 48)
MAcc Rev (adjusted)	r = 0.84	r = 0.84	r = 0.99 (N = 62)

Note. SVCU = Space Visualisation Contralateral Use, PHU = Preferred Hand Use, BMC = Bilateral Motor Coordination, MAcc Rev = Motor Accuracy Revised, N = number of cases; r = Person's r. For all tests, $p < 0.05$. (Ayres & Marr, 1991).

2.2.2.3 Midline Crossing

The SIPT test, *Space Visualisation*, primarily used for assessing visual perception, is also employed as a midline crossing test, based on the *Space Visualisation Contralateral Use* (SVCU) score. The SVCU tasks require picking up one of the two blocks placed 3 inches (7.62 cm) apart and in front of each hand on either side of the child's midline, and fitting the block into a form board (see Figure 2.1).

Figure 2.1. Layout of the Space Visualisation Contralateral Use (SVCU) Midline Crossing Instrument



Note. The correct response would be to pick up the left block.

Since the blocks can be picked up ipsilaterally (i.e., on the same side) or contralaterally (i.e., on the opposite side), the extent of midline crossing can be observed. There are

thirty test items similar to the example shown in Figure 2.1. The form board is presented with different peg placement for each trial, becoming progressively more challenging, and the correct blocks must be fitted into the form board. Equal numbers of contralateral responses (i.e., 15 if all 30 items are administered) are possible using either the right or the left hand consistently. (See Appendix 2G for the SVCU score sheet.)

Test-retest and interrater reliability for the SVCU are reported in Table 2.2, and validity related evidence has been summarised in Appendix 2F.

2.2.2.4 Bilateral Motor Coordination

The SIPT *Bilateral Motor Coordination* (BMC) test for the arms requires bimanual movement that demonstrates a smoothly executed interaction between the extremities (Ayres, 1989), involving bilateral coordination of arms, hands and feet by imitating unfamiliar rhythmical and/or simultaneous movement. The test consists of 10 upper extremity and 4 lower extremity items, but since this study focused on *bimanual* (rather than bilateral) coordination, only the upper extremity items were used. Test items consist of different rhythmical clapping and tapping patterns scored according to a criterion-based scoring system (see Appendix 2H for the BMC score sheet). Test-retest and interrater reliability for the BMC test are reported in Table 2.2, and validity related evidence is summarised in Appendix 2F.

Inspection of the SIPT tests generated reasonable confidence that together they possessed the potential to provide the basis for a profile to indicate varying degrees of handedness establishment.

2.2.3 Test Administration Procedures

The sequence of various test items was alternated to minimise order effects. One third of the children started with the hand preference assessment, one third with bimanual coordination and one third with midline crossing. In addition, the four trials of the EHI were interspersed with the other test items so that any practice effects and monotony were minimised. The duration of the entire test procedures was approximately 35 minutes per

child. The researcher is qualified in the administration of both the Southern California Sensory Integration Tests (SCIST) and the SIPT, and she administered all tests herself.

2.2.3.1 Hand Preference

There are several methods to assess hand preference. The standard Edinburgh Handedness Inventory (EHI), an inventory for adults, requires a written *self report* on hand preference, which is unsuitable for young pre-school children who are unable to read and write. Alternatives to self report include the *tell method* and *parental report*, but these have been found not to be highly reliable in children (Longoni & DeGennaro, 1992; Rigal, 1992; Whittington & Richards, 1987). The *demonstration method* is another option, consisting of task executions by the child (Fennell, Satz & Morris, 1983). This has been considered to be the most reliable hand preference assessment for children (Longoni & DeGenaro, 1992; Rigal, 1992) and has been used in several studies (Bishop, 1990b, 1990c; Bruml, 1972; Longoni & DeGennaro, 1992; McManus, Sik, Cole, Mellon, Wong & Kloss, 1988; Rigal, 1992; Ross, Lipper & Auld, 1992; Vasconcelos, 1993).

The standard adult version of the EHI includes the options of stating whether a hand is always (++), usually (+) or not preferred (+ in both left and right columns), thereby incorporating a *within-task* consistency measure (Oldfield, 1971). Within-tasks consistency has been emphasised as an important aspect when evaluating hand preference in children (Bishop, 1990a, 1990b). However, for children the standard EHI consistency method would again need to be based on the unreliable tell method. A better alternative would be to incorporate consistency into the demonstration method by including repeated trials of task demonstration.

For the present study, the *demonstration* method of the EHI was employed by administering four trials for each of the ten items, resulting in a total of 40 task executions to allow for a within-tasks consistency measurement (see Appendix 2I for EHI score sheet). Each test item was placed in the child's midline for demonstration and then removed before presenting the next item. The child was then asked to demonstrate how the item would be used (see Appendix 2J for EHI instructions).

2.2.3.2 Hand Performance

The MAcc was administered according to specifications stipulated in the SIPT manual (Ayres, 1989). The MAcc A3 sheet was taped to the table in the child's midline and a red felt pen was placed vertically in the centre of the sheet. The child was instructed to pick up the pen (the hand used to pick up the pen was recorded as the preferred hand use/PHU), and trace on the heavy black line in the practice section after a brief demonstration by the examiner. The child was then asked to trace around the butterfly without lifting the pen, commencing on the contralateral side to the hand used. The child was encouraged to stay on the heavy black line and maintain a constant moderate speed, assisted by verbal feedback from the examiner to slow down or speed up, until the ideal pace was achieved (i.e., the aim was to complete the task in one minute). The task was then repeated with the other hand (see Appendix 2K for MAcc instructions).

2.2.3.3 Midline Crossing

The Space Visualisation test was administered according to specifications in the SIPT manual (Ayres, 1989), with one difference. According to the standard test procedure the test is terminated after five errors that are not necessarily consecutive. This means that children performing well on the test experience more opportunity to display midline crossing than those with poor visual perceptual skills. The ability for space visualisation was of no interest to this study, and the completion of 30 items was deemed too challenging for 5-year old children, particularly with the progressively increasing difficulty level. Therefore, for the present study, children completed the first 20 items only, regardless of mistakes made. This adaptation also allowed for improved comparison of midline crossing behaviour within the sample since all children completed the same number of test items. The examiner ensured a swift change of blocks with accurate placement, to keep the child's attention. The child was instructed not to finger or turn the blocks before picking them up (see again Appendix 2G for SVCU instructions).

2.2.3.4 Bilateral Motor Coordination

The BMC subtest for arms was administered according to specifications in the SIPT manual (Ayres, 1989) (see again Appendix 2H for BMC instructions). The examiner sat

opposite the child, instructing the child to watch the pattern carefully until it was completed, and to use the same hands as the examiner (i.e., mirror image). The examiner demonstrated the movement pattern of each item and then asked the child to repeat the same pattern. If the response was incorrect or poor, a second demonstration was given.

2.2.4 Scoring Procedures

2.2.4.1 Hand Preference

It has been suggested that hand preference should be quantified in degrees rather than combined arbitrarily into right and left handed categories to provide a unitary scale for use across studies (Bishop, Ross, Daniels & Bright, 1996). The EHI, typically quantified as a percentage or *laterality quotient*, was deemed to provide a useful continuum of hand preference scores for investigating degrees of handedness. Within the context of existing knowledge, multiple handedness groups could still be derived from such a continuous scale if needed, but a continuum could not be obtained from a binominal classification.

The EHI total score of 40 was converted to a laterality quotient (LQ) as follows:

$$\text{LQ} = \frac{\text{Number of Right Handed responses} - \text{Number of Left Handed responses}}{40} \times 100$$

40 (Total number of responses)

Based on the EHI, left handers obtained a percentage between -1% and -100%, and right handers between 1% and 100%. An arbitrary cut-off point for *established* versus *unestablished* handedness employing a laterality quotient between 60% and 70% has been proposed by several authors (Bear, Schiff, Saver, Greenberg & Freeman, 1986; Dellatolas, Annesia, Jallon, Chavance & Lellouch, 1990; Schachter, Ransil & Geschwind, 1987). Whilst these studies did not provide normative data, they were used as guidelines, and it was decided to take the more stringent option in defining unestablished handedness at a laterality quotient smaller or equal to 60%. The categorisation of the laterality quotient into three hand preference groups allowed for between-group comparisons within the sample.

The consistency measure based on four trials of the EHI was scored according to a three-point scale. If a child used one hand consistently for an item across all four trials, a score

of two was given. If the child used one hand three times, a score of one was given, and if each hand was used twice across one item, consistency was zero. A maximum of 20 points could be scored across the 10 items, regardless of the direction of hand preference. The score was multiplied by five to obtain a percentage. Since no cut-off point for consistency has been proposed in the literature to the researcher's knowledge, the 95% confidence interval (CI) of the mean, which calculates the interval around the sample mean that will include the true, unknown population 95% of the time (Norušis, 1990), was taken as a reference. Children falling below the 95% CI were classified as being inconsistent.

2.2.4.2 Hand Performance

The manual scoring procedures of the Southern California Sensory Integration Tests (SCSIT) were adopted for the MAcc in the absence of computerised SIPT scoring. The error score, based on the deviation from the heavy black line (and the short, medium and long dashed lines as stipulated) in inches, was obtained by using a line measure. The error score of each hand was subtracted from 200 to obtain an *accuracy score* for the right and left hands respectively. The time to complete the tracing was recorded in seconds, multiplied by 0.2 and added to the accuracy score to obtain an *adjusted score* for each hand. The adjusted score was deemed a more suitable measure since performance should include accuracy in addition to speed for a more exact measure (Fitts, 1954; Schmidt & Lee, 1999; Steingrüber & Lienert, 1971).

In the absence of appropriate normative SCSIT data on an Australian sample against which performance could be compared, a *performance level* of the MAcc was computed for the present study. The figure 200, from which the error score is subtracted in the SCSIT, was taken as the maximum possible error score. In addition, the number 12 was added to 200 to cover the ideal time of completion, which is 60 seconds ($60 \times 0.2 = 12$). The MAcc performance level (PL) was calculated as a percentage as follows:

$$\text{MAcc PL} = \frac{\text{Adjusted MAcc score}}{212 \text{ (Total possible error score)}} \times 100$$

The highest performance level achieved by either hand was recorded but the direction of handedness was not noted since it was irrelevant in the context of overall performance. This method does not allow for a comparison of individual performances in relation to

the norm, since no normative studies have employed this scoring method, but it does differentiate between various levels of performance within the sample.

The MAcc *interhand difference (IHD)* indicated to what extent one hand outperformed the other, regardless of the actual level of performance. The IHD was calculated as follows:

$$\text{MAcc IHD} = \text{Right MAcc Performance Level} - \text{Left MAcc Performance Level}$$

As with the laterality quotient, a negative score indicated superior left handed performance, and a positive score denoted superior performance with the right hand.

2.2.4.3 Midline Crossing

For SVCU midline crossing, the hand used to pick up one of the two blocks was recorded as the *preferred* hand. If the child used the right hand to pick up the block on the right side, or the left hand to pick up the block on the left side, the response was recorded as *ipsilateral*. If the child used the hand opposite to the chosen block, then the response was recorded as *contralateral* (see again Figure 2.1). The number of responses performed with each hand was added. Three measures were calculated. First, the *preferred hand score (PHU)*, as stipulated in the SCSIT, (Ayres, 1976; Cermak, Quintero & Cohen, 1986) was calculated as follows:

$$\text{PHU} = \frac{\text{Response of the writing/preferred hand}}{20 \text{ (Total response)}} \times 100$$

Second, the *midline crossing extent (MCE)* was computed as follows, regardless of which hand was used:

$$\text{MCE} = \frac{\text{Number of contralateral responses}}{20 \text{ (total number of responses)}}$$

This score provides similar information to the SVCU score stipulated in the SCSIT (i.e., $30 - [\text{ipsilateral responses} / \text{contralateral responses}]$). However, the SVCU score was not used in this study since a standard 20 of the 30 SVCU items were employed.

Third, for the purpose of this study, the *midline crossing quotient (MCQ)* was calculated, identical to the laterality quotient, and also reflecting interhand differences in midline crossing. Since half of the correct responses (i.e., 10) were placed on the ipsilateral side, and the other half (i.e., 10) contralaterally, the maximum number of contralateral reaches that could be achieved by using one hand consistently was 10 (i.e., 50% of a total of 20).

Therefore, the difference between left and right contralateral responses was divided by 10 to obtain the MCQ.

$$\text{MCQ} = \frac{\text{Right handed Responses} - \text{Left handed responses}}{10 \text{ (Total number of possible contralateral responses)}} \times 100$$

2.2.4.4 Bilateral Motor Coordination

Scoring procedures were based on the SIPT Manual. A score of two points was given if the child was able to execute the movement smoothly and correctly as demonstrated, and one point was given if there were slight irregularities or the demonstration had to be repeated. A score of zero denoted incorrect movement patterns or movement irregularity that did not improve upon a second trial. Up to ten items were administered, unless the child scored zero for four consecutive items, in which case the test was discontinued. The maximum score was 20. For the purpose of this study, the score was converted to a percentage by multiplying the final score by five to provide a comparative measure for the other tests (i.e., EHI, MAcc and SVCU).

2.2.5 Data Analysis

Descriptive analyses were employed to obtain means and standard deviations of interhand differences and performance levels of the four tests, and to examine frequency distributions for skewness and kurtosis in left and right handers. Left and right handed responses were compared on all tests (e.g., EHI hand preference, MAcc hand preference). There were equal numbers of boys and girls ($n = 61$ each), one-way Analysis of Variance (ANOVA) was performed for each measure to establish if there were significant gender differences for any of the measures. To minimise escalation of Type I error with multiple application of ANOVA, the more conservative significance level of $p = 0.01$. The EHI was further investigated in terms of Consistency and extent of established handedness. Pearson's Chi and Cramer's V were employed to observe the strength of a relationship between parental report and EHI results on hand preference in left, right and unestablished handedness groups. Finally, unequal numbers of left and right handers precluded a detailed comparative analysis between the two handedness groups, but for exploring preliminary tendencies, bar charts were constructed to display extent of hand performance (MAcc), midline crossing (SVCU) and bimanual coordination (BMC) in terms of the EHI classification (see Appendix 2L).

2.3 Results

One Way ANOVA found gender differences not to be significant in any of the tests (see Table 2.3 for details), although gender differences in bimanual coordination approached significance (also see Figure 2.14 and Table 2.12). Hand preference based on the Edinburgh Handedness Inventory (EHI) will be referred to as *EHI hand preference groups* hereon.

Table 2.3. One-Way ANOVA Values for Gender on Hand Preference, Consistency, Hand Performance, Midline Crossing and Bilateral Motor Coordination

<i>Measure</i>	<i>F-Ratio</i>	<i>Significance</i>
Hand Preference (EHI)	F = 0.384	$p = 0.536$
Consistency	F = 0.621	$p = 0.432$
Hand Performance	F = 0.437	$p = 0.510$
Midline Crossing	F = 3.068	$p = 0.082$
Bimanual Coordination	F = 6.029	$p = 0.016$

Note. $p = \text{significant at } 0.01 \text{ level.}$

2.3.1 Hand Preference

The EHI distribution for the entire sample (N = 122) would not be informative because of mixed negative and positive values in left and right handed responses. The distributions were thus displayed separately for EHI left handers (n = 16, all EHI negative values) and EHI right handers (n = 106, all EHI positive values) for the interhand difference distributions (see Figure 2.2 and Table 2.4).

Figure 2.2. Distribution of Edinburgh Handedness Inventory (EHI) in EHI Left and Right Handed Responses

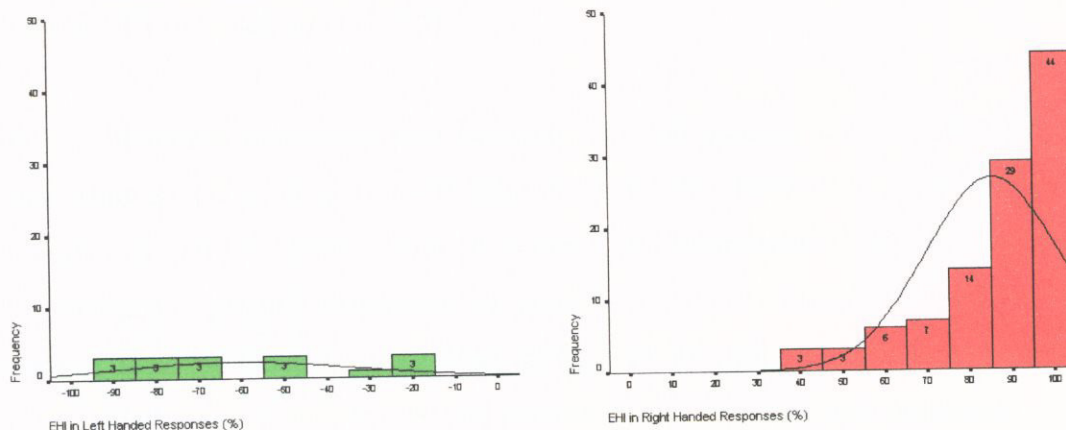
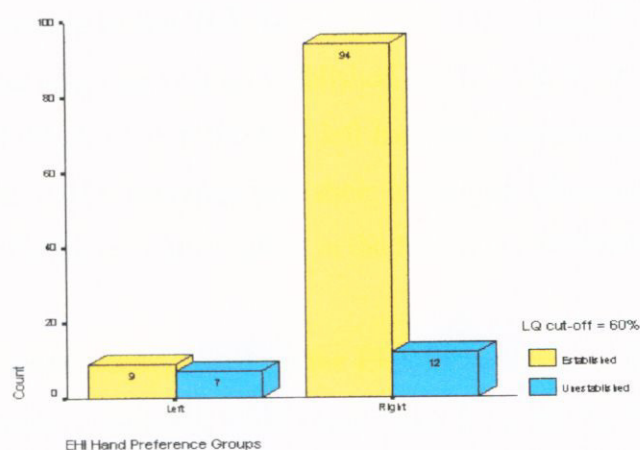


Table 2.4. Descriptive Information on EHI Left and Right Handed Distributions

	<i>Left</i>	<i>Right</i>		<i>Left</i>	<i>Right</i>
<i>N</i>	16	106	<i>Skewness</i>	0.51	-1.30
<i>Mean</i>	-61.75	85.33	<i>Kurtosis</i>	-1.20	1.06
<i>SD</i>	27.53	15.77	<i>95% CI</i>	-76.42; -47.08	82.29; 88.37

Note. N = number of children in each group; SD = standard deviation; CI = confidence interval.

The distribution for left and right handed responses showed strong differences in kurtosis. There was a more even and wider spread of EHI values in left handed responses (kurtosis = -1.20), while right handed responses were negatively skewed (-1.30) and positively kurtosed (1.06). The extent of established hand preference (i.e., whether this was established or unestablished) in relation to EHI left and right responses is displayed in Figure 2.3, using the 60% LQ cut-off point for the entire sample (i.e., if $LQ \leq 60\%$, the child was classified as unestablished).

Figure 2.3. Extent of Established Hand Preference in Relation to EHI Left and Right Responses

Note. EHI = Edinburgh Handedness Inventory; LQ = laterality quotient.

Almost half of EHI left handers (43.8%) were found to be unestablished, compared to 12 of the 106 EHI right handers (11.3%).

Table 2.5 illustrates the comparison between EHI and parental report hand preference groups, using the 60% LQ as a cut-off point for established handedness (thereby reducing the number of EHI left handers from 16 to nine), and information from the initial parent questionnaire on parental estimation of hand preference (whereby the 'definite' and 'tendency' hand preference groups were collapsed). Overall, 102 (83.6%) of children were classified in accordance to EHI and parental reports (PR) on hand preference.

Table 2.5. Cross-Tabulation of Hand Preference Groups Comparing the Edinburgh Handedness Inventory (EHI) and Parental Report (PR) on Established Hand Preference

	EHI Unestablished <i>n</i> = 19	EHI Left <i>n</i> = 9	EHI Right <i>n</i> = 94
PR Unestablished <i>n</i> = 2	<i>n</i> = 1 PR: 50.0% EHI: 5.3% Total: 0.8%		<i>n</i> = 1 PR: 50.0% EHI: 1.1% Total: 0.8%
PR Left <i>n</i> = 18	<i>n</i> = 8 PR: 44.4% EHI: 42.1% Total: 6.6%	<i>n</i> = 9 PR: 50.0% EHI: 100.0% Total: 7.4%	<i>n</i> = 1 PR: 5.6% EHI: 1.1% Total: 0.8%
PR Right <i>n</i> = 102	<i>n</i> = 10 PR: 9.8% EHI: 52.6% Total: 8.2%		<i>n</i> = 92 PR: 92.2% EHI: 97.8% Total: 75.4%

Note. The green squares indicate 100% agreement between Edinburgh Handedness Inventory (EHI) and Parent Report (PR) categories. PR percentages are represented in rows and EHI percentages in columns. *n* = number of cases in each square.

Seventy five percent agreement was found between EHI and PR groups in the right handed group. Only two parental reports (PR) indicated unestablished hand preference, compared to 19 according to the EHI. Ten of these 19 EHI unestablished handers were PR right handers, and only one EHI unestablished hander was reported to be left handed by parents. Also, whilst all nine of the EHI left handers were also PR left handed, twice as many parents (*n* = 18) indicated that their child had left handed tendencies. The majority of misclassifications thus occurred in the left and unestablished categories.

The distribution for consistency, based on the EHI, is displayed in Figure 2.4 and Table 2.6. of the entire sample. According to the consistency measure, thirteen (81.3%) EHI left handed responses, and 94 (88.7%) EHI right handed responses were classified as *established* (LQ = 60%), showing very similar proportions.

Figure 2.4. Distribution of Consistency

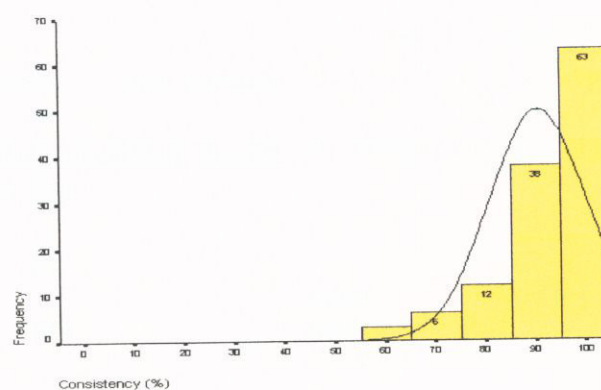


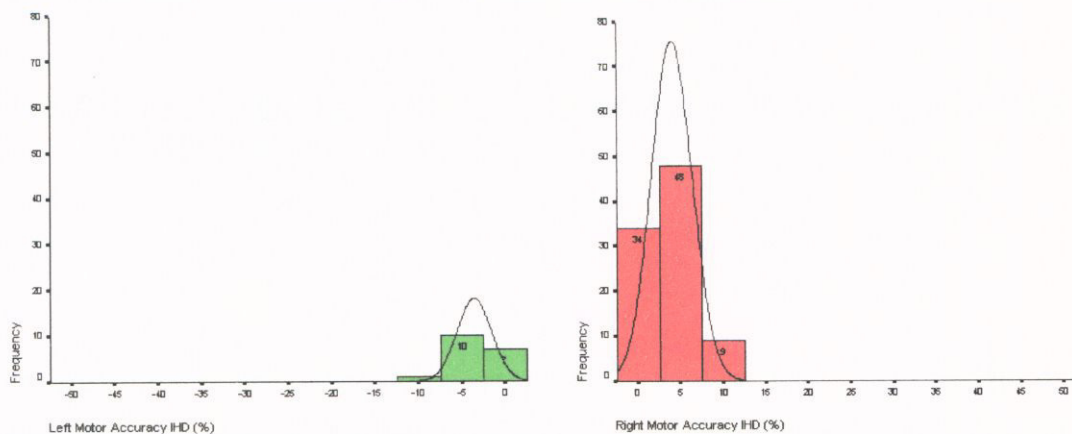
Table 2.6. Descriptive Information on Consistency Distribution

<i>No</i>	122	<i>Skewness</i>	-1.41
<i>Mean</i>	90.45	<i>Kurtosis</i>	1.92
<i>SD</i>	9.75	<i>95% CI</i>	88.70; 92.20

Sixty three (52%) children were 100% consistent, and a total of 101 children (83%) achieved a consistency score of 90 or higher. The distribution was negatively skewed (-1.41) and positively kurtosed (1.92), with a mean of 90.45 ± 9.75 (\pm refers to standard deviation).

2.3.2 Hand Performance

Figure 2.5 and Table 2.7 illustrate the MAcc interhand differences (IHD) in left and right handed responses respectively, whereby left IHD values indicate superior performance in the left hand compared to the right hand, and vice versa. Whilst IHD values of 0 ($n = 13$) are important for calculating the IHD mean, they do not contribute to comparative size of IHD between left and right handers and were thus excluded from the distributions illustrated below.

Figure 2.5. Distribution of Motor Accuracy (MAcc) Interhand Differences (IHD) of Superior Left Handed and Right Handed Performance

Note. All MAcc IHD values of the cases depicted on 0 of the x-axis exceed 0 but are smaller than 5.

Table 2.7. Descriptive Information on Left and Right Motor Accuracy (MAcc) Interhand Differences (IHD)

	<i>Left</i>	<i>Right</i>		<i>Left</i>	<i>Right</i>
<i>N</i>	18	91	<i>Skewness</i>	-1.45	0.79
<i>Mean</i>	-3.62	3.94	<i>Kurtosis</i>	3.26	0.21
<i>SD</i>	1.97	2.39	<i>95% CI</i>	-4.60; -2.63	3.45; 4.44

The mean and standard deviation (\pm) in both MAcc left and right handed responses was very similar and small. Altogether, thirty children (25.6%) showed an IHD of 5 or smaller. Only 10 children (12%) exceeded an IHD of 10. Left handed responses were strongly kurtosed and negatively skewed. In addition, there were 18 MAcc left handed responses compared to 16 EHI left handed responses. (See Appendix 2L for graphs on EHI left and right handed groups compared to the MAcc IHD.)

Figure 2.6 and Table 2.8 display the distribution of the MAcc *performance* level, based on the best achievement in relation to the maximum possible score of either hand (i.e., hypothetical performance range between 0 and 100).

Figure 2.6. Distribution of Motor Accuracy (MAcc) Performance Level (PL)

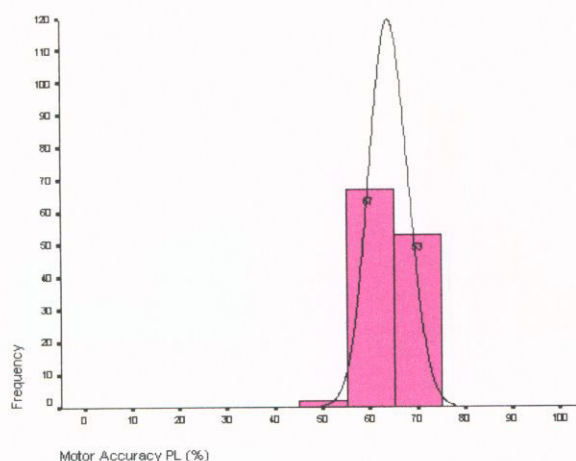


Table 2.8. Descriptive Information on the Motor Accuracy (MAcc) Performance Level (PL) Distribution

<i>N</i>	122	<i>Skewness</i>	-3.75
<i>Mean</i>	63.88	<i>Kurtosis</i>	40.28
<i>SD</i>	7.75	<i>95% CI</i>	63.16; 64.61

If the distribution is analysed within its presenting range (i.e., between 45 and 80), it can be described as a normal distribution (kurtosis 0.45, skewness -0.28) with a mean of 63.95 ± 4.01 . However, it is theoretically possible to score 0 as well as 100, and since it was the aim of this study to evaluate the extent to which the handedness measures detect various degrees of performance, the distribution needed to be analysed within the minimum and maximum possible ranges. As a result, the distribution was severely positively kurtosed (40.28) and negatively skewed (-3.75).

2.3.3 Midline Crossing

Employing the preferred hand use (PHU) score, the mean for the 5-year old population was 55.63 ± 9.24 for EHI left handers, and 53.96 ± 8.57 for EHI right handers. Since the distribution of left and right handed responses in midline crossing was based on negative and positive values of the midline crossing quotient (MCQ), Figure 2.7 and Table 2.9 illustrate the MCQ distribution (as a measure of interhand difference), in the left and right hands separately. Those children that avoided midline crossing on all occasions ($n = 24$) were excluded from the distributions.

Figure 2.7. Distribution of SVCU Midline Crossing Quotient (MCQ) in MCQ Left and Right Handed Responses

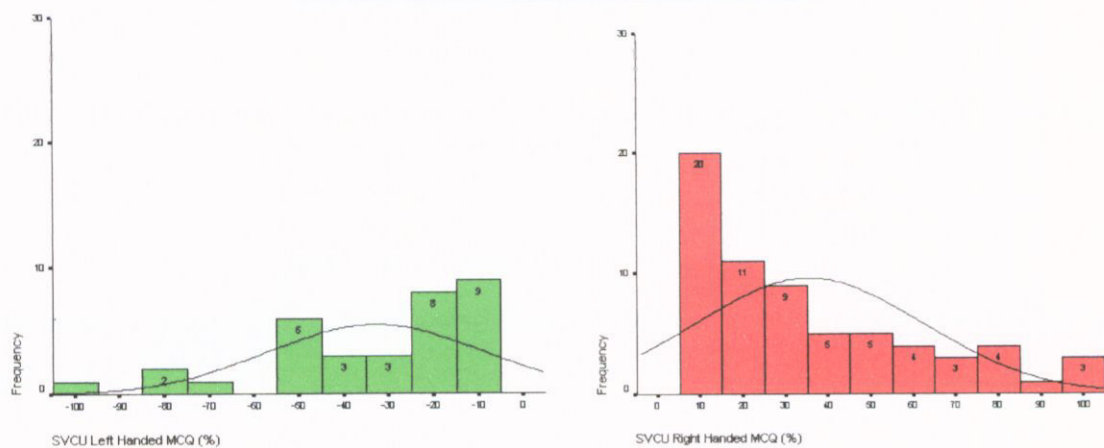


Table 2.9. Descriptive Information on SVCU Midline Crossing Quotient (MCQ) Distributions in MCQ Left and Right Handed Responses

	<i>Left</i>	<i>Right</i>		<i>Left</i>	<i>Right</i>
<i>N</i>	33	65	<i>Skewness</i>	-1.12	0.96
<i>Mean</i>	33.03	35.38	<i>Kurtosis</i>	0.73	-0.15
<i>SD</i>	23.91	26.93	<i>95% CI</i>	-41.51; -24.55	28.71; 42.06

Note. SVCU = Space Visualisation Contralateral Use.

The left handed distribution was skewed negatively (-1.45), and the right handed distribution was skewed positively (0.96), indicating that both groups aggregated towards zero and displayed midline crossing avoidance. The left and right handed distributions showed similar means and standard deviations. The MCQ left handed responses ($n = 33$) exceeded those identified by the EHI ($n = 16$), and the EHI right handed responses decreased from 106 (86.8%) to 65 (53.3%) in the MCQ right handed distribution (see Appendix 2L for a graph displaying the proportion of EHI left and right handers in relation to SVCU MCQ). Based on the entire sample, the midline crossing extent (i.e.,

the percentage of contralateral responses irrespective of which hand used) is displayed in Figure 2.8 and Table 2.10.

Figure 2.8. Distribution of SVCU Midline Crossing Extent

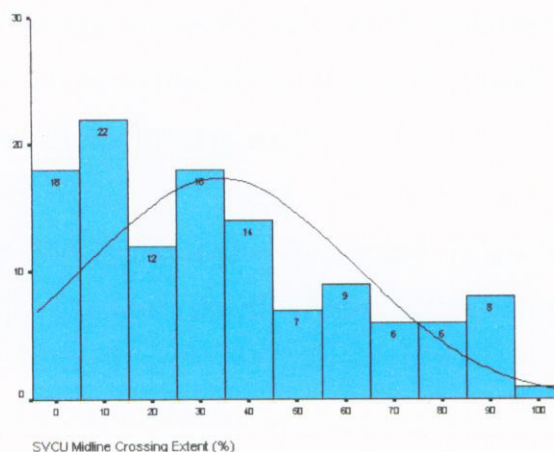


Table 2.10. Descriptive Information on the SVCU Midline Crossing Extent Distribution

<i>N</i>	122	<i>Skewness</i>	0.65
<i>Mean</i>	33.90	<i>Kurtosis</i>	-0.62
<i>SD</i>	27.81	<i>95% CI</i>	28.90; 38.91

Note. SVCU = Space Visualisation Contralateral Use.

The mean (\pm SD) of this distribution was low (33.90 ± 27.81), with 52 (42.6%) of children failing to cross the midline more than twice ($MCQ \leq 20\%$).

2.3.4 Bilateral Motor Coordination

The Bilateral Motor Coordination (BMC) test only measures the level of bimanual coordination and thus could not be differentiated into left and right handed response group. Figure 2.9 and Table 2.11 depict the BMC distribution of the entire sample.

Figure 2.9. Distribution of Bilateral Motor Coordination (BMC) Performance

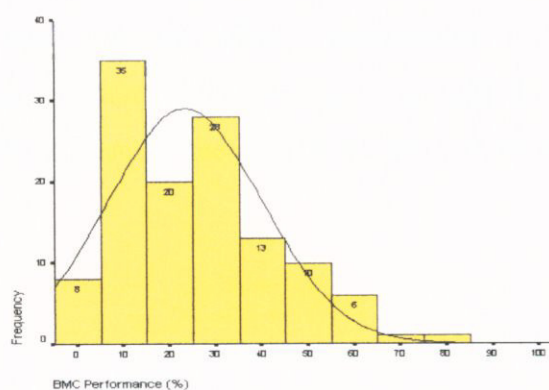
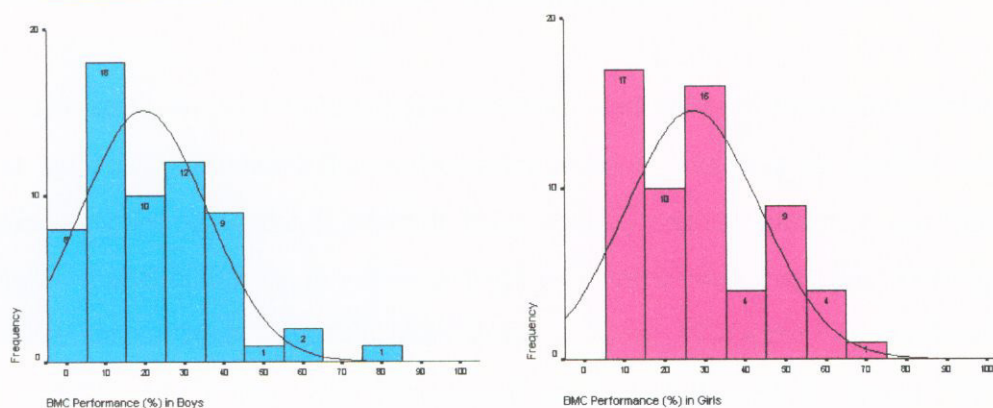


Table 2.11. Descriptive Information on Bilateral Motor Coordination (BMC)

<u>Performance</u>			
<i>N</i>	122	<i>Skewness</i>	0.75
<i>Mean</i>	23.32	<i>Kurtosis</i>	-0.03
<i>SD</i>	16.75	<i>95% CI</i>	20.32; 26.32

The BMC distribution showed a mean of 23.32 ± 16.75 , and it is positively skewed (0.75). Half of the sample ($n = 63$) performed at 20 or below (i.e., a score of 4 / 20), and only 18 children (15%) achieved a score of 50 or above.

Since the difference in BMC performance approached significance for gender ($p=0.01$), Figure 2.10 and Table 2.12 compare the BMC distributions of boys and girls.

Figure 2.10. Comparing Bilateral Motor Coordination (BMC) Performance Between Boys and GirlsTable 2.12. Descriptive Information on Bilateral Motor Coordination (BMC) Performance Distributions in Boys and Girls

	<i>Boys</i>	<i>Girls</i>		<i>Boys</i>	<i>Girls</i>
<i>N</i>	61	61	<i>Skewness</i>	1.02	0.58
<i>Mean</i>	19.67	26.96	<i>Kurtosis</i>	1.22	-0.72
<i>SD</i>	16.10	16.72	<i>95% CI</i>	15.55; 23.79	22.69; 31.25

None of the girls scored below 10% for the BMC test, and boys demonstrated a significantly lower mean in the BMC distribution (19.67 ± 16.10) than girls (26.96 ± 16.72). The male distribution was also more strongly skewed (1.02) and kurtosed (1.22) than the BMC distribution for the girls (skewness = 0.58; kurtosis = -0.72).

2.4 Discussion

2.4.1 Discussion of Results

The hypothesis that existing tests could be used to identify a variety and different levels of hand preference and performance, midline crossing and bimanual coordination in 5-year old normal children for the purpose of a handedness profile, was not satisfactorily supported. Existing tests revealed skewed distributions in hand preference, hand performance, midline crossing and bimanual coordination. Unless the underlying assumption of handedness being a multidimensional and complex phenomenon displaying a range of variability is incorrect, these findings indicate that the tests were not sufficiently sensitive to detect more subtle variations in the neuromotor behaviours related to handedness tested in this sample of 5-year old children.

Hand preference based on the Edinburgh Handedness Inventory demonstrated a marked ceiling effect, appearing to indicate that most children aged 5 years have established their hand preference according to the Edinburgh Handedness Inventory items. It has been repeatedly stated that although the *direction* of hand preference may be apparent from the age of 3 years or earlier (McManus, Sik, Cole, Wong & Kloss, 1988), the *degree* of hand preference continues to develop well into middle childhood (Gesell & Ames, 1947; McManus et al, 1988), and even throughout the life span (Coren, 1992). Based on the assumption that handedness is a fluid and complex phenomenon, multi-faceted rather than unidimensional, it would be expected that an increase in variability (i.e., degrees of handedness) across a variety of handedness tasks would be apparent, particularly in the 5-year old age group where handedness is still developing. The skewness of the results indicates that the Edinburgh Handedness Inventory might not be sufficiently sensitive to assess degrees of hand preference in this age group. Nevertheless, using the Edinburgh Handedness Inventory and the consistency measure in a group of *younger* children might reveal whether the limited degree of hand preference observed in this study is indeed determined by age.

Although the overall agreement between parental report and the Edinburgh Handedness Inventory assessment was high because of the high agreement in the large numbers of right handers, the discrepancy on classifying unestablished and left handers was apparent,

with parents indicating twice as many children with a left-handed tendency than identified by the Edinburgh Handedness Inventory. It could be interpreted from these findings that the Edinburgh Handedness Inventory does not appear to be sensitive to *degrees* of left hand preference in 5-year old children. Alternatively, since parent reports on handedness are subjective and based on a wider range of everyday tasks, they may not be totally reliable. It is likely that both explanations are to some extent correct.

The revised Motor Accuracy test displayed a narrow (strongly kurtosed) range of variability in interhand differences with a limited ability to differentiate between various levels of performance. As mentioned earlier, the scoring adjustment of the Motor Accuracy test reduced the range of interhand differences and raised the level of performance (Ayres, 1989; Smith, 1983). Whilst this procedure might increase the validity in a clinical sample, it might also obscure the finer nuances of difference in skill between the hands in a normative sample. A wider range of interhand differences would be useful for the basis of a handedness profile, where various levels of handedness responses need to be related to each other across different handedness measures. In addition, the *performance* level of the Motor Accuracy test revealed a tight distribution with a small standard deviation. Since only one normal age group was assessed, the small range of performance was not unexpected. It is likely that the developmental level of 5-year old children has limited the range of behaviours in the Motor Accuracy test, both for interhand differences and performance levels. Therefore, greater variability might be demonstrated if younger children were to be included in a sample.

In contrast to the Edinburgh Handedness Inventory and the Motor Accuracy test, midline crossing and bimanual coordination both yielded floor effects, indicating that the items were too difficult for 5-year olds. To some extent it had been expected that 5-year old children would score in the lower range on these two tests, since the Sensory Integration and Praxis Test battery was designed to assess children between the ages of four and ten years. Surprisingly, not only were the floor effects greater than anticipated, but the distribution was also strongly kurtosed, again indicating a lack of variability in these two measures.

As discussed in Chapter 1, there is evidence that midline crossing develops with age (Provine & Westerman, 1979; Schofield, 1976b). Stilwell (1987b), using a different

measure to the Space Visualisation Contralateral Use test, found in a sample of 2- to 6-year old children that even 2-year olds employed contralateral reaching. In contrast, the 5-year olds in the present study using the Space Visualisation Contralateral Use test, crossed the midline with their preferred hand only 2.5 times on average out of a possible 10 contralateral responses.

Cermak, Quintero and Cohen (1980) administered the standardised Space Visualisation Contralateral Use test to 5-year old children and found a higher percentage of contralateral responses compared to the present study. However, the comparison between the studies can only be tentative because of differences in test administration (i.e., in the present study, 20 items were performed with all children, whereas Cermak et al. would have terminated the test of potentially 30 items after 5 errors according to Southern California Sensory Integration Tests stipulation). This might account for differences in midline crossing behaviour across the two studies.

Nevertheless, compared to results found by Stilwell (1987b), the incidence of midline crossing in the study by Cermak et al.'s (1980) findings was low, with 43% of 5-year olds 'lacking' dominance' establishment, as defined by Ayres (1976). If a test of 5-year olds presents with a floor effect, it is unlikely that the Space Visualisation Contralateral Use test would contribute sufficient information on the extent of handedness in younger children. In other words, whilst the Space Visualisation Contralateral Use test has been found appropriate for the purposes of the Southern California Sensory Integration Tests and the Sensory Integration and Praxis Tests, being standardised for children aged 4 years 0 months to 8 year 11 months (Cermak et al., 1980), it lacks the sensitivity to detect multiple levels of contralateral reaching needed for a comprehensive handedness profile.

Similar to midline crossing, the majority of children (85%) were unable to successfully complete half of the Bilateral Motor Coordination items, showing a stronger floor effect than expected. This indicates that the Bilateral Motor Coordination test was too difficult for 5-year old children, particularly boys, who showed an even lower performance mean than girls. The difficulty level may be appropriate for the Sensory Integration and Praxis Tests where the same Bilateral Motor Coordination test is used for children as old as 11 years. However, as a basis for a handedness profile the Bilateral Motor Coordination test did not display enough variation evident in simpler levels of bimanual coordination.

Moreover, the Bilateral Motor Coordination test consists of either symmetrical or rhythmically alternating movement, and an asymmetry between the hands (i.e., a leading hand) cannot be observed in this test. Asymmetry between the hands has been identified as an important aspect of bimanual coordination (Guiard, 1985; Peters, 1981; Provins, 1997), and such asymmetry also bears closer resemblance to functional bimanual tasks, most of which require a leading and an assisting hand. In the context of the forthcoming studies it was decided to divide the modified bimanual coordination measure into a preference and a performance component, making it consistent with the corresponding preference/performance components of the other handedness measures. The preference component would reflect the leading hand during functional bimanual tasks and interhand differences in general, whereas the performance component would identify the level of bimanual cooperation and entrainment between the hands. This distinction would then allow for improved comparison with unimanual hand preference and performance of the other handedness measures.

2.4.2 Conclusion

The failure of findings to meet the Experimental Hypothesis indicated the need for adjustments to the existing collection of tests. The measures of hand preference (i.e., the Edinburgh Handedness Inventory) and hand performance (i.e., Motor Accuracy) showed a skewed, limited range, which may be appropriate for a group of 5-year old children who had established the direction of hand preference. The finding that parents report twice as many left handers as were assessed with the Edinburgh Handedness Inventory further supports this proposition. For hand preference and performance, the variability in range would thus need to be explored further with normal children, since it is likely that a group of younger children would display a greater range of degrees of hand preference. Thus prior to determining a suitable instrument for a handedness profile, a second attempt to explore the range of variability was designed to include the use of the Edinburgh Handedness Inventory and the revised Motor Accuracy test with a younger sample of 3-, 4- and 5-year old normal children.

In contrast, 5-year old children demonstrated obvious difficulties in performing midline crossing with the Space Visualisation Contralateral Use test and bimanual coordination of the Bilateral Motor Coordination test. Therefore, these tests were deemed unsuitable

for a developmental handedness profile that should incorporate lower levels of midline crossing and bimanual coordination. Consequently, as there appeared to be no other appropriate clinical midline crossing or bimanual coordination tests apart from the Sensory Integration and Praxis subtests standardised for the paediatric population, it seemed necessary to explore the suitability of existing non-clinical research tests for a handedness profile. An appropriate midline crossing test should include different complexities of contralateral reaching by introducing both intrapersonal (proximal) and extrapersonal (distal) spaces, since this distinction might yield different results as indicated by the literature. In addition, increased opportunity for contralateral reaches should also feature in the modified midline crossing test. Similarly, bimanual coordination tests should include lower and higher performance levels and asymmetry between the hands with a directly measurable outcome. The following chapter will review existing tests, select and describe the most suitable ones, and implement the new collection of tests in a normative sample including two younger age ranges.

CHAPTER 3

STUDY II: TEST MODIFICATION AND INVESTIGATION OF THE POTENTIAL OF MODIFIED TESTS TO REVEAL THE EXTENT OF HANDEDNESS, BIMANUAL COORDINATION AND MIDLINE CROSSING IN NORMAL CHILDREN AGED 3 TO 5 YEARS

3.1 Introduction

The aim of this chapter is to present a trial of the hand preference and performance tests employed in the first study (the Edinburgh Handedness Inventory [EHI], and the Motor Accuracy test [MAcc], of the Sensory Integration and Praxis Tests [SIPT]) with a sample that included younger normal children aged 3, 4 and 5 years. The ability of the two handedness measures to detect a more variable pattern than occurred in the first study, is explored with *younger* children who would still be in the process of establishing the degree of handedness. As the initial Bilateral Motor Coordination (BMC) and Space Visualisation Contralateral Use (SVCU) midline crossing tests of the Sensory Integration and Praxis (SIPT) Tests used in the first study appeared too challenging for 5-year old children, other existing tests for these behaviours required reviewing. Although the MAcc is only standardised for 4-year olds, 3-year olds were included to compare normal developmental performance. This Introduction Section examines existing midline crossing and bimanual coordination tests used in other research studies for their potential suitability to sensitively detect differences between the hands, with reference to reliability/validity studies and related literature. The process of modifying the most useful tests for midline crossing and bimanual coordination selected for the study is discussed under the Method Section together with the description of the tests, and the efficacy of these modified tests is presented and illustrated in the Results Section. The modified Midline Crossing Test and Bimanual Coordination Test are implemented and compared to the initial tests used in Study I.

3.1.1 Review of Existing Midline Crossing Tests

Apart from the SIPT, few other tests exist that assess midline crossing, and for various reasons summarised in Appendix 3A these were found to be unsuitable for the present study. The most promising of the reviewed tests was the *Test of Manual Midline*

Crossing (TMMC), by Stilwell (1987a, 1987b). This test was developed to assess crossing of the body midline in 2 to 6 year olds. The 36-item test consists of three trials of 12 peg placements each. The pegboard features six equally spaced holes on each side of the centre hinge, and a wooden hand placement board with a centre hole and one hole on either side of the centre hole (see Appendix 3B for a diagram of this test).

The TMMC requires the child to sit opposite the centre hinge, and move a peg from one of the three holes in the hand placement board to an open hole in the pegboard, which is randomly varied by the examiner. The number of times the child crosses the midline during the initial reach to pick up the peg *and* to place the peg is both recorded as a contralateral reach. Contralateral reaches are prompted by *demand* responses, whereas ipsilateral reaches are expected during *non-demand* responses. The reliability of the TMMC has been determined by two measures of internal consistency, both of which were found to be highly reliable (Spearman-Brown, $r = 0.883$ and Chronbach's alpha, $r = 0.843$) (Stilwell, 1987a, 1987b).

3.1.2 Review of Existing Bimanual Coordination Tests

The performance of bimanual everyday tasks is difficult to quantify. Most functionally based assessments use speed (e.g., time taken to thread beads, Bruininks, 1978) or accuracy (e.g., cutting out a circle, Bruininks, 1978) as a measure of performance level. However, these measures fail to provide sufficient information about the interaction between the hands involved in bimanual tasks and performance. Conversely, test equipment for research purposes has often been designed to investigate specific, simplified components of bimanual coordination requiring non-functional movement patterns. Consequently, a task such as Guiard's (1985, 1996) assembly structure with x and y cranks is removed from functional task performance in a real life situation.

In addition, little attention has been paid to the leading hand in functional bimanual tasks such as dealing cards and opening a jar lid, in terms of measurement of asymmetry. The inability of tests to assess bimanual tasks in terms of hand preference has been considered a major weakness (Guiard & Ferrand, 1996). Overall, existing tests not only present difficulties in assessing bimanual coordination as a neuromotor behaviour, but fail to

identify the roles of the two hands in relation to functional hand preference, which appears to be task dependent (Peters, 1985). Standardised paediatric tests and research measures designed to measure aspects of bilateral/bimanual coordination, and reasons for their unsuitability for a handedness profile are presented in Appendix 3C.

Recent evaluations of bimanual coordination have been performed using *bimanual circle drawing*, a task that incorporates both temporal and spatial constraints characterising most functional bimanual tasks (Carson, Thomas, Summers, Walters & Semjen, 1997). A number of studies have employed bimanual circle drawing to investigate various aspects of bimanual coordination during *homologous in-phase* or mirror movement patterns in an inward and outward direction, and *heterologous anti-phase* or parallel movement patterns with both hands moving to the left or to the right side (Carson et al., 1997; Fagard, 1987, 1990; Fagard & Pez , 1992; Semjen, Summers & Cattaert, 1995). Furthermore, researchers have used bimanual circle drawing to explore the accuracy of either hand (Carson et al., 1997), visual monitoring of the hands (Swinnen, Jardin & Meulenbroek, 1996), and speed of hands (Semjen et al., 1995). In all these studies, the preferred hand presented with a more stable, more accurate (particularly when monitored visually) and faster pattern than the non-preferred hand. The finding of a qualitative difference between preferred and non-preferred hand performance makes bimanual circle drawing particularly suitable for this study.

Repetitive simultaneous bimanual circle drawing using two pens, however, would have several disadvantages for young children. Once the circles are drawn, it would be difficult to assess which hand was leading or whether both hands had moved simultaneously without using a video camera, even though the quality of the circles would provide a measurable end product. Whilst it would be possible to specify the circle by providing tracing outlines, young children might not be able to adhere to this structure and produce circles of different sizes. In addition, the attention span and motivation of 3- to 5-year old children in repetitive tasks without a purposeful end product is likely to be limited.

In the light of these considerations, a version of bimanual circle drawing using a magnetic pen point along an angled path on an X-Y plotter was deemed to be more

suitable for assessing bimanual coordination in young children. Preilowski (1972, 1975) developed this concept initially for individuals with partial callosotomies, where vertical movements were performed by turning a knob with the one hand and horizontal movements executed by turning a knob with the other hand. When both hands turned the knobs at the same time, a diagonal was created. The apparatus by Preilowski, however, is large and not easily transportable. Several authors addressed this disadvantage by employing a similar apparatus for children under 10 years, in the form of a commercially available toy called *Etch-a-Sketch*¹ (Brown, 1991; Fagard, 1987, 1990; Fagard & Pez , 1992; Steese-Seda, Brown & Caetano, 1995). Although this type of test is also ‘non-functional’, no other measurable *functional* test was found that could provide a measurable interhand differences and a quantitative performance level. Thus, for the purpose of this thesis, the principal of the Etch-a-Sketch apparatus was considered most suitable.

3.1.3 Experimental Hypotheses

The following two hypotheses were established specific to the present study.

Experimental Hypothesis 1: The Edinburgh Handedness Inventory (EHI) and the Motor Accuracy test (MAcc) would show greater variability of hand preference and hand performance with a wider age range of 3- to 5-year old children than with the narrow age group of the previous study.

Experimental Hypothesis 2: The modified Midline Crossing Test (MCT) and Bimanual Coordination Test (BCT) tests would demonstrate sufficient range of variability in degrees of midline crossing and bimanual coordination in 3- to 5-year old normal children. This data would form a suitable basis for a normative handedness profile.

If Experimental Hypotheses 1 and 2 were met, the new collection of tests would form the basis for the normative handedness profile. If the hypotheses were not met, the findings would indicate how the tests might need to be adapted in order to provide sufficient information for inclusion in a handedness profile.

¹ Manufactured by Ohio Art, Toy Group Australia (TGA) Pty Ltd, 1 Damian Court, Dandenong, Australia.

3.2 Method

3.2.1 Participants

A sample of 91 normal children aged 3 to 5 years was recruited as a convenience sample from local kindergartens in Melbourne, consisting of 40 girls and 51 boys. There were 30 children in the 3-year age group, 31 children in the 4-year age group and 30 children in the 5-year age group.

Similar to the previous study, children were excluded from the study if they attended occupational therapy, physiotherapy or speech therapy, or if there was a history of mental or physical disability, evidence of developmental delay, behavioural or attention problems, as determined from a parent questionnaire (see again Appendix 2B). Inclusion was also dependent on permission of teachers, principals and parents (see Appendix 2C for an example consent form used), availability of children and the number of children required for each age group. Ethics approval was granted by the La Trobe University (Appendix 3D).

3.2.2 Tests and Instruments

The measures for hand preference (i.e., the initial EHI) and hand performance (the MAcc of the SIPT) were implemented as described in the previous study (see Method Section 2.2 in Chapter 2). The modification of the midline crossing and bimanual coordination tests are discussed in the following section.

3.2.3 Test Modification Procedures

3.2.3.1 Midline Crossing Test (MCT) Modification

The general concept of Stilwell's Test of Manual Midline Crossing (TMMC) was deemed suitable to meet the objectives of the second study. However, several considerations precluded the use of this test in its present form. Firstly, the attention span of young children is limited, particularly when the peg moving task with its extensive repetition comprises only one of several assessments. Distractibility, lack of motivation

and inattention during testing could confound subsequent results. Secondly, no study was found that investigated if the process of contralateral picking up and contralateral placing are equivalent. However, the TMMC appears to be based on the assumption that retrieving and placing actions involve the same degree or type of contralateral reach. For instance, the TMMC does not differentiate between the following contralateral responses: (i) retrieving a peg by initial midline crossing, and (ii) retrieving a peg by initial ipsilateral reaching and the crossing the midline to insert it contralaterally. Should these two types of contralateral responses differ, results might be skewed. Thirdly, the distance of those holes furthest away from the centre hinge are likely to stimulate a different response to the holes closest to the centre hinge, since the distance between them is 8 inches. Stilwell (1987a, 1987b) assessed midline crossing as a function of distance from the midline. Stilwell found, similarly to Atwood and Cermak (1986), that contralateral responses decreased as the reaching distance increased, even though the cut-off point of an optimal contralateral reaching distance differed between the two studies. However, Stilwell made no proximal-distal differentiation in the TMMC test. In the context of a handedness profile and the inconclusive literature, it was decided that the proximal-distal factor should be controlled so that the *degree* of contralateral reaching could be assessed more accurately. Based on the above considerations, the TMMC needed modification. In addition, the following principles by Stilwell (1987b) guided the midline crossing test construction:

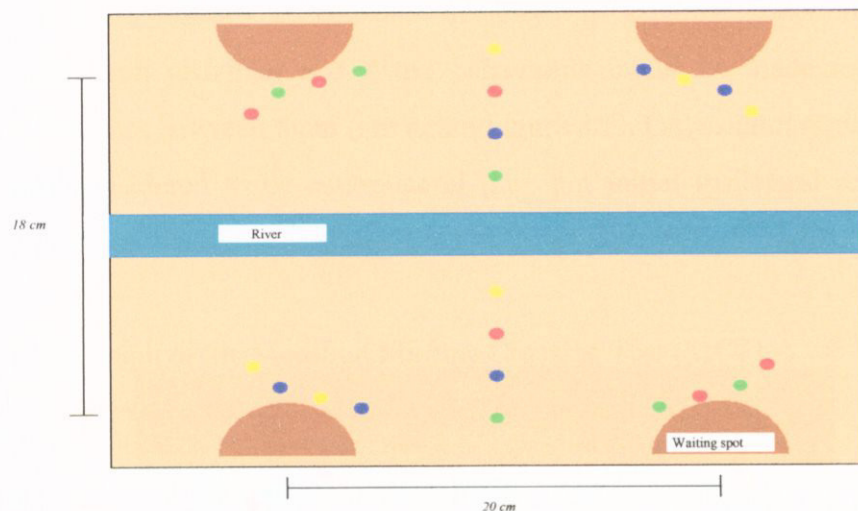
“a) During task completion, the child should not be aware of the requirements for manual midline crossing, (b) the test design or the scoring criteria should consider the methods of postural compensation that children use to avoid midline crossing, and (c) when test norms are determined, the developmental age changes should be taken into account” (p.785).

Midline crossing research also highlights other critical features to be taken into account when testing contralateral reaching. Firstly, there appears to be an optimal distance between left and right placements. If the pegs are too close (e.g., 0.75 inches/1.9 cm), minimal to no midline crossing is required and if they are too far apart (e.g., 6 inches/15.2 cm), crossing appears to be too difficult for younger children (Atwood & Cermak, 1986). The authors suggested an optimal distance of 3 inches (7.62 cm) between the two SIPT blocks (i.e., each block 3.81 cm from midline). Stilwell (1987b), on the other hand, found an increase of contralateral reaching between 2 and 6 inches from midline, and a decrease in contralateral reaching beyond 6 inches. Since there appeared to

be no consensus on an optimal measurement for the purpose of the present study, the distance between the child's axillae (armpits), a guide line used by some SIPT examiners for the Space Visualisation Contralateral Use (SVCU) (Atwood & Cermak, 1986), was taken as a yard stick for the optimal distance between the hands in relation to the body midline. Prior to test modification, the distance between the axillae of ten normal children aged 5 to 6 years old were measured, and an average of approximately 20 cm was obtained.

To incorporate Stilwell's first principle of avoiding the focus on contralateral reaching, a story was invented as a backdrop to the modified midline crossing test, which will be referred to hereon as the *Midline Crossing Test (MCT)* (see Appendix 3E for the complete story). For the MCT, a large wooden board 42 cm long and 30 cm wide was divided horizontally with a painted river 3 cm wide (see Figures 3.1 and 3.2).

Figure 3.1. Diagram of Modified Midline Crossing Test (MCT)

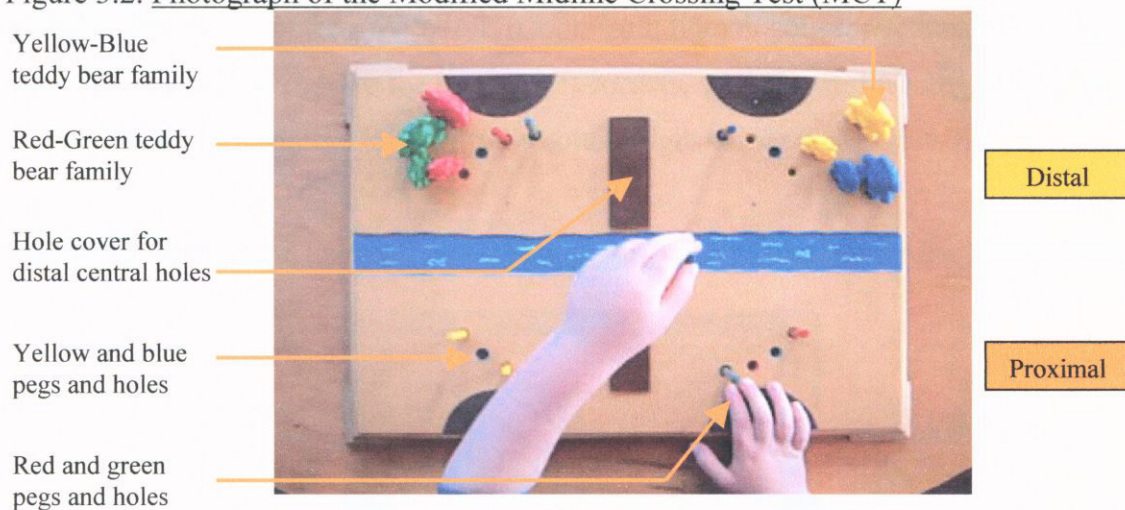


On either side of the river along the vertical centre line four 1-cm-wide holes were drilled, 1 cm apart and 2 cm deep. Stilwell's (1987a, 1987b) hand placement board was modified by providing two velvet-textured semi-circles (8.5 cm diameter), referred to as 'waiting spots', for the hands. The centres of the waiting spots were spaced 20 cm apart (mean axillae width) and served as resting places for the hands between peg movements. This allowed the hands to be consistently placed at a standardised distance from midline, allowing each hand an equal chance for contralateral reaching, and also addressing the second principle of controlling postural compensation (Stilwell, 1987a, 1987b). As illustrated in Figures 3.1 and 3.2, above each of the waiting spots a set of 4 peg holes was

drilled in a slight arc towards the river so that all holes were approximately equidistant from the centre of the board. Each of the four central peg holes was painted in one of the primary colours (red, blue, yellow, green), and this colour sequence was repeated on the other side of the river. Each of the arcs of four holes was painted with two primary colours: the bottom right and top left arc holes were painted alternately red and green, while the bottom left and top right arc holes were painted alternately yellow and blue. The board could be rotated 180° and still present the same colour sequence and waiting spots to the child.

In conjunction with the pegboard, eight coloured pegs (i.e., two of each colour) were constructed to fit into the matching coloured holes, and hole covers were fabricated to cover the sets of four holes when not required (see Figure 3.2). In addition, four large (3.5 cm) and four small (2.5 cm) plastic teddy bears, each in a different primary colour, were used to prompt moving of the matching coloured peg. A small toy lion was also part of the equipment. The design of the Midline Crossing Test allowed for incorporating both proximal and distal reaches at constant distances in separate trials. In this way, comparisons between proximal and distal behaviours could be made to assess any significant differences between them (see again Figure 3.2). Only *initial* midline crossing behaviour was considered to be contralateral (i.e., not initial ipsilateral reaching with contralateral placing).

Figure 3.2. Photograph of the Modified Midline Crossing Test (MCT)

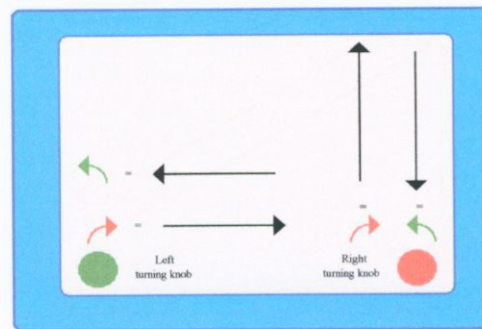


Note. Child uses initial *ipsilateral* peg retrieval with the left hand.

3.2.3.2 Bimanual Coordination Test (BCT) Modification

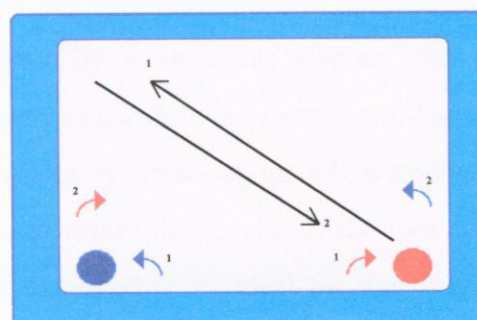
The Etch-a-Sketch appeared to contain many elements necessary to adequately assess bimanual coordination in younger children, consistent with Preilowski's (1972, 1975) principles, and incorporating fundamental principles of Brown's (1991) Test of Bimanual Coordination. The Etch-a-Sketch is a 18 cm by 13 cm large screen, displaying a knob of approximately 2.5 cm in diameter on either lower corner of the front panel. When the left knob is turned inwards, the magnetic pen point etches a horizontal line to the right, if it is turned outwards, the horizontal line etches to the left. Similarly, when the right knob is turned inwards, a vertical line etches downwards, if it is turned outwards, the vertical line etches upwards (see Figure 3.3).

Figure 3.3. Independent Left and Right Knob Turning on the Etch-a-Sketch to Achieve Horizontal and Vertical Lines



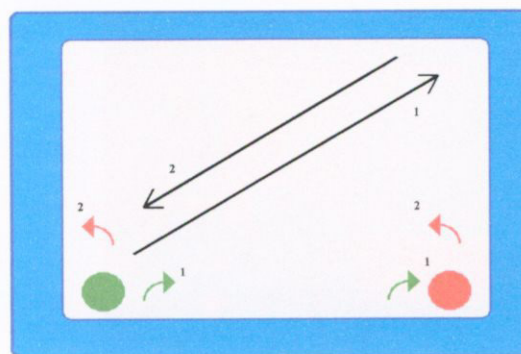
If both knobs are turned simultaneously with the left and right hands, a diagonal line will appear, depending on the direction in which the knobs are turned. If both knobs are turned outwards in opposite directions (i.e., mirror, homologous movement), the diagonal extends from the top right to the bottom left corners, while inward turning of both knobs creates a diagonal from the top left to the bottom right corner (see Figure 3.4).

Figure 3.4. Inward and Outward Homologous Bimanual Movement on the Etch-a-Sketch



If both hands turn the knobs in the same direction to the left (i.e., parallel, heterologous movement), the diagonal line will protrude from the top right to the bottom left corner. If both hands turn to the right, the line extends from the left bottom to the right top corner (see Figure 3.5). Regardless of the direction of turning, if both hands turn at the same time and speed, the angle of the slope will be 45 degrees. If the hands do not perform the movement simultaneously but sequentially, ‘steps’ will appear on the screen. If the right hand leads the movement or turns faster, the diagonal will be steeper (i.e., larger than 45°), whereas if the left hand leads or turns faster, the diagonal will be flatter (i.e., smaller than 45°). To erase the etched lines, the Etch-a-Sketch is turned upside down with a shaking movement.

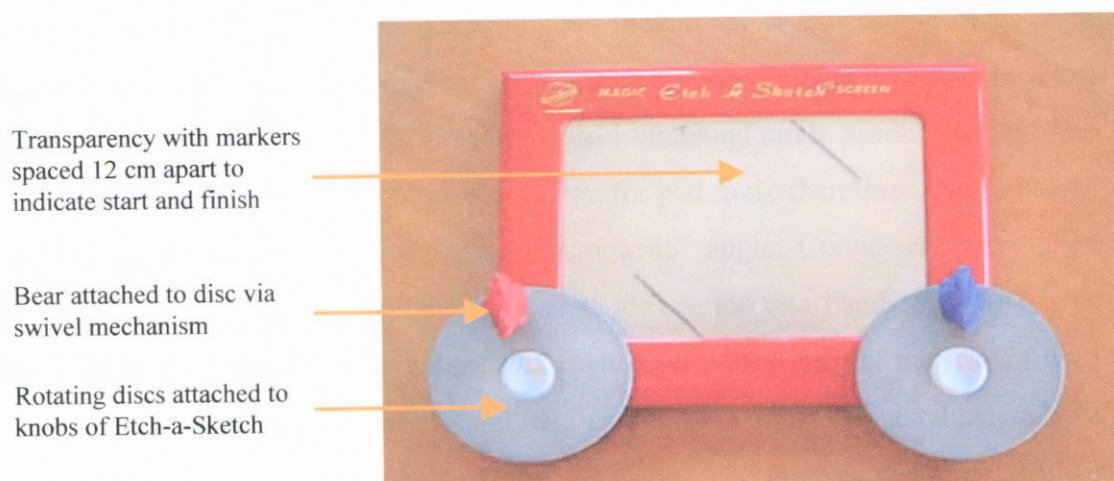
Figure 3.5. Left and Right Parallel Heterologous Bimanual Movement on the Etch-a-Sketch



Certain modifications to the Etch-a-Sketch in its commercial form were necessary. Steese-Seda, Brown and Caetano (1995) argued that turning the knobs required a more distal response with finger movement, as opposed to Preilowski's initial apparatus (and possibly also to drawing circles), where movement was generated mostly from the shoulder, elbows and possibly wrists. As discussed in Chapter 1, (see Section 1.2.2.2 on the proximal/distal distinction), the significance of distinguishing between proximal and distal movement control is unconfirmed. In addition, the movements of the Etch-a-Sketch apparatus are characterised by a stop-start pattern that differs from a continuous homologous or heterologous circle-drawing movement. Fagard and Pez  (1992) adapted the knobs by mounting two rotary cranks on top of the knobs, so that the etching could be executed by using bimanual rotary movement of the two arms similar to manual circle drawing. This adaptation appeared to be ideal for this study involving young children, who would probably not have fully developed the distal control required for smooth

turning of the knobs, ensuring circular movement of a standard size. The concept of two rotary cranks (Fagard & Pez , 1992) was thus adopted in the design of the bimanual coordination measure, hereon referred to as the *Bimanual Coordination Test (BCT)*, for the current study. Two removable discs of 10 cm in diameter were attached to the Etch-a-Sketch turning knobs using an Allen key. In keeping with the teddy bear theme of the MCT, a 3.5 cm large plastic teddy bear was attached to the edge of each of the discs with a swivel mechanism. This allowed each bear to be turned in any direction while being grasped by the hands during the turning motion of the discs. A non-slip mat prevented the Etch-a-Sketch from moving (see Figure 3.6 for a photograph of the BCT).

Figure 3.6. Photograph of Modified Bimanual Coordination Test (BCT)



Steese-Seda, Brown and Caetano (1995) used three 12 cm long templates that were placed over the Etch-a-Sketch screen, each marking an angled path 1 cm wide, at 45°, 22.5° and 67.5° respectively. The child was required to etch the line on the designated path by turning both knobs simultaneously. The emphasis was thus not on speed but on accuracy. Steese-Seda et al. (1995), who found a definite age effect in their study of normal right handed children aged between 6 and 12 years, argued that a greater level of maturity of the corpus callosum is required for drawing the 22.5° and 67.5° slopes, because one hand has to turn faster than the other. Since myelination of the corpus callosum related to bimanual coordination is thought to take place between 4 to 18 years of age (Ahrens, Blumenthal, Jacobs & Giedd, 2000; Gazzaniga, 1970), these two angles were considered too difficult for the present study involving 3- to 5-year old children. Steese-Seda et al.'s (1995) advanced bimanual visuomotor coordination differs from the

simple performance of simultaneous homologous and heterologous movement where the focus is predominantly on even, simultaneous bimanual movement itself. This simpler version of bimanual coordination was considered to be more suitable for younger children. It was thus decided to encourage the child to concentrate on moving the hands simultaneously rather than demanding asymmetrical bimanual coordination required to trace the 22.5° and 67.5° angled paths. A transparency with two short markers placed over the screen indicated the beginning and the end of a 12 cm long invisible line at 45° (see again Figure 3.6).

Consideration was also given to the speed component. Research indicates that several cycles of rapid heterologous (parallel) movement are required before one hand (usually the non-preferred one), reverts to a homologous movement to mirror the other hand (usually the non-preferred one) (Semjen, Summers & Cattaert, 1995). It would thus not be possible to capture the entrainment seen in rapid bimanual circle production with the Etch-a-Sketch, since its rather small screen allows for just more than three cycles before the etching point reaches the opposite corner at a 45° angle. Conversely, very slow deliberate movement might override a natural tendency for one hand to lead. It was therefore decided to stress the importance of *simultaneity* of bimanual movement over speed. The required speed of approximately 1.5 cycles per second was established by a demonstration trial to counter possible slow, alternating or laborious performance. As excursion was limited to 12 cm and instructions were non-specific (i.e., not too fast and not too slow), time taken was not incorporated as a quantitative factor for the BCT in this study.

3.2.4 Test Administration Procedures

All tests were administered by the researcher.

3.2.4.1 Handedness

The same procedures for administering the EHI and the MAcc as described in the previous study were also employed in the current study (refer Section 2.2.4.1 in Chapter 2 for more detail). The MAcc is officially standardised only for children from 4 years 0

months and older. However, since the MAcc was used for inter-subject comparison within the sample, it would still provide an adequate measure of hand performance for 3-year old children.

3.2.4.2 Midline Crossing Test (MCT)

The examiner and child were seated opposite each other at a table. The pegboard was placed at a 5 cm distance from the table edge in the child's midline, and four pegs (one of each colour) were placed in the corresponding centre holes proximal to the child. The distal centre holes were free whilst all four arcs were concealed with hole covers. The child placed both hands on the waiting spots while the story of the teddy bears and the lion unfolded (see again Appendix 3E for details of the MCT instructions). A practice trial was then performed where the child transported four pegs from proximal to distal centre holes.

For each item, the examiner randomly selected a coloured bear from a container and placed it behind the matching coloured hole distal to the child. The items were equally divided into potential contralateral, ipsilateral and midline responses (see Section 3.2.5.2 on the MCT scoring procedure, and Appendix 3F for MCT score sheet). The child was reminded when necessary to place both hands on the waiting spots before each new item. As soon as a new teddy bear appeared, the child picked up the matching peg and placed it in the hole in front of the teddy bear, displaying either an ipsilateral or a contralateral response. The order of the peg placements is detailed on the score sheet (see again Appendix 3F). In addition, after half the test was performed (i.e., after Trial 3), the Bimanual Coordination Test was introduced to minimise monotony and assist the child to maintain attention. The Midline Crossing Test took approximately 20 (i.e., 2 x 10) minutes.

3.2.4.3 Bimanual Coordination Test (BCT)

The child was told that two teddy bears are sitting on a round-about unable to turn themselves (see Appendix 3G for instructions of the BCT). Since the teddy bears are friends they want to be turned at the same time, not too fast and not too slowly, and they require the help of the child. The child was instructed to hold the teddy bear heads with

fingertips and turn them at the same speed and at the same time in 4 different combinations from the starting position at 12 o'clock (see Table 3.3 under Section 3.2.5.3 for scoring details of the BCT). In the first trial the teddy bears were turned so that they were facing back-to-back to each other, indicating that the required movement was an outward homologous/mirror pattern. In the second trial the teddy bears were looking towards each other to elicit an inward homologous/mirror pattern. In the third trial the bears both looked to the left for a heterologous/parallel movement to the left, and in the fourth trial the bears were positioned to look to the right to support a heterologous/parallel movement to the right (see Appendix 3H for the BCT score sheet).

At the beginning of each trial, the examiner guided the movement of the child by placing her hands over the child's hands and performing 2 complete cycles. The examiner then returned the etching point to the appropriate corner, erased the screen and started the child off by guiding the movement for half a cycle or until the first marker indicated the start of the 12 cm distance. Thereafter no further assistance was given and the child proceeded independently. After completion of each trial, the examiner traced the response line accurately with a thin permanent pen onto a transparency, indicating the start and finish of the line. The BCT took approximately 10 minutes.

3.2.5 Scoring Procedures

3.2.5.1 Handedness

The same scoring procedures described in the previous study were also employed in the second study (see again Section 2.2.4.1 in Chapter 2).

3.2.5.2 Midline Crossing Test (MCT)

Recording.

A scoring sheet with columns was designed to record the child's left and right ipsilateral or contralateral responses (see again Appendix 3F for MCT score sheet). Since the examiner sat opposite the child, the column for right handed responses was placed on the left side (i.e., mirror image) to facilitate scoring. A column for 'swaps' was included in

case the child changed hands between picking up and placing, and responses were grouped under the following headings:

- (i) *Practice Trial: Midline to Midline.* Only hand preference was noted (Total: 4 midline items only.)
- (ii) *Trial 1 and Trial 6: Midline to Contra/Ipsilateral.* Each trial consisted of 4 pegs picked up from midline, after which 2 were placed ipsilaterally, and 2 contralaterally. (Total: 8 items across the two trials.)
- (iii) *Trial 2: Contra/Ipsilateral to Contra/Ipsilateral, proximal to distal.* Four pegs were picked up from each proximal arc and placed into the holes of the contralateral distal arcs. (Total: 8 items, 4 starting on the left and 4 on the right.)
- (iv) *Trial 3 and Trial 4: Contra/Ipsilateral to Contra/Ipsilateral, distal to proximal.* In each trial, 2 pegs were picked up from each of the distal arcs and placed into the holes of the contralateral proximal arcs. (Total: 8 items across the two trials.)
- (v) *Trial 5 and Trial 7: Contra/Ipsilateral to Midline.* In each trial, 2 pegs were picked up from each of the proximal arcs and placed in the distal middle row. (Total: 8 items across the two trials.)

Scoring.

The total number of items in this test was 32, excluding the 4 practice items. On the calculation sheet (see again Appendix 3I), the responses were added under columns provided for left and right handed responses, in addition to being marked as ipsilateral or contralateral responses. Hypothetically, it is possible that a child demonstrates unestablished hand preference but no midline crossing avoidance, crossing over with either hand on all 24 items where the pegs are positioned in the arcs and not in midline. For this reason, the possible contralateral starting score was 24 when both hands were used, and a total possible contralateral starting score of 12 was used for calculating the score for one hand.

The midline crossing quotient (MCQ) was calculated as previously:

$$\text{MCQ} = \frac{\text{Right responses} - \text{Left Responses}}{32 \text{ (Total responses)}} \times 1000$$

Three types of start responses were identified, based on the ideal fully established midline crossing preference with *one* preferred hand: (i) *ipsilateral start*, (ii) *midline*

start, and (iii) *contralateral start*, where the initial pick up was contralateral, and the placing required ‘uncrossing’ of the midline. The 16 contralateral items were further divided into *distal contralateral starts* (i.e., pick up = distal, placing = proximal), and *proximal contralateral starts* (i.e., pick up = proximal, placing = distal). The number of right and left hand responses was recorded separately with regard to each type of start response. Table 3.1 provides an example illustrating the scoring procedure for the Midline Crossing Quotient. (See also Appendix 3J for a summary calculation sheet for the modified tests, and Appendix 4I [Part v and vi] for a case example.)

Table 3.1. Example of Scoring Procedure and Additional Information to Evaluate the Midline Crossing Quotient (MCQ) of the Midline Crossing Test (MCT)

	<i>Left Hand</i>	<i>Right Hand</i>
Raw Score of total hand use	9 (31%)	23 (69%)
Crossing Midline Quotient (R) 23 - (L) 9 14 ----- = ----- x 100 = (R) 23 + (L) 9 32		44% RH
Contralateral start with <i>one</i> hand (24 items / 2)	0 / 12 (0%)	3 / 12 (25%)
Interhand contralateral start difference: (R) 25% - (L) 0%		25% RH
Midline start	0 / 8 (0%)	8 / 8 (100%)
Proximal contralateral start	0 / 8 (0%)	1 / 8 (13%)
Distal contralateral start	0 / 8 (0%)	2 / 8 (25%)
Swaps	2	0

Note. In this example, the child displays more midline crossing avoidance than unestablished hand preference, since the right hand was used for all midline starts and 19% of possible contralateral starts, whereas the left hand was used only for ipsilateral responses. Swaps are also considered predominantly midline crossing behaviour.

Interpretation.

The design of the test ensured that half the responses would be ipsilateral and the other half contralateral for an established hander. Two extremes of midline crossing behaviours were possible. If a child performed all 32 items with the preferred hand, this was considered to demonstrate *fully established midline crossing behaviour*. If, on the other hand, a child avoided crossing the midline altogether, all 32 responses would be ipsilateral, whereby 16 items would be performed by the right and 16 items by the left hand. This response was referred to as *unestablished midline crossing behaviour*. Between these two extremes, any combination of responses was possible. The child’s level of established midline crossing preference was reflected in the *midline crossing*

quotient (MCQ), a continuum between an exclusively ipsilateral ($MCQ = 0\%$) or a maximum contralateral response ($MCQ = 100\%$) with a preferred hand, and no response with the non-preferred hand. The MCQ is thus comparable to an interhand difference measure of midline crossing.

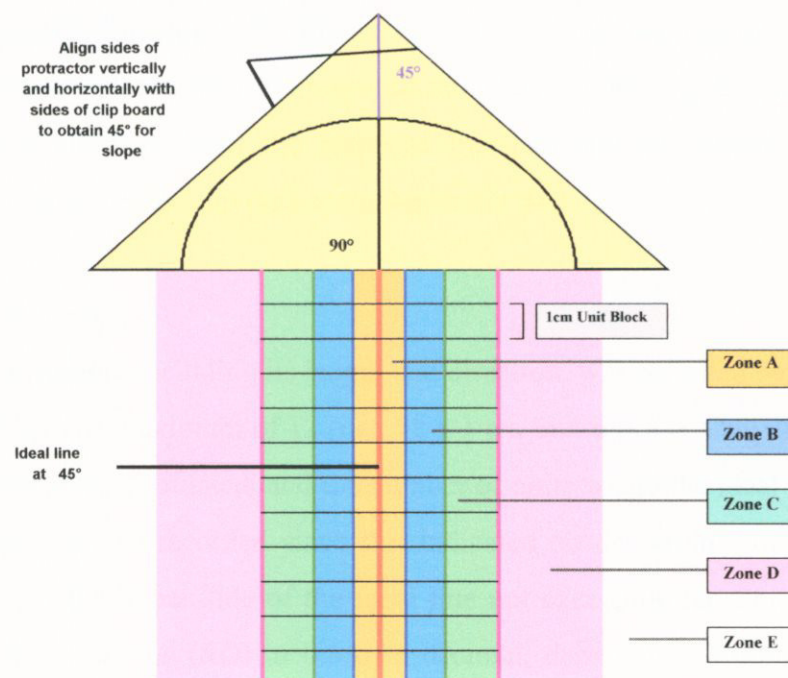
A distinction between contralateral reaching and hand preference could be inferred in the following cases. A child was considered to have predominantly midline crossing rather than hand preference problems if either hand was used consistently for ipsilateral reaches (i.e., avoiding midline crossing), but the same hand was used consistently in midline (see again Table 3.1 for an example). Conversely, if a child picked up a peg in midline with either hand and/or swapped hands for the peg placement, poorly established hand preference was indicating in the first instance.

3.2.5.3 Bimanual Coordination Test (BCT)

Scoring material.

A *master transparency* with a 12 cm *ideal line* at 45° was used as the *scoring guide* to evaluate the extent of the deviation of the *response line* on the *response transparency* in relation to the ideal line (see Figure 3.7 for illustration of the scoring guide).

Figure 3.7. Scoring Guide for Bimanual Coordination Test (BCT)



The right angle of a protractor (yellow part in Figure 3.7) was attached to the one end of the master transparency, so that the line extending through the 90° angle of the protractor (black line in the yellow triangle) was continuous with the ideal line. The 0.2 cm ideal line on the master transparency was transparently orange. Using the measurements of the MAcc (SCSIT, SIPT) as a model, four zones were created. A thin blue line, parallel to and 0.2 cm from each side of the edge of the ideal line marked Zone A. Parallel to Zone A on either side, two coloured lines (green and pink) marked Zones B, C and D at distances of 0.6 cm, 1.2 cm and 2 cm apart respectively. Beyond Zone D, Zone E extended without limits.

Perpendicular to the four zones, the master transparency also featured rows spaced 1 cm apart, thereby creating 12 *unit blocks*. This facilitated calculation of the length of a response line in a particular zone. If a response line fitted a zone for approximately half a block or less it was recorded to 0.5 cm, if it was more than 0.5 cm, it was recorded as one 1 cm unit. A clipboard featuring a vertical and a horizontal line for alignment of both response transparency and scoring guide was used to guide accurate placement when measuring deviations of the ideal line. (See Appendix 3K for a photograph of the BCT scoring material, with a completed response transparency featuring the four trials.)

Scoring preparation.

To ensure accurate scoring, the protractor of the scoring guide was placed parallel to the sides of the clipboard, ensuring a 45° alignment with the ideal line, and the zoned part of the scoring guide was placed over the response transparency bearing the traced response lines. To prevent slippage, both the response transparency and scoring guide were clamped together with a large clip (see again Appendix 3K).

Scoring process.

The amount of deviation, including its length and direction, was recorded by counting the number of units up to a maximum of 12 (i.e., 12 x 1 cm unit blocks). Only the deviations from the ideal line were calculated, and the number of units where the ideal line, covered the response line was not recorded since this indicated no deviation. For Zone A, the number of units on the upper side of the ideal line not exceeding the Zone A line was recorded as *right deviations (RD)* to 0.5 of a decimal, depicting a leading right hand.

Deviations on the lower side of the ideal line were recorded as *left deviations (LD)* also to 0.5 of a decimal, illustrating greater use of the left hand. Sections of the response line parallel to the ideal line, regardless of the zone, were recorded as *middle (M)*. For Zone B (blue), the units of deviation were scored only between the blue and the green lines, and the score was halved as the initial deviation (Zone A) had already been calculated. This method of calculation was also based on the principles of the Motor Accuracy Test of the SCSIT/SIPT, and those of the Developmental Test of Visual Perception (Frostig, 1993). The same procedure was applied to Zones C, D and E. Larger deviations resulted in larger left and right scores. This scoring procedure was repeated for each of the trials. The total left and right deviations (LD and RD) and the parallel sections of each trial (M) were added to constitute four subtotals for each of the trials, and these subtotals were added to the total deviation or error scores of the left and right hands respectively. (See again Appendix 3J for BCT calculations on the summary calculation sheet, and Appendix 4I [Part vii and viii] for case example.)

Homologous and heterologous performance.

The first two trials were calculated separately to obtain a deviation/error score of the homologous movement patterns, the last two trials constituted the heterologous movement patterns. Together the total bimanual performance was calculated (see scoring calculations further on in this section). In addition, total right, left and middle deviation/error scores were recorded (see again Appendix 3J).

Unimanual responses.

A response line presenting with sections of at least 0.5 cm length that were either horizontal or vertical, was indicative of alternate unimanual turning. Horizontal sections showed isolated left hand turning, and vertical sections reflected isolated right hand turning. The right angle of the protractor was used to assess vertical and horizontal sections of the recorded line that were at least 0.5 cm long. The total units of vertical lines over the four trials were recorded under *left only (LO)* and the total of horizontal lines under *right only (RO)*. This provided a measure of a simultaneous bimanual coordination deficit.

Reversions.

If a child was unable to maintain the direction of the bimanual circle movement, one or both hands would have reverted to the opposite direction. If this section was longer than one unit (i.e., 1 cm), it was referred to as a *reversion*. Sometimes this took the form of a loop, later returning to the initially required direction. In such a case, it was recorded as an *incomplete reversion* and a penalty of 3 points was given. The penalty was divided equally between left and right if there was evidence that both hands were involved to the same extent (i.e., more or less 45°). If the slant was more horizontal or more vertical, it was reflective of the left or right hand having turned faster, and a ratio of 2:1 points, corresponding to left versus right deviation respectively, was awarded. The penalty was never recorded under M, since M denoted the desired slope for that trial. If the recorded line was reversed or changed direction at 90° or more, and continued to do so for 3 or more units without returning to the original slope for at least another 3 units, it was recorded as a *complete reversion*, and a penalty of 6 points was added to the total deviation score of that trial. The penalty points were again divided between the right and left hands according to the guidelines for incomplete reversions.

If a section of the response line extended in the correct direction for a few units, the deviation was calculated as described above up to or from the point of reversion. The master transparency was then readjusted to fit over the new incorrect slope, and the deviation calculated for the left and the right hands until a total of 12 units was reached. For example, even if the incorrect slope was exactly 4 units at 45°, half would be allocated to LD and the other half to RD. If the response line was more perpendicular, more than half of the penalty points would be assigned to RD (the steeper the line, the more penalty points), whilst if the response line was more horizontal, more penalty points would be allocated to LD. The ratio for this allocation was determined by the extent of the deviation. This allowed for evaluation of the total deviation of the recorded line (i.e., error score) even though it changed direction.

Table 3.2 summarises all possible reversion patterns. The left column features the number of the required trial, the second column describes the expected response of the required trial, the third column lists the trial number of a possible reversion, and the fourth column describes the movement pattern of that particular reversion.

Table 3.2. Possible Patterns of Reversions from the Expected Bimanual Coordination Responses in the Bimanual Coordination Test (BCT)

<i>From Trial</i>	<i>Expected Response</i>	<i>To Trial</i>	<i>Description of Reversion</i>
1	Homologous / mirror / outward (<i>slope: bottom right to top left</i>)	2	Both hands revert from outward to inward movement.
	LEFT: left outward movement	3	Right hand remains the same, left hand reverts from outward/left to inward/right.
	RIGHT: right outward movement	4	Left hand remains the same, right hand reverts from outward/right to inward/left.
2	Homologous / mirror / inward (<i>slope: top left to bottom right</i>)	1	Both hands revert from inward to outward movement.
	LEFT: right inward movement	3	Left hand remains the same, right hand reverts from inward/left to outward/right.
	RIGHT: left inward movement	4	Right hand remains the same, left hand reverts from inward/right to outward/left.
3	Heterologous/ parallel/ to the left (<i>slope: top right to bottom left</i>)	1	Left hand remains the same, right hand changes from inward/left to outward/right.
	LEFT: left outward movement	2	Right hand remains the same, left hand changes from outward/left to inward/right.
	RIGHT: left inward movement	3	Both hands revert from parallel to the left-to parallel to the right.
4	Heterologous /parallel/ to the right (<i>slope: bottom left to top right</i>)	1	Right hand remains the same, left hand reverts from inward/right to outward/left.
	LEFT: right inward movement	2	Left hand remains the same, right hand reverts from outward/right to inward/left.
	RIGHT: right outward movement	4	Both hands revert from parallel to the right to parallel to the left.

Scoring calculations.

The possible minimum deviation/error score was 0, in which case the response line, like the ideal line, would be completely straight and sloped at 45°. For each trial, the maximum possible deviation/error score for one hand was 42 (i.e., and for all four trials 168), calculated as follows: 12 deviation points for Zone A, 24 points for Zones B, C, D and E, each obtaining up to 6 points (i.e., the 12 points for each of these zones was halved because their deviations duplicate the deviation of Zone A already penalised), plus a maximum of 6 penalty points for reversions (see again Appendix 3H for score sheet). The Bimanual Coordination Test *performance level (PL)* was obtained as a percentage as follows:

$$\text{BCT PL} = \frac{168 (\text{Total maximum deviation}) - \text{Total deviation/error score}}{168 (\text{Total maximum deviation})} \times 100$$

Similarly, the homologous score, based on the first two trials, was calculated by subtracting the homologous error score from 84 (i.e., half of the maximum deviation), and dividing the result by 0.84 (i.e., divide by 84 and multiply by 100 to obtain a percentage). Calculation of the heterologous score, as well as left and right hand scores were identical.

The calculation of the *interhand difference (IHD)* was computed as follows:

$$\text{BCT IHD} = \text{Right PL} - \text{Left PL}$$

The following example in Table 3.3 illustrates the scoring procedure.

Table 3.3. Example of Scoring Trials of the Modified Bimanual Coordination Test (BCT) Based on Error Scores (ES) and Raw Scores (RS)

<i>Trial</i>	<i>Left Deviation (LD) / 42</i>	<i>Right Deviation (RD) / 42</i>	<i>Middle (M)</i>	<i>Subtotal</i>
1	3.0	4.0	11.5	18.5 / 42
2	8.5	0.0	20.0	28.5 / 42
<i>Homologous ES</i>	11.5	4.0	31.5	47.0 / 84
3	21.0	8.0	6.0	35.0 / 42
4	6.5	12.5	6.0	25.0 / 42
<i>Heterologous ES</i>	27.5	20.5	12.0	60.0 / 84
TOTAL ES	39.0	24.5	43.5	107.0 / 168

Calculations of BCT Raw Scores (RS)

Homologous RS for LEFT HAND	$42 - 11.5 / 0.42$	=	73% BCT PL
Homologous RS for RIGHT HAND	$42 - 4.0 / 0.42$	=	90% BCT PL
Heterologous RS for LEFT HAND	$42 - 27.5 / 0.42$	=	35% BCT PL
Heterologous RS for RIGHT HAND	$42 - 20.5 / 0.42$	=	52% BCT PL
HOMOLOGOUS RS	$84 - 15.5 / 0.84$	=	82% Hom
HETEROLOGOUS RS	$84 - 48.0 / 0.84$	=	43% Het
LEFT HAND RS	$84 - 39.0 / 0.84$	=	54% Left
RIGHT HAND RS	$84 - 24.5 / 0.84$	=	71% Right
BC Performance Level	$168 - 63.5 / 1.68$	=	62%
BCT Interhand Differences	71% - 54%	=	17% (Right)

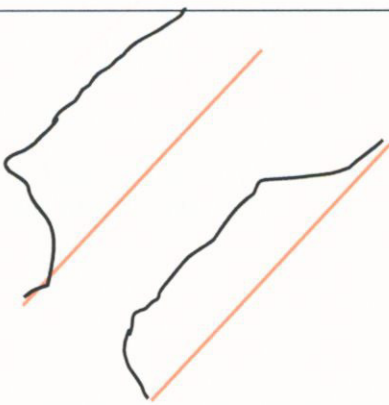

Note. BCT = Bimanual Coordination Test; ES = Error Score; RS = Raw Score.

Interpretation.

While a high M score suggests good bimanual coordination at first glance, bimanual coordination would only be truly good if there is minimal LD and RD, in which case the M score would be low. Similarly, a low M score is only an indicator of good bimanual coordination if LD and RD are also low, and if these are high, the opposite is true. The M measure thus always needs to be evaluated in conjunction with the LD and the RD.

If the initial section of the response line deviated to slant more vertically, the right hand would have turned faster or more frequently, and if the response line deviated to the horizontal plane, the same would be true for the left hand. It has been found that the preferred hand tends to lead in simultaneous bimanual movement (Stucchi & Viviani, 1993) and is also more stable in maintaining circular movement (Semjen, Summers & Cattaert, 1995). Thus the preferred hand's action may present with a clear initial leading movement resulting in an overall deviation from the ideal line in the direction of the preferred hand. Possible combinations of deviations have been summarised in Table 3.4.

Table 3.4. Interpreting Different Deviation Combinations of the Modified Bimanual Coordination Test (BCT)

<i>Type of Score</i>	<i>Interpretation</i>	<i>Example</i>
Large middle (M) score	This does not necessarily indicate less overall deviation, since an initial 2 or 3 units of right only (RO) or left only (LO) line sections could take the response line beyond Zone D. However, a large M illustrates that the child 'recovered' the original slope and was able to maintain it for the majority of units.	
High right deviation (RD) and left deviation (LD) scores and high middle (M) score	This means that there were some acute deviations in the response line but a substantial section was parallel to the ideal line.	

(table continues)

Table 3.4 (continued)

Type of Score	Interpretation	Example
Low right deviation (RD) and left deviation (LD) scores and low middle (M) score	This suggests that the response line was very close to the ideal line, with a low overall score.	
High right deviation (RD) and left deviation (LD) scores and low middle (M) scores	This indicates that there were major deviations and/or reversions and very little parallel sections in the response line. The deviation is approximately angled at 45°, thus the deviations score would be equally divided between left and right deviations for this section.	
Frequent right only (RO) or left only (LO) responses and a high discrepancy between the hands	This type of response line indicates poor bimanual coordination, whereas an absence of RO or LO responses and a low discrepancy between the hands suggest good bimanual coordination.	

Note. The diagonal orange line represents the ideal line at 45° and the black line depicts the response line. Within a normative sample, only a slight lead of the preferred hand would be expected.

3.2.6 Data Analysis

Firstly, descriptive analyses were conducted to obtain the means and standard deviations of hand preference, performance and consistency, midline crossing and bimanual coordination. Again, the extent of left and right hand use was compared in the individual tests rather than to the EHI measure. Frequency distributions were then performed on the data from the tests to detect skewness and kurtosis and to enable a preliminary visual comparison of the distributions of Study II with Study I, and between left and right handed responses. One-way analysis of variance (ANOVA) and Tukey's B post hoc tests were performed on each measure to establish if there were significant differences on the

tests between the three age groups of the sample. One-way ANOVA was also employed to determine gender differences in performance (with $p = 0.01$). In addition, handedness as reported by parents of the three age groups was compared with the EHI findings of this study using Chi square and Cramer's V. As in the first study, a detailed comparative analysis between the two handedness groups with unequal numbers of left and right handers, was not central to this study. Nevertheless, preliminary tendencies were illustrated as bar charts to display the extent of hand performance (MAcc), midline crossing (SVCU) and bimanual coordination (BMC) in terms of the EHI classification in Appendix 3L. Although establishing test validity and reliability (including test-retest and interrater agreement) for the modified tests is an essential next step, it is however, beyond the scope of this thesis.

3.3 Results

The extent of hand use in the different tests was distinguished by linking the abbreviations of the test to hand preference (e.g., 'EHI hand preference groups'). Table 3.5 summarises the results of one-way ANOVA for gender for all tests used, hereon referred to as *handedness measures*.

Table 3.5. Summary of One-Way ANOVA Indicating Significant Gender Differences on All Handedness Measures

<i>Measure</i>	<i>F-ratio</i>	<i>p</i>	<i>Mean: Girls</i>	<i>Mean: Boys</i>
EHI	4.928	0.029 ^a	90.50±16.32	73.73±24.90
Consistency	6.155	0.015 ^a	94.00±9.82	87.06±15.40
MAcc Interhand Differences	1.873	0.175	7.55±7.76	4.80±10.66
MAcc Performance Level	0.237	0.628	57.59±5.62	57.00±5.89
Midline Crossing	6.703	0.011 ^a	69.05±24.26	49.94±26.80
BC Interhand Differences	0.001	0.982	4.75±9.05	4.70±9.93
BC Performance Level	0.758	0.386	51.47±14.08	50.52±12.94

Note. $p = 0.01$ level; ^a = approaching significance at $p = 0.01$; \pm = standard deviation; EHI – Edinburgh Handedness Inventory; MAcc = Motor Accuracy; BC = Bimanual Coordination.

Although the differences in means were not significant at $p = 0.01$, the results indicate that girls were more strongly lateralised, showed greater consistency and were more likely to cross the midline than boys.

3.3.1 Hand Preference

One-way ANOVA with Tukey's B was not significant between any of the age groups ($F = 1.779$, $p = 0.175$). As in the first study, the Edinburgh Handedness Inventory (EHI) distribution was divided into left and right handed responses. Positive scores were considered to be EHI right handed, and negative scores indicated EHI left handed responses.

Figure 3.8 depicts the number of EHI left and right handed responses in the three age groups. In the entire sample of normative children ($n = 91$), there were 8 left handers (9%), and the majority of left handed responses ($n = 5$, 63%) were displayed by the 5-year olds.

Figure 3.8. Comparison of Age Groups for EHI Left and Right Hand Preference Groups

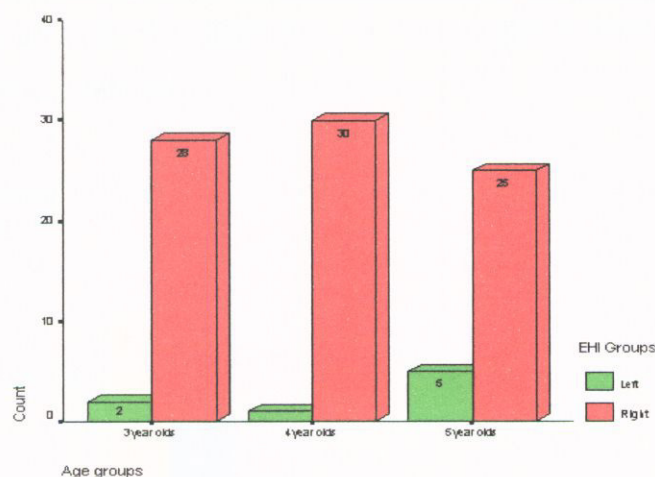


Figure 3.9 and Table 3.6 compare the EHI left ($n = 8$, 9%) and EHI right ($n = 92$, 91%) distributions respectively.

Figure 3.9. Distributions of EHI Left and Right Hand Preference Groups

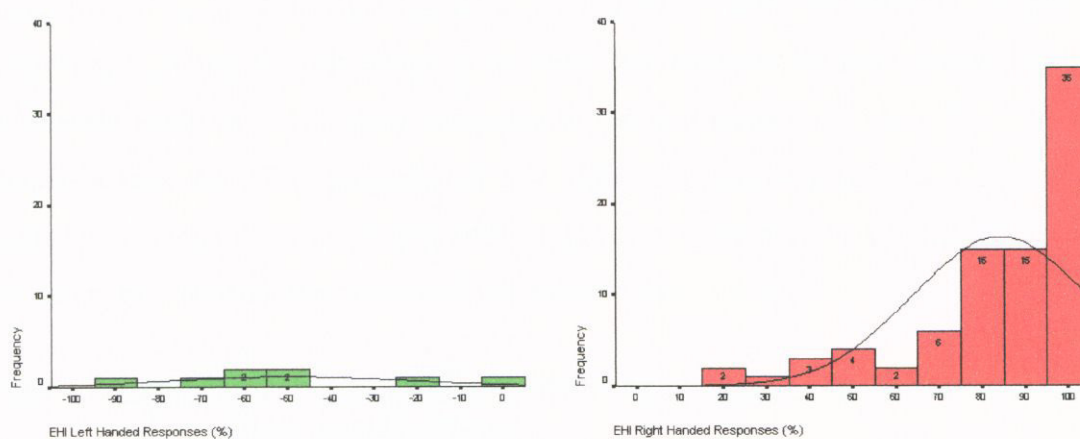


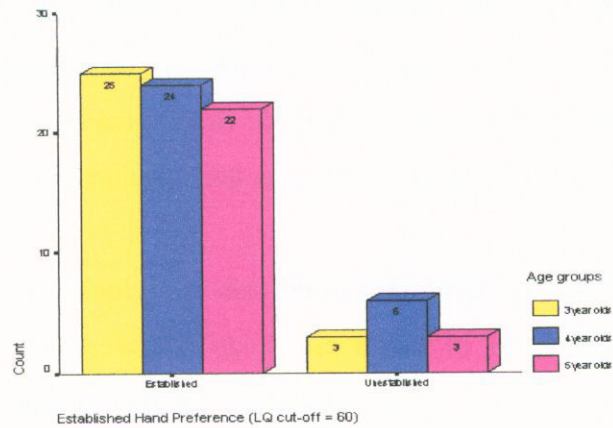
Table 3.6. Descriptive Information on EHI Left and Right Handed Distributions

	<i>Left</i>	<i>Right</i>		<i>Left</i>	<i>Right</i>
<i>N</i>	8	83	<i>Skewness</i>	0.66	-1.51
<i>Mean</i>	-50.00	84.10	<i>Kurtosis</i>	0.35	1.75
<i>SD</i>	28.28	20.24	<i>95% CI</i>	-73.65; -26.35	79.68; 88.52

The mean was notably lower in left handed responses (-50.00 ± 28.28) compared to right hand responses (84.10 ± 20.24), and also compared to left handed responses in the first study (-61.75 ± 27.53). Right handed responses, however, showed virtually the same mean as in the first study (85.33 ± 15.77). The right distribution was still strongly negatively skewed (-1.51) and positively kurtosed (1.75), with 71 (86%) established handers (i.e., LQ above 60%).

Figure 3.10 illustrates the level of establishment according to the three age groups, using LQ at 60% as a cut-off point for established versus unestablished handedness (i.e., $LQ \leq 60\%$ was considered unestablished).

Figure 3.10. The Extent of Established Hand Preference in Relation to the Three Age Groups



There was little difference between the age groups in regard to *established* and *unestablished* hand preference based on an LQ below 60%. In addition, despite the younger age groups, the percentage of unestablished handers was only slightly higher in the present study ($n = 18, 20\%$) compared to the first study ($n = 15, 12\%$). Table 3.7 illustrates how the EHI categories of left, right and unestablished (i.e., $LQ \leq 60\%$) handedness compared to the degree of hand preference reported by parents in the initial questionnaire, reducing the number of left handers from 8 to 5.

Table 3.7: Cross-Tabulation of EHI Hand Preference Groups and Parental Report (PR) on Established Hand Preference

	EHI Unestablished $n = 15$	EHI Left $n = 5$	EHI Right $n = 71$
PR Unestablished $n = 7$	$n = 3$ PR: 42.9% EHI: 20.0% Total: 3.3%	$n = 1$ PR: 14.3% EHI: 20.0% Total: 1.1%	$n = 3$ PR: 42.9% EHI: 4.2% Total: 3.3%
PR Left $n = 17$	$n = 9$ PR: 52.9% EHI: 60.0% Total: 9.9%	$n = 4$ PR: 23.5% EHI: 80.0% Total: 4.4%	$n = 4$ PR: 23.5% EHI: 5.6% Total: 4.4%
PR Right $n = 67$	$n = 3$ PR: 4.5% EHI: 20.0% Total: 3.3%		$n = 64$ PR: 95.5% EHI: 90.1% Total: 70.3%

Note. The green squares indicate 100% agreement between Edinburgh Handedness Inventory (EHI) and parental report (PR). PR percentages are represented in rows and EHI percentages are displayed in columns. n = number of cases in each square.

Overall, there was 78.0% agreement between EHI and PR classifications, compared to 81.3% in the previous study. Of the seven children reported to be unestablished by parents, only three (42.9%) were also found to be unestablished on the EHI, while one (14.3%) was evaluated as left handed and three (42.9%) as right handed. According to parental report (PR), seventeen children were reported to be more left handed, with only four (23.5%) of these also classified as left handed by the EHI. Another four (23.5%) were right handed according to the EHI and the remaining nine (52.9%) were classified unestablished. Greatest agreement was observed in the right handed category where 64 (95.5%) of right handers were identified as such by PR, and 71 (90.1%) by the EHI.

Figure 3.11 and Table 3.8 display the distribution of consistency *within-tasks* of the entire sample. One-way ANOVA with Tukey's B failed to reveal significant differences between any of the age groups in consistency ($F = 0.112$, $p = 0.895$) at the 0.05 significance level. The descriptive statistics of EHI and consistency distributions are therefore based on the entire sample.

Figure 3.11. Distribution of Consistency

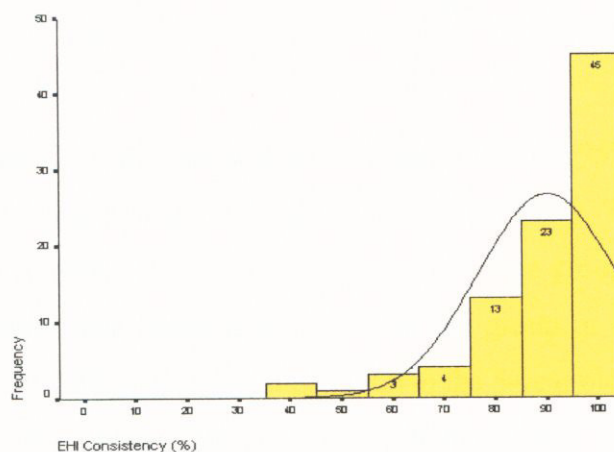


Table 3.8. Descriptive Information on the Consistency Distribution

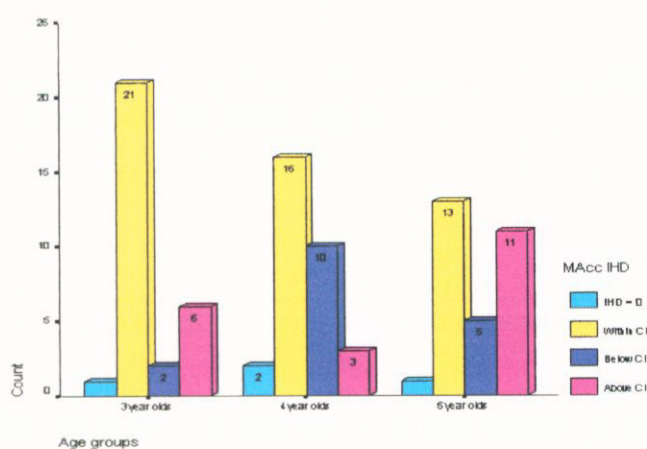
<i>N</i>	91	<i>Skewness</i>	-1.80
<i>Mean</i>	90.11	<i>Kurtosis</i>	3.41
<i>SD</i>	13.62	<i>95% CI</i>	87.27; 92.95

The consistency mean of this study (90.11 ± 13.62) was almost identical to that of the first study (90.45 ± 9.75), showing a slightly smaller standard deviation. The distribution of the present study was negatively skewed and positively kurtosed, again resembling the previous study.

3.3.2 Hand Performance

One-way ANOVA with Tukey's B was significant for MAcc *performance levels* (PL) across all age groups ($F = 36.381$, $p = 0.000$), but it was not significant for MAcc *interhand differences* (IHD) at significance level of 0.05 for any of the age groups ($F = 1.873$, $p = 0.175$). Figure 3.12 relates IHD values in MAcc to the three age groups, based on the 95% confidence interval (CI).

Figure 3.12. Comparing Motor Accuracy (MAcc) Interhand Differences (IHD) Between the Age Groups



In the 3-year old group, 21 (70%) showed IHD values within the 95% CI, compared to 16 (52%) and 13 (43%) in the 4- and 5-year old groups respectively. This means that the 3-year old group showed greater IHD values than the older age groups. IHD values below the 95% CI range were most frequent in the 4-year old group ($n = 16$, 52%), and IHD values above the 95% CI range were most common in the 5-year old group. Four children across the age groups showed no differences between the hands.

Figure 3.13 and Table 3.9 depict the IHD distributions in MAcc left and right hand groups, excluding IHD values of 0 ($n = 4$).

Figure 3.13. Distribution of Motor Accuracy (MAcc) Interhand Differences (IHD) in MAcc Left and Right Handed Responses

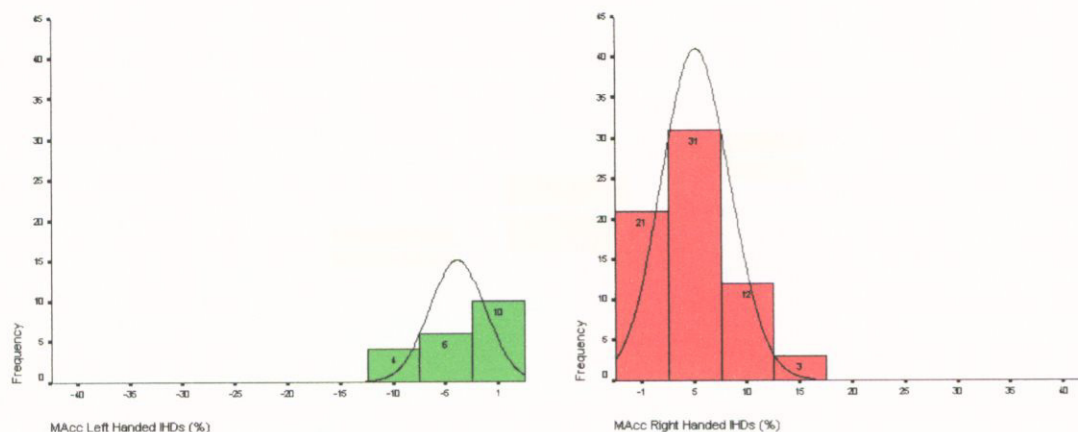


Table 3.9. Descriptive Information on Motor Accuracy (MAcc) Interhand Differences (IHD) in MAcc Left and Right Handers

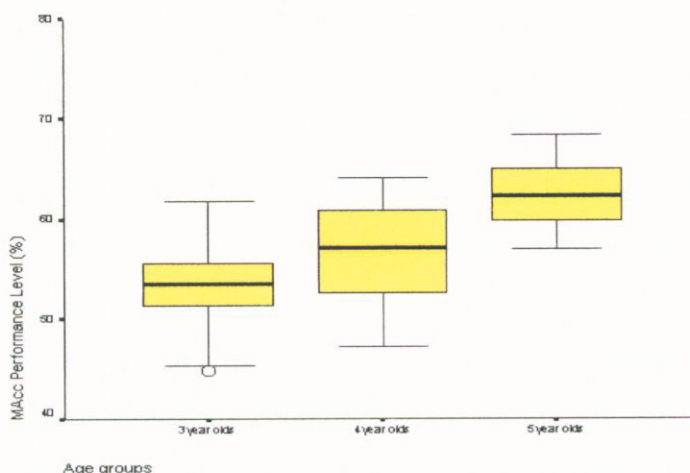
	<i>Left</i>	<i>Right</i>		<i>Left</i>	<i>Right</i>
<i>N</i>	20	67	<i>Skewness</i>	-0.68	1.05
<i>Mean</i>	-3.42	4.62	<i>Kurtosis</i>	-1.02	1.09
<i>SD</i>	2.63	3.25	<i>95% CI</i>	-4.61; -2.19	3.83; 5.41

Note. The four cases with no IHD were excluded from the descriptive information.

The shapes of the left and right distributions were very similar to those of the previous study (see Figure 2.5 in Chapter 2), the left being negatively kurtosed (-1.02) and the right positively kurtosed (1.09). The right distribution also demonstrated positive skewness (1.05), indicating floor effect. As previously, MAcc right handed responses showed a slightly higher mean (4.62 ± 3.25) compared to MAcc left handed responses (-3.42 ± 2.63). Also, the number of MAcc left handed responses ($n = 14$) almost doubled the number of EHI left responses ($n = 8$). Overall, the proportions were similar to those of the first study, displaying a tendency towards interhand differences smaller than 5 percent.

Since one-way ANOVA with Tukey's B showed significant differences in means between all age groups ($F = 36.381, p = 0.000$), the distribution of these three groups is compared in Figure 3.14 and Table 3.10.

Figure 3.14. Distribution of Motor Accuracy (MAcc) Performance Level (PL) in 3-, 4- and 5-Year Old Children



Note. The horizontal black line in the box denotes the median.

Table 3.10. Descriptive Information on Motor Accuracy (MAcc) Performance Level (PL) Distributions in Different Age Groups

	3 years	4 years	5 years		3 years	4 years	5 years
<i>N</i>	31	31	30	<i>Skewness</i>	-0.33	0.04	0.12
<i>Mean</i>	52.92	56.57	62.31	<i>Kurtosis</i>	-0.05	-1.23	-0.94
<i>SD</i>	4.33	5.04	3.32	<i>95% CI</i>	51.31; 54.54	54.72; 58.42	61.07; 63.55

The MAcc performance mean increased progressively with age, the distributions in the 4- and 5-year old groups were kurtosed, and none of the distributions were significantly skewed. Figure 3.15 and Table 3.11 show the distribution of the MAcc performance levels (PL) of the entire sample, based on the highest score achieved by either the right or left hand.

Figure 3.15. Distribution of Motor Accuracy (MAcc) Performance Level (PL)

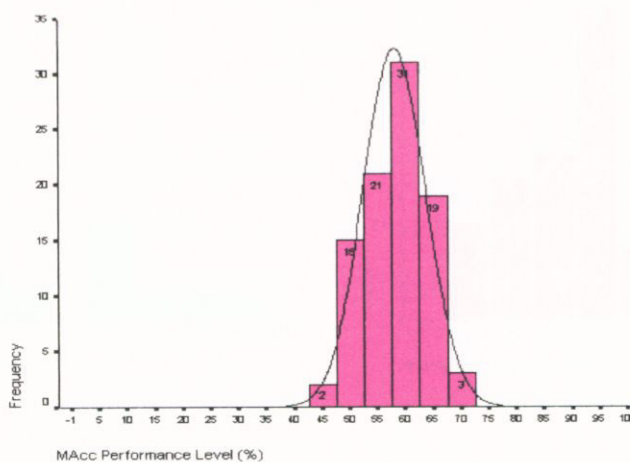


Table 3.11. Descriptive Information on the Motor Accuracy (MAcc) Performance Level (PL) Distribution

<i>N</i>	91	<i>Skewness</i>	-1.53
<i>Mean</i>	57.28	<i>Kurtosis</i>	19.13
<i>SD</i>	9.29	<i>95% CI</i>	55.36; 59.13

As mentioned in the previous study, it is possible to score between 0% and 100% for the performance on the MAcc, thus the distribution was analysed in the context of the total score range. It can be seen in Figure 3.15 that the distribution of scores was strongly positively kurtosed (19.13) and negatively skewed (-1.53), displaying a very small range even when the three age groups are combined. However, the kurtosis and skewness were substantially less abnormal than in the previous study (Study II: kurtosis = 18.36, skewness = -1.47; Study I: kurtosis = 46.93, skewness = -5.09), where the mean was also significantly higher (71.77 ± 8.27).

3.3.3 Midline Crossing

One-way ANOVA with Tukey's B revealed that there were no significant differences ($F = 1.610, p = 0.206$) in midline crossing between any of the three groups.

Figure 3.16 and Table 3.12 compare the distribution of midline crossing, based on the midline crossing quotient (MCQ), in MCQ left and right handed responses.

Figure 3.16. Comparing Distributions of Midline Crossing Quotient (MCQ) in MCQ Left and Right Handed Responses

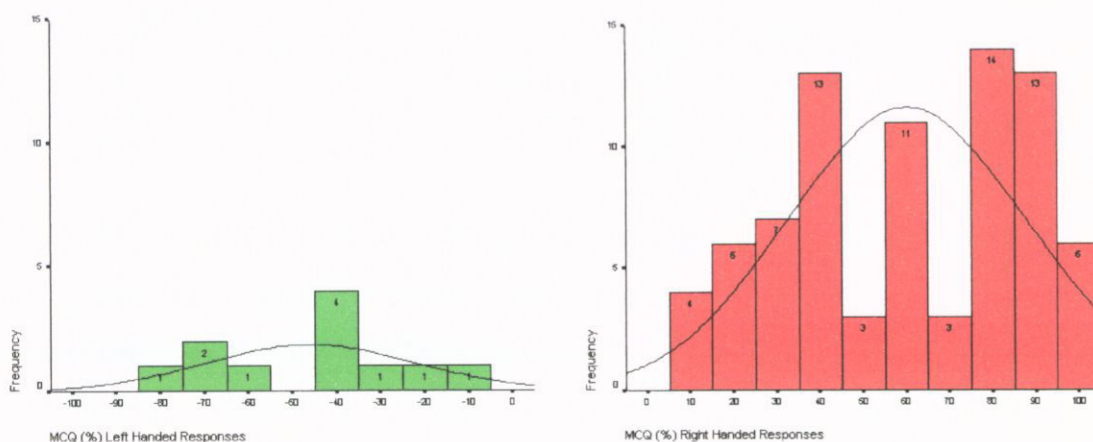
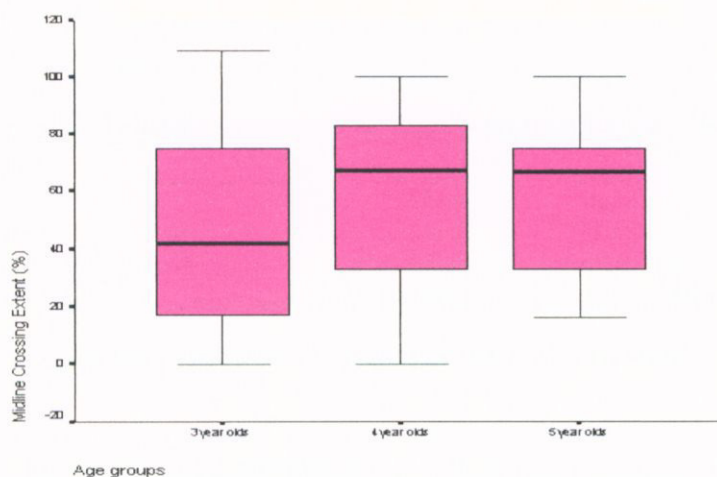


Table 3.12. Descriptive Information on Midline Crossing Quotient (MCQ) Distribution in MCQ Left and Right Handed Responses

	<i>Left</i>	<i>Right</i>		<i>Left</i>	<i>Right</i>
<i>N</i>	11	80	<i>Skewness</i>	-0.06	-0.22
<i>Mean</i>	46.18	60.01	<i>Kurtosis</i>	-0.79	-1.16
<i>SD</i>	23.61	27.46	<i>95% CI</i>	30.32; 62.04	53.90; 66.12

The mean of MCQ was notably lower in the MCQ left handed responses than in the MCQ right handed group. Neither distribution was particularly skewed, but right handers were negatively kurtosed (-1.16), indicating a wider range than normal. Figure 3.17 and Table 3.13 illustrate the descriptive statistics of the midline crossing *extent* between the three age groups (i.e., total contralateral reaching, regardless which hand was used).

Figure 3.17. Midline Crossing Extent Across the Three Age Groups



Note. The horizontal line inside the box plot depicts the median.

Table 3.13. Descriptive Information on Midline Crossing Extent (MCE) in the Three Age Groups

	<i>3 years</i>	<i>4 years</i>	<i>5 years</i>		<i>3 years</i>	<i>4 years</i>	<i>5 years</i>
<i>N</i>	30	31	30	<i>Skewness</i>	0.35	-0.30	-0.11
<i>Mean</i>	52.43	59.77	62.76	<i>Kurtosis</i>	-0.90	-1.37	-1.15
<i>SD</i>	26.82	30.13	24.35	<i>95% CI</i>	42.42; 62.45	48.72; 70.83	53.67; 71.86

Compared to the SVCU of Study I (Chapter 2), where 20% of children showed midline crossing avoidance and 62% demonstrated reluctance for contralateral reaching, the modified Midline Crossing Test showed a non-skewed distribution in all age groups, with means ranging between 52 and 62 percent. All distributions were negatively kurtosed or flatter than normal, indicating a wide spread of data ranging between 6% and 100%. The distribution for the midline crossing extent (MCE), as a PL for midline crossing, was

based on the entire sample (see Figure 3.18 and Table 3.14). The distribution was not skewed, with a mean of 54.04 ± 30.68 , but negatively kurtosed (-1.18). (See Appendix 3L for a comparison between EHI hand preference groups and MCE.)

Figure 3.18. Distribution of Midline Crossing Extent (MCE) of Entire Sample

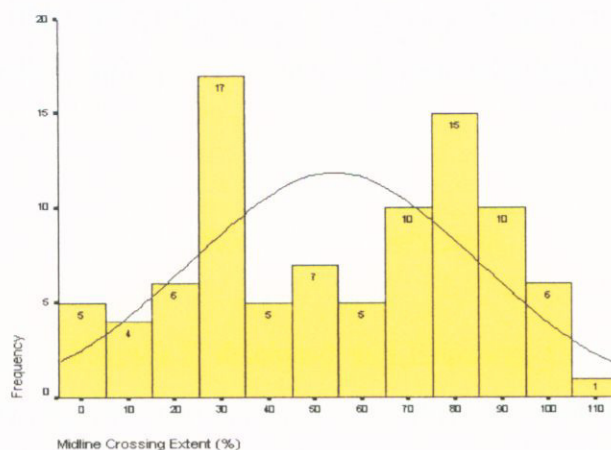


Table 3.14. Descriptive Information on the Midline Crossing Extent (MCE) of Entire Sample

<i>N</i>	91	<i>Skewness</i>	-0.12
<i>Mean</i>	54.04	<i>Kurtosis</i>	-1.18
<i>SD</i>	30.68	<i>95% CI</i>	47.65; 60.43

Figure 3.19 and Table 3.15 compare the distribution of the midline crossing extent (MCE) in 5-year olds in the present study to that of the previous study.

Figure 3.19. Midline Crossing Extent (MCE) in 5-Year Old Children Comparing Studies I and II

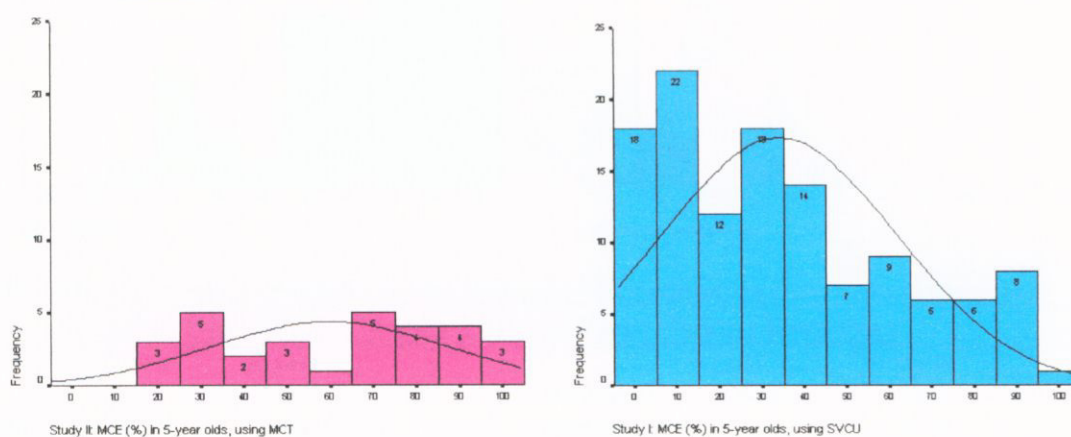


Table 3.15. Descriptive Information on the Midline Crossing Extent (MCE) Across the Two Studies

	<i>Study II</i>	<i>Study I</i>		<i>Study II</i>	<i>Study I</i>
<i>N</i>	30	122	<i>Skewness</i>	-0.10	1.02
<i>Mean</i>	59.60	25.62	<i>Kurtosis</i>	-1.18	0.14
<i>SD</i>	27.34	24.45	<i>95% CI</i>	49.39; 69.81	21.24; 30.01

Instead of the midline crossing quotient (MCQ), which includes hand use in the midline, the *contralateral start percentage* was calculated for the 5-year olds in the present study, so that the modified test could be compared more accurately with the SVCU. It is clear that the distribution of scores of the 5-year olds was notably different from that of Study II. Five-year old children in Study II demonstrated a much higher mean than the 5-year olds in Study I, and there were differences in skewness (Study I was positively skewed, indicating a floor effect) and kurtosis (Study II was negatively kurtosed, implying a broader spread).

3.3.4 Bimanual Coordination

One-way ANOVA with Tukey's B disclosed that Bimanual Coordination *performance* levels (PL) were only significantly different between the 3-year and 5-year age groups ($F = 2.948, p = 0.058$). Figure 3.20 and Table 3.16 compare IHD values of bimanual coordination between Bimanual Coordination Test (BCT) left and right handers.

Figure 3.20. Comparison of Bimanual Coordination Test (BCT) Interhand Differences (IHD) in BCT Left and Right Handers

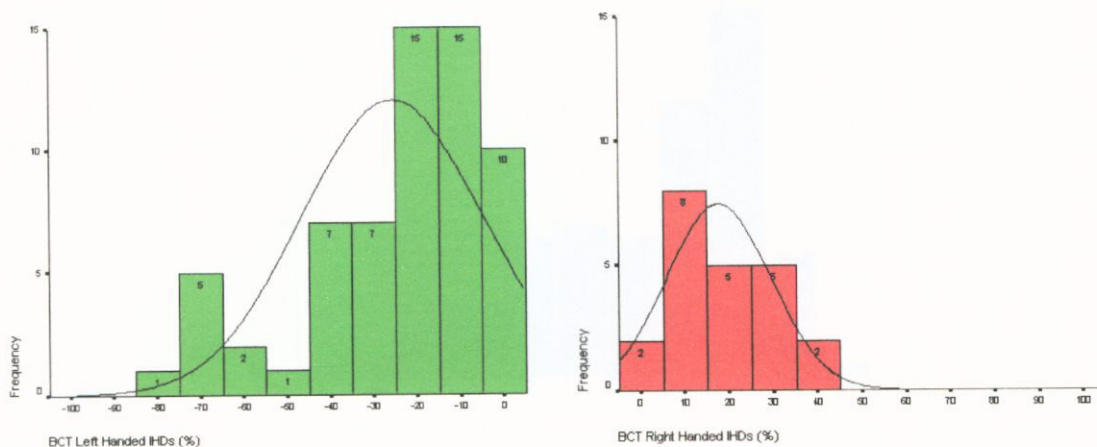


Table 3.16. Descriptive Information on Bimanual Coordination Interhand Differences (IHD) Distributions in BCT Left and Right Handed Responses

	<i>Left</i>	<i>Right</i>		<i>Left</i>	<i>Right</i>
<i>N</i>	69	22	<i>Skewness</i>	-1.14	0.62
<i>Mean</i>	-25.75	17.56	<i>Kurtosis</i>	0.56	-0.32
<i>SD</i>	20.85	11.77	<i>95% CI</i>	-31.00; -20.50	12.34; 22.77

Approximately two thirds of the entire sample, regardless of left or right handedness, showed a greater left handed lead during the BCT. This unexpected high number of left IHD values in the BCT warrants further comparison with EHI hand preference groups.

Figure 3.21 illustrates that it was a greater proportion of EHI right handers who demonstrated more left hand involvement during the modified BCT.

Figure 3.21. Comparison of Bimanual Coordination Test (BCT) Interhand Differences (IHD) in EHI Left and Right Handers

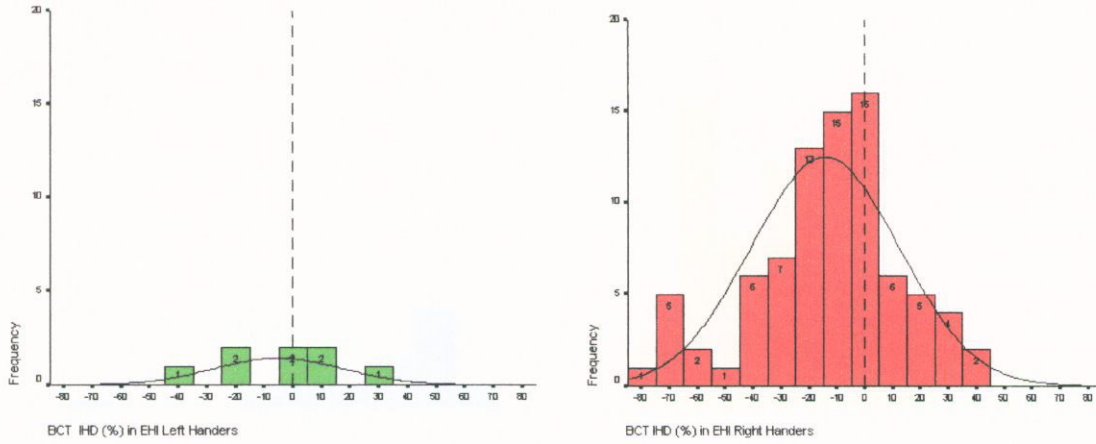


Figure 3.22 and Table 3.17 display the PL distribution of BCT of the entire sample.

Figure 3.22. Distribution of Bimanual Coordination Test (BCT) Performance Level (PL)

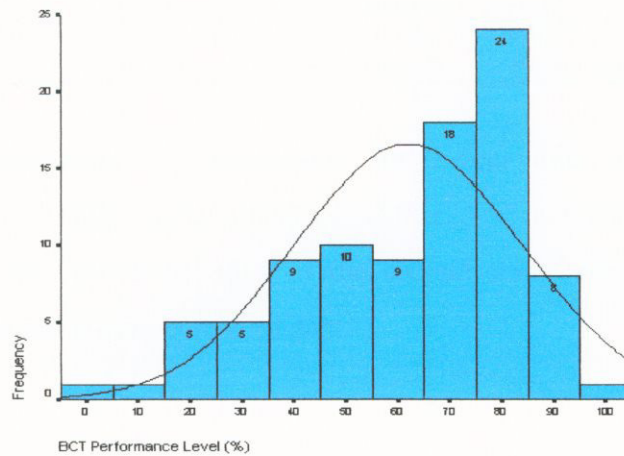


Table 3.17. Descriptive Information on the Bimanual Coordination Test (BCT) Performance Level (PL) Distribution

<i>N</i>	91	<i>Skewness</i>	-0.72
<i>Mean</i>	61.84	<i>Kurtosis</i>	-0.24
<i>SD</i>	21.86	<i>95% CI</i>	57.29; 66.39

The BCT distribution of the present study shows a mean of 61.84±21.86 and minimal skewness and kurtosis. There appears to be a slight ceiling effect. Figure 3.23 and Table

3.18 compare the previous and present studies on bimanual coordination PL distribution in 5-year old children.

Figure 3.23. Comparing the Two Studies on Bimanual Coordination Test (BCT) Performance Level (PL) Distributions in 5-Year Old Children

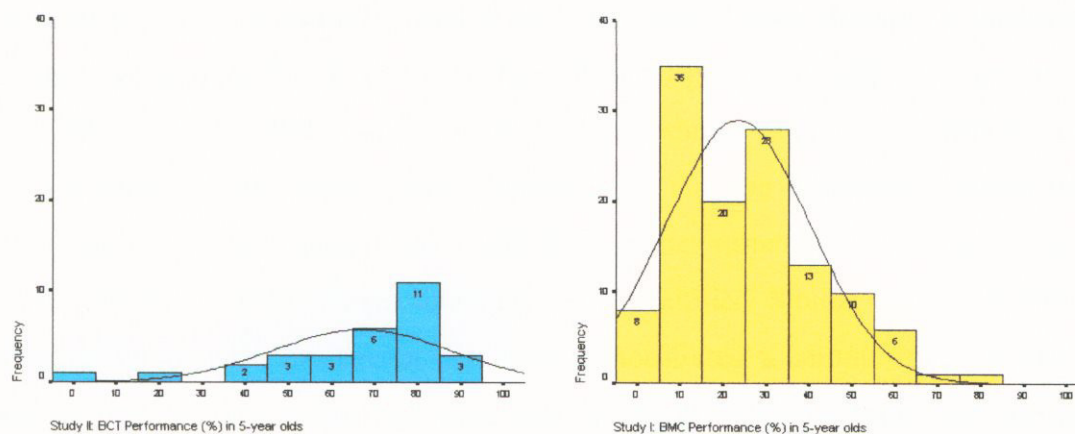


Table 3.18. Descriptive Information on Bimanual Coordination Test (BCT) Performance Level (PL) Distributions in Studies I and II

	<i>Study II</i>	<i>Study I</i>		<i>Study II</i>	<i>Study I</i>
<i>N</i>	30	122	<i>Skewness</i>	-1.47	0.75
<i>Mean</i>	66.96	23.32	<i>Kurtosis</i>	0.03	-0.03
<i>SD</i>	25.52	16.75	<i>95% CI</i>	59.30; 74.62	20.32; 26.32

The bimanual coordination PL distribution for 5-year olds of the present study demonstrated a significantly higher mean of 66.96 ± 25.52 compared to the first study (23.32 ± 16.75). Overall, the distribution of the second study was a more normal one, showing a wider and more even spread of data.

3.4 Discussion

3.4.1 Discussion of Results

The aim of this study was to assess the suitability of the adjusted handedness test selection for a normative profile, including the two modified tests. Despite the inclusion of younger age groups, the distributions for left and right hand preference and hand performance using the same tests as in the previous study, continued to demonstrate limited variability. Thus, Experimental Hypothesis 1, that the Edinburgh Handedness Inventory and the Motor Accuracy test would show greater variability of hand preference and hand performance with younger children, was not fulfilled. Similar to the first study, the distribution for right handers in particular demonstrated a ceiling effect for hand preference, with an almost identical mean score across the studies. There was also no difference in consistency between the studies. Furthermore, the Edinburgh Handedness Inventory failed to detect significant differences between the age groups for degree of established handedness.

In addition, the discrepancy between hand preference groups based on parent report and the Edinburgh Handedness Inventory was only slightly higher than in the previous study, again mainly due to misclassifications in the left and unestablished categories. This further supports the finding that the Edinburgh Handedness Inventory does not appear to be age sensitive. It is possible that most of the Edinburgh Handedness Inventory items are lateralised early in life, thus displaying very similar distributions for the different age groups. One study employing the Edinburgh Handedness Inventory with children also failed to find an effect for age (Brito, Lins, Paumgarten & Brito, 1992), whereas other studies found support for increasing hand preference with age (e.g., McManus, Sik, Cole, Mellan, Wong & Kloss, 1988). This discrepancy might be linked to the nature of the assessment tasks involved, and a lack of consensus on a specific age at which handedness is established, ranging from 3 to 9 years (Gesell & Ames, 1947; McManus et al., 1988; Tan, 1985) (see Section 1.4.3 on unestablished handedness in Chapter 1 for more detail).

Whilst the Motor Accuracy *performance level* increased significantly across all age groups, the *interhand differences* of the Motor Accuracy were not found to be

significantly different, and the distribution appeared similar to that of the first study. Interestingly, the 3-year old children revealed larger interhand differences than older groups. At first sight, this finding appears surprising, since it is clear that the preferred hand becomes more skilled with age through maturation of the neuromotor system. Moreover, through practice a corresponding increase in interhand differences would be expected in older children. Some studies have demonstrated an increasing preferred hand advantage with age (DeAgostini, Paré, Goudot, & Dellatolas, 1992; Mandell, Nelson & Cermak, 1984).

Other developmental studies, however, have found that younger children display larger interhand differences in skilled tasks (Annett, 1970a; Brito, Lins, Paumgarten & Brito, 1992; Curt, Maccario & Dellatolas, 1992; Denckla, 1974). Annett (1970a) argued that the performance of both hands improves with age, with the non-preferred hand making greater gains than the preferred one, thereby decreasing the interhand difference with age. The divergent results of the studies could possibly be attributed to the nature of the 'skill'. For example, findings by Mandell et al. (1984) indicated an increase in interhand differences in finger tapping, but a decrease in preferred hand advantage in Motor Accuracy performance was evident in older children compared to younger ones. In another study, peg moving performance did not improve with age whereas a graphic task did, prompting the authors to suggest that the impact of age is related to the nature of the task (DeAgostini, Paré, Goudot & Dellatolas, 1992). The decrease in Motor Accuracy test interhand differences found in the present study appears in accordance with the literature proposing that the size of interhand differences are not necessarily due to age but rather on the nature of the task. Further research in this area is required to clarify the relationship between interhand differences, age and task disposition.

While the Motor Accuracy test appears to be a valid tool for assessing performance levels and interhand differences, the results on the Motor Accuracy test in this study nonetheless presented with a kurtosed effect and a lack of variability in the data. This might partly be a consequence of revisions to the MAcc, including adjustments to decrease the difference between the hands (Smith, 1983). In the light of these findings, the Motor Accuracy test does not appear to be a suitable measure for the purpose of a normative handedness profile. Instead, the need for modifications to the tests for hand

preference and hand performance is indicated in order to detect greater variations in the degrees of handedness establishment.

In contrast, both the modified Midline Crossing Test and the modified Bimanual Coordination Test showed greater variability, thus fulfilling Experimental Hypothesis 2, which stated that the two modified tests would demonstrate sufficient range of variability in degrees of midline crossing and bimanual coordination in 3- to 5-year old normal children. This data would form a suitable basis for a normative handedness profile. The failure of the Midline Crossing Test to reveal significant differences between the age groups appears to indicate that the variability in performance was due to individual variability in contralateral reaching rather than age. Repeating this test with older age groups might determine whether this variability decreases with age. Alternatively, age-related changes might have been confounded by the unequal numbers of left and right handers in the sample. Further testing of a sample with equal left and right handers is warranted before conclusions about age-related changes can be drawn.

When the 5-year old group was compared to the Space Visualisation Contralateral Use distribution in the first study, Midline Crossing Test scores were normally distributed compared to the floor effect found in the Space Visualisation Contralateral Use distribution, indicating that the latter was too difficult in the first study. The negative kurtosis of the modified test suggested a flatter, broader distribution than previously. In addition, in accordance with the literature (e.g., Gabbard, Helbig & Gentry, 2001), right handers crossed the midline more frequently than left handers, which was also the case in the previous study using the Space Visualisation Contralateral Use measure.

The bimanual coordination interhand differences employing the modified Bimanual Coordination Test were small in both left and right handers. This was expected, since the aim of the test was to produce simultaneous movement of both hands. While the *interhand differences* did not change significantly with age, bimanual coordination *performance* was found to be significantly different between the 3- and 5-year groups with a non-skewed distribution, indicating that this test detects age-related changes. The positive kurtosis revealed that the majority of children performed around the mean of the Bimanual Coordination Test, which was significantly higher than that of the previous

study. Overall, the distribution of the present 5-year old group was more normal compared to that of the 5-year olds in the first study (i.e., no floor effect), suggesting that the modified test was not too difficult for any of the three age groups. Unexpectedly, right handers in particular demonstrated greater deviation with the *non-preferred* left hand. These results are in contrast with consistent findings that the preferred hand leads, moves faster and with less variability in bimanual tasks in normal individuals (Peters & Durdning, 1979; Provins & Cunliffe, 1972; Todor, Kyprie & Price, 1982). Investigating bimanual coordination in a clinical sample of dyslexic school-aged boys by using the Etch-a-Sketch instrument, Gladstone, Best and Davidson (1989) also found a superior left hand performance, prompting the authors to suggest that dyslexics typically exhibit a deficit in left hemispheric inhibition. In this context, it is possible that normal 3- to 5-year old children, as represented in the present sample, would demonstrate similar results because of their age-related neurological immaturity. Further investigation is required by applying the Bimanual Coordination Test to an older, normal sample to explore this possibility in greater detail.

As in Study I, findings of the present study did not indicate significant gender differences, although girls tended to be more lateralised (i.e., scoring a higher laterality quotient), more consistent and employed more contralateral reaching than boys. Because of this tendency, gender-based analysis should also be included in the following study, where left and right handers are equally represented. This is important as other studies have found similar gender differences (e.g., Brito, Lins, Paumgarten & Brito, 1992; DeAgostini, Paré, Goudot & Dellatolas, 1992; Karapetsas & Vlachos, 1997).

3.4.2 Conclusion

Whilst the present study seemed to confirm the suitability of the two modified tests, the Midline Crossing and Bimanual Coordination Tests, findings also indicate a need to develop new hand preference and hand performance measures. A modified hand preference test should contain the present Edinburgh Handedness Inventory items, since these have been reported valid and reliable (see Section 2.1.1 on test description, reliability and validity in Chapter 2). However, the ten Edinburgh Handedness Inventory items should be supplemented by additional items, thereby providing a greater

opportunity to identify hand preference according to different categories (e.g., trained versus untrained tasks). In addition, it would be beneficial to implement a consistency measure, similar to that employed in the previous studies, by using multiple trials for each item. For hand performance, a different tracing task might increase a wider range of responses, and a more stringent scoring method might detect a larger range of errors more sensitively. Tracing is a trained task. Since the distinction between trained and untrained tasks will be made for hand preference, it would be useful to make a similar distinction in hand performance. To this end an untrained performance task could be introduced to determine the inherent *motor ability* that has not been subjected to direct practice.

The development of modifications to the hand preference test (i.e., the Edinburgh Handedness Inventory) and the hand performance test (i.e., the Motor Accuracy test) is described in the following chapter. Furthermore, the implementation of initial and modified tests with an older normal sample, consisting of equal numbers of left and right handers, are discussed and relevant inter-group differences reported.

CHAPTER 4

STUDY III: COMPARING INITIAL AND MODIFIED TESTS BASED ON A NORMATIVE SAMPLE OF LEFT AND RIGHT HANDED CHILDREN

4.1 Introduction

The purpose of this chapter is three-fold. Firstly, the hand preference and hand performance tests were modified to provide more detailed information on the degree of handedness. The initial Edinburgh Handedness Inventory (EHI) for hand preference was extended and modified as the *Functional Hand Preference Test (FHPT)*, comprising of different categories of hand preference tasks. The Motor Accuracy (MAcc) test and the Hand Dominance Test (HDT) were adapted to form the modified *Skill Test*, and an additional *Ability Test*, consisting of hammering and tapping tasks, was included for hand performance. Together with the modified Midline Crossing Test (MCT) and the Bimanual Coordination Test (BCT), the modified Functional Hand Preference Test (FHPT), Skill Test and Ability Test constitute a collection of five handedness measures, collectively referred to as the *Handedness Profile Test Battery*. The Tests and Instruments Section examines existing tests as a basis for the modified tests with reference to the literature. Since the modification process is intricately linked with existing literature, arguments for the proposed modifications are presented and explored under the Method Section rather than in the Introduction, to avoid unnecessary repetition.

Secondly, a third normative study using equal numbers of left and right handers to compare each handedness group on the initial tests (i.e., EHI, MAcc, SVCU and BMC) and the modified Handedness Profile Test Battery, is implemented and analysed. In other words, whereas the previous study compared some of the initial and modified tests across two different samples, the present study makes this comparison within the same sample of children. Finally, the suitability of the Handedness Profile Test Battery is discussed as a basis for a normative handedness profile.

4.1.1 Experimental Hypotheses

Two experimental hypotheses were identified for the third normative study.

Experimental Hypothesis 1: There would be notable differences between the initial and modified hand preference and performance tests. These differences might not necessarily be significant in terms of *means* since the factors underlying the tasks appear to be similar, but the modified tests would show greater *variability* and spread compared to the initial tests.

Experimental Hypothesis 2: The modified tests would sensitively differentiate degrees of handedness in a variety of related neuromotor behaviours as required for a comprehensive handedness profile.

If the preliminary comparisons performed in the present study between initial and modified midline crossing and bimanual coordination tests are confirmed, and if the modified hand preference and hand performance tests also display the required variability of data, the selection of modified tests would then be suitable as a basis for a normative handedness profile. However, if the above hypotheses were not met, further modifications would be needed to obtain tests with the required sensitivity to provide the necessary range to accommodate children at all levels of established handedness.

4.2 Method

4.2.1 Participants

Sixty two normal children (26 girls and 36 boys) aged 5 and 6 years were recruited as a convenience sample for this study, consisting of 31 left handers and 31 right handers. Since those children with variable handedness starting school are most in need of a handedness profile, 5- to 6-year old children appeared to be the most appropriate age range for this study. Selection of normative left and right handers was inadvertently based on parental report, and thus on the assumption, that parents would report the 'correct' handedness. There is evidence that parental report might be unreliable (Rigal, 1992; Whittington & Richards, 1987), which was partly supported in Study I, where discrepancies were revealed between parental report and EHI hand preference groups in left and unestablished handers. Additional information was thus obtained to complement parental report. Left handers were unambiguously defined as such by parents *and* teachers, and all were drawing and writing with their left hand. Right handers were also defined as definitely established by parents *and* teachers, with no history of early left handedness or extensive periods of ambiguous hand use. Both parents and teachers were given a questionnaire and asked to rate the child's handedness using a 5-point scale (see Appendix 2B). Left and right handers selected according to these criteria are hereon referred to as *presenting* left and right handers.

Due to limited availability of presenting left handers in this age range, left handed children aged between one and six months younger ($n = 7$), and between 1 and 5 months older ($n = 8$), than the 5 to 6 year old range, were included in the sample. Should one-way ANOVA indicate that these children performed significantly differently to the 5- to 6-year old children on any of the handedness measures, they would be excluded from further analysis. Parental permission was obtained using an Informed Consent Form (see Appendix 2C for an example), and ethics approval for assessing handedness in a normative sample had been granted previously from La Trobe University (see Appendix 2D and Appendix 3D).

4.2.2 Tests and Instruments

All children were assessed using the four initial tests (i.e., EHI, MAcc, Space Visualisation Contralateral Use [SVCU] measure, and Bilateral Motor Coordination [BMC] test), and the five modified tests (i.e., Functional Hand Preference Test [FHPT], Skill Test, Ability Test, Midline Crossing Test [MCT], and Bimanual Coordination Test [BCT]). Table 4.1 displays the tests used in the present study, and where they were previously described. The three modified tests, FHP, Skill and Ability (indicated with a ♦-symbol in the table) will be outlined in this chapter.

Table 4.1. Initial and Modified Tests Used with the Present Normative Sample

<i>Measure</i>	<i>Initial Test</i>	<i>Modified Test</i>
<i>Hand Preference</i>	Edinburgh Handedness Inventory (EHI) – <i>initial test described in Section 2.2.2.1, Chapter 2. Repeated in Chapter 3.</i>	♦Functional Hand Preference Test (FHPT) - <i>modified test, described in Sections 4.2.3, 4.2.4 and 4.2.5 in this chapter.</i>
<i>Hand Performance</i>	Motor Accuracy Revised (MAcc) – <i>initial test described in Section 2.2.2.2 in Chapter 2. Repeated in Chapter 3.</i>	♦Hand Performance: Skill Test a) Bear Tracing Task (BTT) subtest b) Bead Dotting Task (BDT) subtest ♦Hand Performance: Ability Test c) Hammering subtest d) Tapping subtest - <i>both modified tests, described in in Sections 4.2.3, 4.2.4 and 4.2.5 in this chapter.</i>
<i>Midline Crossing</i>	Space Visualisation Contralateral Use (SVCU) measure – <i>initial test described in Section 2.2.2.3 in Chapter 2.</i>	Midline Crossing Test (MCT) – <i>modified test described in Section 3.2.3.1 in Chapter 3.</i>
<i>Bimanual Coordination</i>	Bilateral Motor Coordination (BMC) – <i>initial test described in Section 2.2.2.4 in Chapter 2.</i>	Bimanual Coordination Test (BCT)– <i>modified test described in Section 3.2.3.2 in Chapter 3.</i>

Note. ♦ = tests modified and described in this chapter.

4.2.3 Test Modification Procedures

4.2.3.1 Functional Hand Preference Test (FHPT)

The multidimensional nature of handedness requires a combination of untrained and trained, unimanual and bimanual functional tasks to fully evaluate the extent of its

establishment (Bryden, Bulman-Fleming & MacDonald, 1996; Provins & Cunliffe, 1972). As discussed in Chapter 3, the EHI has the potential to be expanded to include such tasks.



Untrained tasks are often not clearly differentiated from *unskilled* tasks in the handedness literature. Some tasks may be *untrained* and relatively free from learning through imitation but still require skill in the form of accurate placing and holding, such as building a tower with small blocks. In other words, it is unlikely that a child would be taught which hand to use when building a tower. Some tasks may also be *unskilled* but are subjected to strong socio-cultural pressures and training, such as shaking hands. Finally, there are skilled tasks such as cutting with scissors and drawing, that are also directly subjected to training, teaching, imitation and repeated practice. In these activities it is likely that a child receives input on the correct way to hold the scissors or the pencil, which includes by default the hand used. Given that the learning of manual tasks through practice and training takes place within a predominantly right handed environment (Harris, 1990; Olsson & Rett, 1989; Peters, 1990; Peters & Murphy, 1992), possible misclassification is thus more likely to occur in untrained/trained tasks than unskilled/skilled ones. It was thus deemed important that a handedness profile should incorporate an untrained-trained distinction in the hand preference measure.

The EHI consists of several trained items that might fail to identify 'unpronounced' left handers who are strongly influenced by the right-handed environment. These items are based on: (i) right handed equipment (e.g., using scissors or a knife with a single left-sided blade for right handers), (ii) social norms (e.g., eating with a spoon traditionally placed with its handle protruding to the right), and (iii) imitation (e.g., writing, drawing, striking a match, throwing a ball, brushing teeth). Only two of the ten EHI items could provide opportunity for spontaneous preferred hand choice (i.e., opening a little box and sweeping with a broom). Even if a child shows 'non-preferred' left hand use in those three items but uses the 'preferred' right hand consistently on the trained items, a classification of established right or left handedness would result. Alternatively, if handedness of the same child is assessed using equal numbers of untrained and trained tasks, this child might well be classified differently. This in turn might impact on clinical decision making and treatment.

The distinction between hand use in the unimanual and bimanual distinction of tasks has also failed to receive much attention in the literature. As mentioned in Chapter 1, bimanual tasks usually involve a leading and an assisting hand, and the pattern of preference in unimanual actions could be significantly different from the hand that leads in bimanual tasks. The EHI contains four bimanual items (i.e., cutting with scissors, striking a match, opening a lid or a box and using a broom). Based on these considerations it was decided to establish four different categories: (i) *unimanual untrained* items, (ii) *unimanual trained* items, (iii) *bimanual untrained* items, and (iv) *bimanual trained* items. It must be noted that each child is unique in its environment, and one child might have had experience with an item that is classified as untrained, or no experience with a so-called trained item. For this reason, it was deemed important to assess six items under each of the four categories, as this would increase the likelihood of a more reliable reflection of the child's hand preference in that category. The total of 24 items was divided equally into the four categories with 6 items each (see Figure 4.1 for a photograph of the FHP equipment). Collectively these handedness assessment items are called the *Functional Hand Preference Test (FHPT)*.

Figure 4.1. Photograph of Functional Hand Preference Test (FHPT) Items



Note. Items written in blue are the ten EHI items retained for this test. Pen and crayon for writing and drawing are not represented on the photograph. * = 7  and 11 .

There is no standardised hand preference test for children containing the four proposed categories of unimanual untrained, unimanual trained, bimanual untrained and bimanual trained tasks. Numerous studies investigating children's handedness have employed their

own selection of hand preference items (e.g., Curt, DeAgostini, Maccario & Dellatolas, 1995; McManus, Sik, Cole, Kloss, Mellon & Wong, 1988). Bishop (1990a) suggested that researchers should select a test battery most suitable to the aims and objectives of the study. In addition to the ten EHI items, the researcher selected an additional 14 items according to their *apparent* untrained/trained and unimanual/bimanual characteristics and their suitability for children. Reliability or factor structures were found for some hand preference items (see Appendix 4A), and no study addressed hand preference items according to the four proposed categories. This was deemed to be unproblematic, since the same FHPT items would be used for all children, enabling inter-sample comparability.

The *untrained unimanual* items consisted of the following tasks: stacking beads on a vertical pin, placing pegs in holes, spinning a spinning top, pushing a small ball with a little bear (soccer), stacking blocks, and throwing a dice. The *trained unimanual* items were writing, brushing teeth, throwing a ball, eating with a spoon, drawing, and cutting with a knife. The *untrained bimanual* items included dealing cards, opening and closing a tube, taking off stickers, turning a screw, opening a small box, and sweeping with a hand broom. The hand broom replaced the long handled broom to achieve a consistent table-top nature for all items, since standing up for sweeping was found to be disruptive to the flow of test administration in the previous studies (see again Appendix 4A for similar test-retest reliability figures for the two types of sweeping). The *trained bimanual* items consisted of striking a match, cutting with scissors, opening a padlock with a key, sewing with string, using a knife and fork, and using a screw driver (see FHP score sheet in Appendix 4B for more detail). In addition, four trials of each item were performed for a within-task consistency measure for reasons discussed previously (see Section 2.2.1.1 on hand preference Chapter 2).

4.2.3.2 Hand Performance

As discussed in Chapter 1, superior control of one hand may not necessarily indicate that it is also the preferred hand. For example, if a left handed child learns and practices using the right hand for drawing and writing, it is possible that a higher performance level will be achieved with the right hand, as case studies of switched handers have shown (e.g., Coren, 1992; Peters & Murphy, 1992; Sattler, 1998; Stutte, Schilling & Weber, 1977).

Thus, while activities such as tracing and dotting appear to be suitable for assessing forms of trained performance (i.e., hereon referred to as *Skill*), hand performance should also reflect the more inherent and innate proficiency (hereon referred to as *Ability*) which is relatively free of training, to obtain a more coherent understanding of the presenting variability in handedness.

In addition, speed is an important factor of hand proficiency when considered in a multi-factorial context (Annett, 1985; Barnsley & Rabanovitch, 1970). More specifically, speed and accuracy need to be combined to achieve an accurate measure of performance (Fitts, 1954). For the purpose of a modified hand performance test, speed and accuracy were combined for both Skill and Ability.

Skill Test.

Tracing with the preferred and non-preferred hands can demonstrate the extent to which one hand has acquired superior control as reflected in assessment tasks (e.g., Ayres, 1989; Steingruber, 1975). Similarly, several studies have employed timed dotting as a 'skilled' task to assess superior hand performance (e.g., Annett, 1992a; Carlier, Duyme, Capron, Dumont & Perez-Diaz, 1993; Steingrüber, 1975; Tapley & Bryden, 1985). While tracing requires continuous motor execution, dotting involves control of rapidly alternating stop-start movements and placing. Even though tracing and dotting require different types of motor prerequisites, the level of both tracing and dotting accuracy is closely related to the learnt task of drawing and writing (Annett, 1992a; Steingruber, 1975; Tapley & Bryden, 1985), and they are thus considered to be *trained, skilled* tasks.

Selecting tracing and dotting as two suitable Skill hand performance tasks, the Motor Accuracy (MAcc) test (Ayres, 1989) test and the Hand Dominance Test (HDT), a standardised handedness test for children (Steingrüber, 1975), were used as guidelines. The MAcc test was described in the first study (see Sections 2.2.2 to 2.2.4 in Chapter 2). The standardised version of the Hand Dominance Test (HDT) consists of three parts: (i) a maze-like angled path for tracing, (ii) a path of irregularly spaced circles, 0.5 cm in diameter for dotting, and (iii) rows of equally spaced adjacent squares, also for dotting (see Appendix 4C for the first two parts of the HDT). All three tasks have to be attempted at maximum speed and precision for 30 seconds. The distance of the traced

path is measured (but deviations from the path are not penalised), and the number of successfully dotted circles and squares are counted.

The following principles of the MAcc and HDT were used for developing the tracing and dotting tasks as subtests of the modified Skill Test:

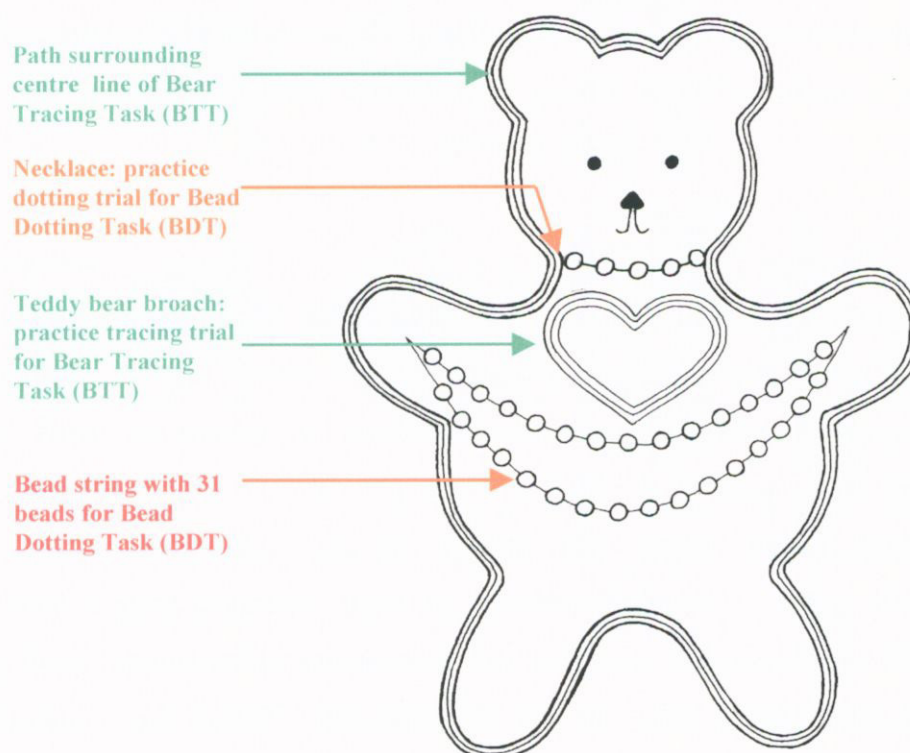
- continuous tracing along a heavy black line or a centre line, starting on the left and ending on the right (MAcc and HDT);
- starting at the top of the page (HDT), and not at the bottom like the MAcc;
- recording the time taken to complete tracing and dotting tasks to the nearest full second (MAcc);
- the child's choice of performing task first with the preferred and then with the non-preferred hand (MAcc and HDT);
- measuring the deviation from the heavy black line into the outside area bounded by short, medium and long dashed lines, whereby larger deviations receive greater penalty than smaller ones (MAcc);
- time was incorporated by using the MAcc calculation of multiplying the seconds by 0.2 and adding it onto the error score. The error score was then subtracted from a larger number (i.e., 200 for the MAcc) to obtain a positive score;
- the accurate and rapid placement of well-shaped dots in small circles, starting on one side and finishing on the other (HDT).

Based on these principles, the Bear Tracing Task (BTT) and the Bead Dotting Task (BDT) were constructed as subtests of the Skill Test, and they will be discussed separately.

Bear Tracing Task (BTT) Subtest. The BTT consisted of two parallel outlines of a bear (in accordance with the bear theme used in the Midline Crossing Test), forming a *path* 0.5 cm apart, including the path outlines (see Figure 4.2 with green text for BTT). However, there are several differences between the BTT and the MAcc/HDT. Firstly, unlike the A3-sized MAcc sheet which required initial midline crossing and adduction of the arm (and sometimes excessive postural adjustments, based on clinical observations), the BTT was A4-sized and secured with adhesive tape so that the inner vertical edge of the paper was in the child's midline. The starting point was at the top of the page and no midline crossing was required. Secondly, a rounded tracing path similar to the MAcc was thought to be more suitable than the angled paths of the HDT, (since the latter invites

discontinuous stop-start movement), allowing for more accurate assessment of smooth, graded tracing. In addition, the frequent changes of direction in the HDT were deemed more challenging as they require more refined adjustment than the MAcc. Incorporating a greater challenge might provide increased variability. The BTT was thus designed to consist of a more frequently curved path than the MAcc. Thirdly, a different scoring method, similar to the Developmental Test of Visual Perception (Frostig, 1993), was employed for the BTT, thus eliminating the need for a line measure for scoring.

Figure 4.2. Bear Tracing Task (BTT) and Bead Dotting Task (BDT) as Two Subtests of the Modified Skill Test



Note. This example size of the Bear Tracing Task (BTT) is reduced to approximately one third of its original A4 size.

Staying on the 0.5 cm path might be a challenge for 3- to 5-year old children, or older children with neuromotor deficits, whilst a thin centre line would be more appropriate for older or visuo-motorically more advanced children. A 0.1 cm *centre line* was constructed in the middle of the path, leaving 0.2 cm between either side of the centre line and the border of the path (see again Figure 4.2 and Appendix 4D). Accuracy within the 0.5 cm path is referred to as the *Simple Version*, and accuracy for maintaining the pen on the centre line comprised the *Advanced Version* of the BTT. A practice tracing trial preceded

the test item, requiring the child to trace the centre line within a 0.5 cm heart shaped path (or ‘broach’) on the bear’s chest (see again Figure 4.2).

Bead Dotting Task (BDT) Subtest. The second subtest of the Skill Test consisted of a dotting task that was modified from the HDT, with the following differences. Instead of 75 circles, the bear of the BTT holds a string of only 31 ‘beads’, since younger children are unlikely to have the concentration span and physical endurance to effectively dot larger numbers of circles (see Figure 4.2 with orange text for BDT). In addition, the beads were spaced evenly at 0.4 cm to allow for a performance rhythm to develop. A practice dotting trial of 5 beads around the bear’s neck was used prior to the dotting task. Finally, the scoring method included evaluating the quality of dot formation, which was not included in the HDT (see Section 4.2.5.2 for more detail).

Ability Test.

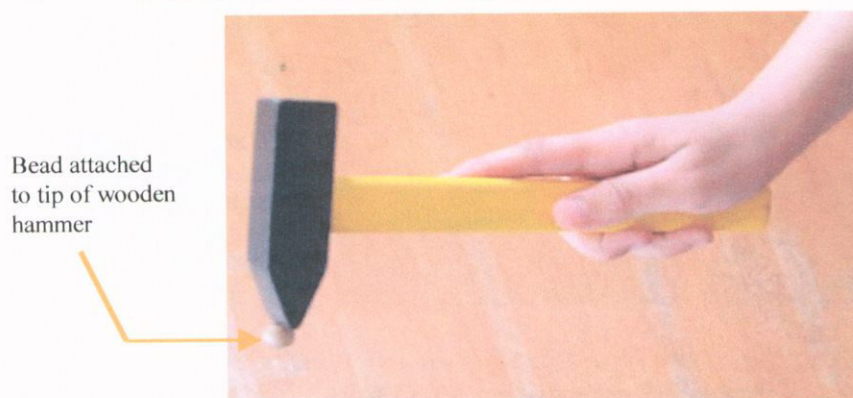
Tapping as a motor performance task is used most frequently in research to distinguish manual asymmetry in rapid repetitive upper extremity movements (McManus, Kemp & Grant, 1986). Numerous studies have shown that the preferred hand taps faster compared to the non-preferred hand (e.g., Peters, 1978, 1990; Peters & Durdin, 1979; Watter & Burns, 1995). However, stipulations for tapping differ across studies, with some employing hand tapping controlled from the shoulder girdle (e.g., Peters, 1990) and others using finger tapping with stabilisation of the wrist (e.g., Watts & Burns, 1995). No specific information was available that compared the two forms of tapping to assess if distally controlled tapping was indeed similar to proximally controlled tapping/hammering. For this reason, both *hammering* (as a form of hand tapping) and *tapping* (as a form of finger tapping) were included as subtests to the Ability Test.

Hammering Subtest. Test administration and scoring were based on test procedures used by Knickerbocker (1980), who proposed a ‘Timed Hammering Sample’ to observe the
 “presence or absence of established hand dominance” (p.201).

For Knickerbocker’s test, a piece of carbon paper is stapled face down between two sheets of paper and secured to the table. The top paper features a circle 4 inches in diameter, and the child is presented with a wooden hammer in the midline. The child is then requested to hit as fast and hard as possible when the stopwatch is activated. The number of hammer blows in 15 seconds (or 20 or 30 seconds, depending on the child’s

age and abilities) is recorded. The two hands are compared on the frequency of hammering blows and the quality of the hammering executions (e.g., wild uncontrolled movement, poor visual attention). Knickerbocker's Timed Hammering Sample was modified in the following manner for the Ability Test. A small 0.5 cm bead was attached to a wooden toy hammer to provide a clear point of contact without being too sharp, thereby enabling precise response strikes whilst avoiding tears in the paper (see Figure 4.3 for the adapted hammer).

Figure 4.3. Photograph of Adapted Wooden Hammer with Bead for Hammering Subtest

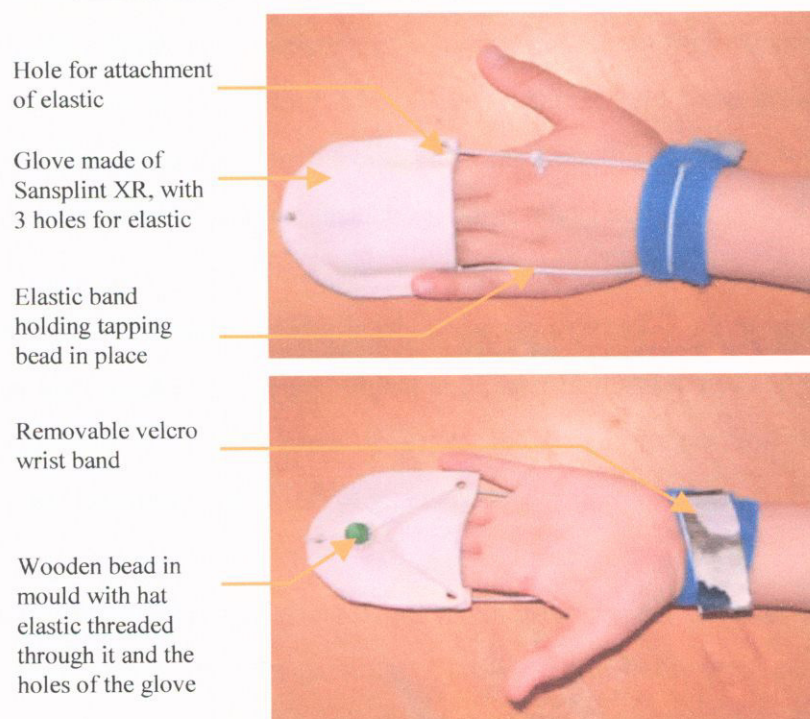


The top and bottom pages contained two adjacent 8 cm diameter circles for the left and right hands for easy comparison. Each of the two circles of the top page, hereon referred to as the *cover sheet*, also displayed a round shaded centre, 0.6 cm in diameter, to facilitate accurate placement of the hammering (see Appendix 4E for hammering and tapping response and cover sheets).

Tapping Subtest. Using the same principles of Knickerbocker (1980) for tapping, a glove-like sleeve fitting over the child's three middle fingers was constructed of Sansplint XR splinting material². A 0.5 cm wooden bead was attached to the ventral side at the level of the distal phalynx of the middle finger, by constructing a little mould with Sansplint in the centre of the ventral glove. The bead was placed in the mould, threaded with hat elastic and held in place by attaching it to the three holes on the periphery of the glove and to the a wrist band with Velcro fastening (see Figure 4.4 for a photograph of adapted tapping glove). The A4 response and cover sheets used for the tapping subtest were identical to those of the hammering subtest (see again Appendix 4E).

² Smith and Nephew Rehab, Centre Court Business Park, 25-27 Paul Street, North Ryde, NSW, Australia.

Figure 4.4. Photograph of Adapted Tapping Glove for Tapping Subtest



4.2.4 Test Administration Procedures

All tests were administered by the researcher.

4.2.4.1 Functional Hand Preference Test (FHPT)

Prior to the assessment the parents were asked to inform the child that some teddy bear games would be played rather than hand preference assessed. In addition, no discussion of left or right handedness took place in front of the child. In this way it was hoped to reduce possible distortions of spontaneous hand use which might occur if a child consciously used one particular hand for whatever reason (e.g., having been taught that using the right hand is correct and desirable).

The child sat opposite the examiner with feet well supported, a table height of 5 cm above elbow level. The examiner randomly presented one item at a time in the child's midline, such as a toothbrush, saying "Show me how you would use this", or "What would you do with this?" When the child had finished demonstrating the use of the object, the examiner used it herself, mirroring the child's performing hand to prevent

imitation that could obscure the natural hand preference for the task. The examiner usually used the items incorrectly (e.g., holding the toothbrush upside down while brushing teeth) before re-presenting it in midline, asking, “Do I use it like this?”, or “Is this correct?”. This procedure was introduced to increase the child’s motivation to repeat the performance of rather mundane tasks by incorporating humour.

During those items containing multiple objects such as bead stacking and peg insertion, the child was instructed to move one object at a time. In these items, the number of trials was increased from 4 to 8 in order to allow for greater opportunity to demonstrate spontaneous and consistent hand use (e.g., stacking 8 beads).

The examiner recorded the responses of all items immediately onto the score sheet, and the hand used first was noted for each item. The different items were presented in quick succession, and items not in use were stored out of the child’s sight. Administration of the FHPT took approximately 25 minutes, depending on the child’s cooperation.

4.2.4.2 Hand Performance: Skill Test

Bear Tracing Task (BTT).

The child was asked to trace a picture of a bear (i.e., the BTT) for each of the two bear families (i.e., the red-green family and the yellow-blue family) as a ‘farewell gift’, using a red felt-tipped pen with first one and then the other hand. The child’s choice of hand used to pick up the pen in the midline was recorded as the ‘first hand’. The child was then asked to trace the small heart shaped ‘broach’ as a practice trial, tracing to the right with the right hand and to the left with the left hand. Clear instructions were given for the child to stay on the centre line without lifting the pen during the tracing task. Children deviating from the centre line were encouraged to rejoin it without lifting the pen. Using a stopwatch, the time to complete the tracing task was recorded to the nearest second. Once the BTT was completed, the child proceeded with the Bead Dotting Task (BDT) using the same hand.

Bead Dotting Task (BDT).

The examiner demonstrated making a dot (or a ‘tiny diamond’) by pressing briefly with the tip of the red felt-tipped pen into the centre of the first practice bead. The child

completed the four remaining practice beads untimed. The direction for the first row of the dotting task was the same as that for the tracing task (i.e., to the right with the right hand and to the left with the left hand), immediately followed by dotting in the opposite direction for the second row. The first bead was placed in line with the child's body midline to eliminate the need for midline crossing. If a dot was not placed inside a bead, the child was encouraged to continue with the next bead without re-dotting the previous bead. The stopwatch was started on the second bead, timing the child's dotting

The administration of the BTT and the BDT together took approximately 8 to 10 minutes.

4.2.4.3 Hand Performance: Ability Test

As the Ability tasks were short and novel, it was deemed unlikely that boredom and lack of motivation would affect performance, and the tasks were thus presented without a storyline. However, in accordance with the central teddy bear theme of the test battery, the teddy bears were placed at the sides to "watch the competition".

Hammering.

A brief demonstration was given by the assessor, taking care to perform even, fast movements, avoid distal support at the elbow or lower arm, and produce little force. The child was then encouraged to perform a few blows on the table for a practice trial. It was also stressed that the child should continue hammering as fast as possible until told to stop. After the practice trial the child was asked to hammer at top speed onto the shaded centre on the hammering response sheet for 15 seconds, producing *response strikes*. The activity was then repeated with the other hand.

Tapping.

After attaching the tapping glove to the hand volunteered by the child, the assessor demonstrated tapping, using her own hand for rapid alternating wrist extension and flexion with extended fingers. The child was asked to imitate the tapping motion by resting the ventral side of the wrist on the table while maintaining the hand in extension. Since arm-hand differentiation is likely to be difficult for young or children with deficiencies, the researcher stabilised the dorsal wrist. The remaining procedures were the

same as those for hammering. The administration of both hammering and tapping took approximately 8 minutes.

When administered in one session, the modified Handedness Profile Test Battery took approximately 60 minutes, and the initial tests about 30 minutes. The following order of test administration was used for all children: Space Visualisation Contralateral Use measure, Functional Hand Preference Test, Midline Crossing Test (Part 1), Bimanual Coordination Test, Midline Crossing Test (Part 2), Skill Test, Bilateral Motor Coordination, and Ability Test. A short break was taken if the child showed signs of fatigue or lapses in concentration.

4.2.5 Scoring Procedures

4.2.5.1 Functional Hand Preference Test (FHPT)

For the Functional Hand Preference (FHP) tasks, all responses were recorded as left or right on the FHP score sheet. Swaps and the use of both hands simultaneously were noted in writing. If all responses were performed with one hand, 4 points were given for that hand. If one hand was used three times and the other hand once, or if the ratio was roughly three quarters to one quarter when there were more than four responses, a score of 3:1 was given to each hand respectively. A score of 2 was given to each hand if both hands were used equally. In each of the four categories, one additional point was given to the hand that initiated the tasks most often (i.e., at least 4 out of the 6 items were started with this hand). If both hands initiated 3 tasks, half a point was given to each hand for that category.

Four trials of six items amounted to a total of 24 points in each category, plus one point for first hand use, bringing the subtotals to 25 points. Thus the overall maximum raw score for all four categories was 100 points. From the total raw score a FHP laterality quotient (LQ) was computed:

$$\text{FHP LQ} = \frac{\text{Right hand responses} - \text{Left hand responses}}{100 \text{ (Total possible FHP responses)}} \times 100$$

In addition, individual use percentages (i.e., R/R+L and L/R+L) were also calculated for each single category, for example:

$$\text{Left hand percentage for untrained FHP} = \frac{\text{Left untrained FHP responses}}{50 (\text{Total untrained FHP responses})} \times 100$$

Finally, a within-tasks consistency measure, hereon referred to as *Consistency*, was a performance measure based on the 24 different FHP items, regardless of which hand was used. Unlike the EHI consistency measure which was based on scores of 2, 1 or 0, Consistency of the FHP was more stringent, and only items that were performed with *one* hand were recorded as consistent. Conversely, the number of items that demonstrated both left and right hand use was totalled under 'ambiguity' (see Appendix 4I [Part ii] for an example of the FHP calculation). Consistency was calculated as follows:

$$\text{Consistency} = \frac{24 (\text{total FHP items}) - \text{Ambiguity}}{24 (\text{total FHP items})} \times 100$$

Across-task consistency, as defined by Peters (1996), is reflective in the FHP laterality quotient.

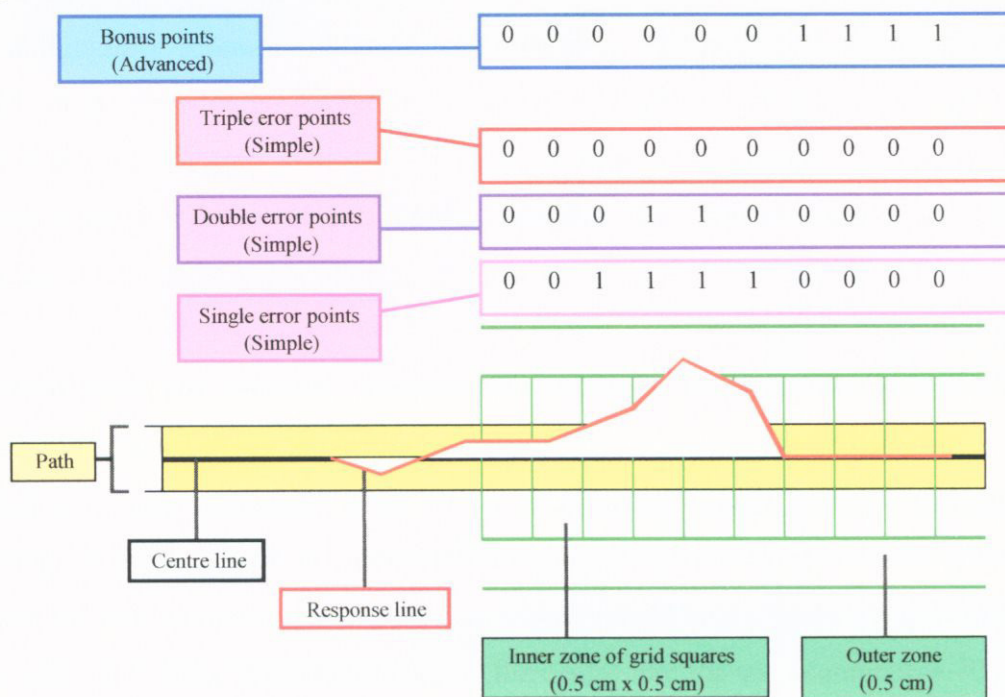
4.2.5.2 Skill Test

The time taken to complete the two subtests, tracing and dotting, was incorporated into the BTT and BDT error score respectively, similar to the scoring procedures used for the MAcc (Southern California Sensory Integration Tests [SCSIT]). The time taken to complete the BTT and the BDT was recorded in full seconds and multiplied by 0.2, based on the principle of the MAcc (SCSIT) calculations, rounded off to the nearest decimal and added to each of the error scores, as outlined below.

Bear Tracing Task (BTT).

The BTT marking guide consisted of the same bear design used for the response sheet. Two rows of 0.5 cm width were constructed around the bear on both the inside and the outside of the path, but only the more proximal rows contained 180 *grid squares* (see Appendix 4F). The BTT marking guide was designed with strong black lines that could be seen through a standard A4 paper. The marking guide was placed beneath the response sheet and aligned with it to facilitate marking of response line deviations extending beyond the path borders of the bear (see Figure 4.5 for an illustration of path, centre and response lines with scoring procedures). Two types of error scores were calculated for the BTT, the *simple error score* and the *advanced error score*, related to the simple and advanced versions discussed earlier.

Figure 4.5. Illustration of Path, Centre, Response Lines and Scoring Procedures



A *simple error type* consisted of any section of the response line extending beyond the path (i.e., bordered by the two lines around the centre line). Even small deviations less than 0.5 cm long were counted as an error for each grid square. Simple error types were penalised with a single, double or triple error point, depending on how far the response line extended into the inner zone grid row, the outer zone or beyond. If the response line deviated into the row of grid squares, a single error point was awarded. If the deviation extended past the grid row into the outer zone, a double error point was allocated, and in cases where the deviations extended beyond the second row, a triple error point was recorded. If a child was able to stay within the path boundaries throughout the BTT, the simple error score would be 0. Furthermore, two errors for each discontinuation (i.e., pen lifts), and a time penalty (i.e., number of seconds x 0.2) were added to the simple error score. The simple error score thus consisted of single, double and triple error points, discontinuation penalties, and time penalty fraction up to a maximum of 250 errors (see Appendix 4D and 4I [Part iii and iv] for examples).

Although it is theoretically possible to obtain a simple error score of 560 (i.e., triple error x 180) or more, if other penalties are added, this would require exact tracing of the outlines of the BTT three zones from the centre line. Such a response was deemed unlikely. Calculating a performance measure in relation to an unrealistically high

maximum error score would skew the overall result. Thus, to assess the maximum possible simple error score, a pilot study of 50 children with aged 4, 5 and 6 years was conducted. Employing the above scoring method, the highest error score obtained was 219. Based on this finding it was decided to take 230 as the maximum error score and add a time penalty fraction for just under 2 minutes (i.e., 100 seconds x 0.2 = 20), resulting in a total simple error score of 250.

An *advanced error type* consisted of any section where the response line does cover the centre line. It appeared easier to calculate the advanced error score by initially recording the number units (i.e., according to the 0.5 cm grid squares) where response and centre lines overlap as *bonus points*. If a child failed to remain on the centre line for sections longer than 0.5 cm, no bonus points were accumulated and the advanced error score was 180 (i.e., 180 – 0 = 180). If a child stayed on the centre line for an accumulative 40 grid squares or bonus points, the advanced error score would be 140 (i.e., 180 - 40 = 140). The same time penalty was also added to the advanced error score (i.e., number of seconds x 0.2). The maximum advanced error score was 200 (i.e., 180 possible errors plus 20 errors for time penalty).

The error scores (ES) of both the simple and the advanced versions (ES) were converted to *raw scores* in percentages, and the total BTT raw score consisted of an average of the simple and advanced raw scores (i.e., summed and divided by 2), using the following calculations for the left and right hands separately:

$$\text{BTT Raw Score} = \left\{ \frac{250 - \text{BTT simple ES}}{2.5 * (\text{Maximum simple ES})} \right\} + \left\{ \frac{200 - \text{BTT advanced ES}}{2 * (\text{Maximum advanced ES})} \right\} / 2$$

* = maximum error score (ES) has been divided by 100 to obtain a percentage.

Bead Dotting Task (BDT).

The BDT error score consisted of two types errors: the *placing errors* (i.e., when the dot has been placed outside the bead), and *dotting errors* (i.e., when dot formation was incorrect – see Appendix 4G for samples of dotting errors). The placing errors showing the most severe form of inaccuracy were awarded three penalty points each, and the dotting errors incurred one or two penalty points, depending on the quality. If a dot resembled a line between 0.1 cm and 0.2 cm, a *single dotting error* point was given. Dots that were ‘misformed’ and either exceeded 0.2 cm in length, or involved changes in direction such as scribbles but were still located inside a bead, were counted as *double dotting errors*. This scoring method differentiated between dot formations that were

generated with fair control as opposed to those with poor control. In addition to the placing and dotting errors, a time penalty was added (number of seconds x 0.2). The total error score of the BDT thus consisted of placing errors, single and double dotting errors and a penalty time fraction.

The maximum possible error score of 90 for dotting was computed (i.e., 30 dots x 3 maximum errors). The BDT was also trialed on 50 children with sensory-motor deficits aged 4 to 6 years. It was found that those children with poor placing control insisted on re-dotting the missed beads, thus taking up more time than would have been the case with dotting 30 beads. The time fraction was thus not added to the maximum BDT error score, since this might obscure the results. To obtain a BDT raw score in percentage from the BDT error score (ES), the following calculation was performed for the left and right hands separately:

$$\text{BDT Raw Score} = \frac{90 - \text{BDT ES}}{90 (\text{Maximum BDT ES})} \times 100$$

Each error type was marked on the BTT/BDT response sheet with a particular symbol to facilitate scoring (see Table 4.2 for symbols use, and again Appendices 4D and 4I [Part iii and iv] for examples).

Table 4.2. Symbols Used for Scoring Bear Tracing Task (BTT) and Bead Dotting Task (BDT) Skill Subtests

<i>Simple BTT Version</i>	
	= single 0.5 cm BTT error (deviation between 0.1 cm and 0.5 cm from centre line)
	= double 0.5 cm BTT error (deviation between 1.0 cm and 1.5 cm from centre line)
	= triple 0.5 cm BTT error (deviation beyond 1.5 cm from centre line)
O	= discontinuation of tracing line (counts as double error)
<i>Advanced BTT Version</i>	
Ψ	= bonus point for each 0.5 cm the response line is drawn on top of the centre line (total bonus points get subtracted from 180 to obtain an error score)
<i>BDT Subtest</i>	
×	= single error for dotting
*	= double error for dotting
∇	= placing error in dotting

Skill raw score.

The overall Skill Test raw score (RS) was obtained by adding the BTT raw score (consisting of simple and advanced error scores) and the BDT raw score. The sum was divided by two for the left and right hands separately. The Skill interhand difference (IHD) was calculated as follows:

$$\text{Skill IHD} = \text{Right Skill RS} - \text{Left Skill RS}$$

To obtain the performance level (PL), the best Skill performance of the two hands was selected, regardless of which hand was better (i.e., no negative signs were given if the left hand showed superior performance). (See again Appendix 4I [Part iii & viii].)

4.2.5.3 Ability Test

Hammering.

The number of hammering blows performed in 15 seconds were counted and recorded. The spread of response strikes produced on the carbon copy by the hammering blows was overlaid with a transparency featuring concentric circles with diameters of 1 cm, 2 cm, 3 cm and 4 cm around the shaded centre (see Appendix 4E for a diagram of the concentric circle guide transparency). Each response strikes falling into the centre scored 4 points, between the first and second circles 3 points, between the second and third circles 2 points, and between the third and fourth circles 1 point. Response strikes falling outside the fourth circle did not receive a score. Since the possible maximum number of blows was approximately 70 within 15 seconds and 4 was the maximum points awarded for one response strike, the maximum possible score achieved was 280 (70 x 4). To obtain a raw score for hammering, the following calculation was made:

$$\text{Hammering Raw Score} = \frac{\text{Number of points awarded}}{280 \text{ (Maximum possible points)}} \times 100$$

Tapping.

The scoring and calculation procedures for tapping were identical to that of hammering.

Ability raw score.

The hammering and tapping raw scores were added and divided by two to obtain an average between the two, constituting the Ability raw score. The calculations of Ability interhand differences (IHD) and Ability performance levels (PL) were identical to those described under Skill raw scores. All error scores of the modified handedness measures were converted to raw scores using the above methods (see Appendix 3J).

4.2.6 Data Analysis

Mann-Whitney U test was conducted for gender on the entire sample because of unequal numbers of boys and girls. One-way ANOVA ($p = 0.01$) was then employed for left and right handers on the modified tests to detect significant differences between them, and left and right handers were subsequently treated separately throughout the analysis. The extent of hand use was not explored in the individual tests as in Studies I and II (e.g., MCT left and right handed responses), but comparisons between the presenting left and right handers were made. As mentioned previously, although a necessary step, establishing test validity, test-retest and interrater reliability for the modified tests is beyond the scope of this thesis. The remaining data analysis consisted of two parts for each measure.

Part 1: Comparing initial and modified tests within the same sample

- a) Descriptive analysis including frequency distributions were performed to compare initial and modified tests, on the extent of skewness, kurtosis and 95% confidence interval or range. Frequency distributions were performed on all initial and modified tests to determine normality of distributions for males and females, and left and right handers across age groups. Those distributions found to be significantly abnormal with the Lilliefors Significance Correction, were analysed using non-parametric tests.
- b) Between-group comparisons (i.e., between the initial and modified tests) were performed on left and right handers separately, using paired t-tests if the distributions were normal. The nonparametric Wilcoxon matched-pairs signed ranks test was employed in cases where the data was not normally distributed (i.e., excessive skewing or kurtosis). This allowed for the observation of significant differences between the initial and modified tests.

Part 2: Exploring modified subtests

The subtests of the modified handedness measures were compared (e.g., proximal versus distal contralateral reaching) and examined in relation to one another for significant differences, using paired t-tests if the distributions were normal. The Wilcoxon test was employed in cases where the data was not normally distributed. Any other aspect peculiar to any of the subtests was discussed.

4.3 Results

One-way ANOVA revealed that left handed children that were a few months older or younger than the 5- to 6-year olds did not perform significantly differently on any of the IHD or PL measures at $p = 0.01$ level (see Appendix 4H for F and p values). All left handed children were thus retained in the forthcoming analyses. Pearson's Chi-Square, indicated no significant gender differences for the entire sample (2.385, $p = 0.123$). When a Mann-Whitney U test was employed for gender in individual handedness measures, no significant differences were found in the initial or the modified tests. Table 4.3 provides a summary, indicating in brackets gender differences approaching significance found in Study II.

Table 4.3. Summary of Mann-Whitney U test for Gender Differences on the Modified and Initial Handedness Tests

<i>Modified Handedness Measure</i>	<i>Modified test: Significance (p)</i>	<i>Initial Handedness Measures</i>	<i>Initial test Significance (p)</i>
Functional Hand Preference	0.189	EHI	0.064 (II: 0.029)
Consistency	0.355	Consistency	0.134 (II: 0.015)
Ability IHD	0.165	N/A	-
Ability PL	0.230	N/A	-
Skill IHD	0.251	MAcc IHD	0.682
Skill PL	0.156	MAcc PL	0.546
Midline Crossing Quotient	0.247 (II: 0.011)	SVCU	0.719
Bimanual Coordination IHD	0.203	N/A	-
Bimanual Coordination PL	0.795	BMC PL	0.324 (II: 0.016)

Note. $p = 0.01$; IHD = interhand differences; PL = performance levels; EHI = Edinburgh Handedness Inventory; SVCU = Space Visualisation Contralateral Use; II = Study II in Chapter 3.

Left and right handers were examined for significant differences in the modified tests using one-way ANOVA ($p = 0.05$ and 0.01), and the results are summarised in Table 4.4. For this particular analysis, the values of left handers were first re-coded into absolute values so that the negative sign no longer denoted left handedness, since this could distort results. Instead, all responses that were *incongruous* with the stipulated handedness (e.g., a left hander performing better with the right hand) were marked with a negative sign, regardless of left or right handedness.

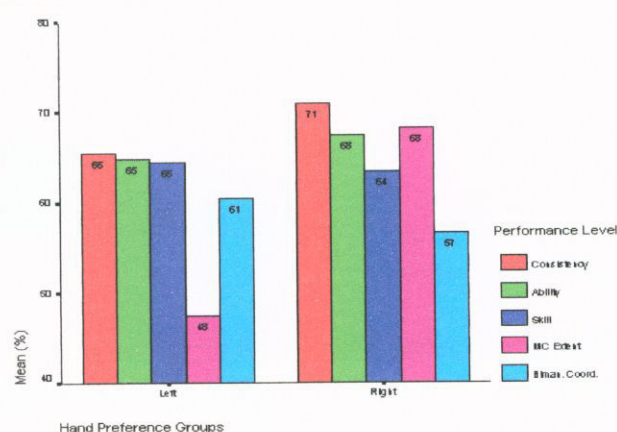
Table 4.4. One-Way ANOVA to Detect Differences Between Left and Right Handers on the Modified Tests

<i>Handedness Measure</i>	<i>F-Ratio</i>	<i>Significance level</i>
Functional Hand Preference	13.54	0.001**
Untrained tasks	4.44	0.039*
Trained tasks	16.66	0.000**
Consistency	4.53	0.037*
Ability IHD	5.77	0.020*
Ability PL	0.04	0.836
Skill IHD	8.99	0.004**
Skill PL	0.15	0.705
Midline Crossing Quotient	4.50	0.038*
Midline Crossing Extent	2.14	0.149
Bimanual Coordination IHD	7.70	0.009**
Bimanual Coordination PL	2.11	0.155

Note. * = significant at 0.05; ** = significant at 0.01; IHD = interhand difference; PL = performance level.

Results show that all interhand difference (IHD) measures revealed significant differences between left and right handers, whilst the performance level (PL) measures did not. The significant difference between left and right handers in all IHD measures ($p = 0.05$), reflective of the magnitude of performance difference between the hands, supports the analysis of left and right handers as separate groups. Figure 4.6 compares left and right handers on the performance levels (PL) in all five handedness measures (see again Table 4.4 for detail).

Figure 4.6. Comparing Performance Levels (PL) in Left and Right Handers on All Handedness Measures



Although right handers demonstrated higher means, particularly in MCE and to a lesser extent Consistency, and left handers exhibited a higher mean in BCT and Skill, the

differences in variance were not significant. The remaining analysis will focus primarily on IHD comparisons between left and right handers in the initial and modified tests.

4.3.1 Hand Preference Tests

4.3.1.1 Comparing Initial and Modified Hand Preference Tests

Figure 4.7 and Table 4.5 illustrate the distributions of left and right handers using the initial Edinburgh Handedness Inventory (EHI) and the modified Functional Hand Preference Test (FHPT).

Figure 4.7. Hand Preference Distributions in Left and Right Handers Using the Edinburgh Handedness Inventory (EHI) and the Functional Hand Preference Test (FHPT) Measures

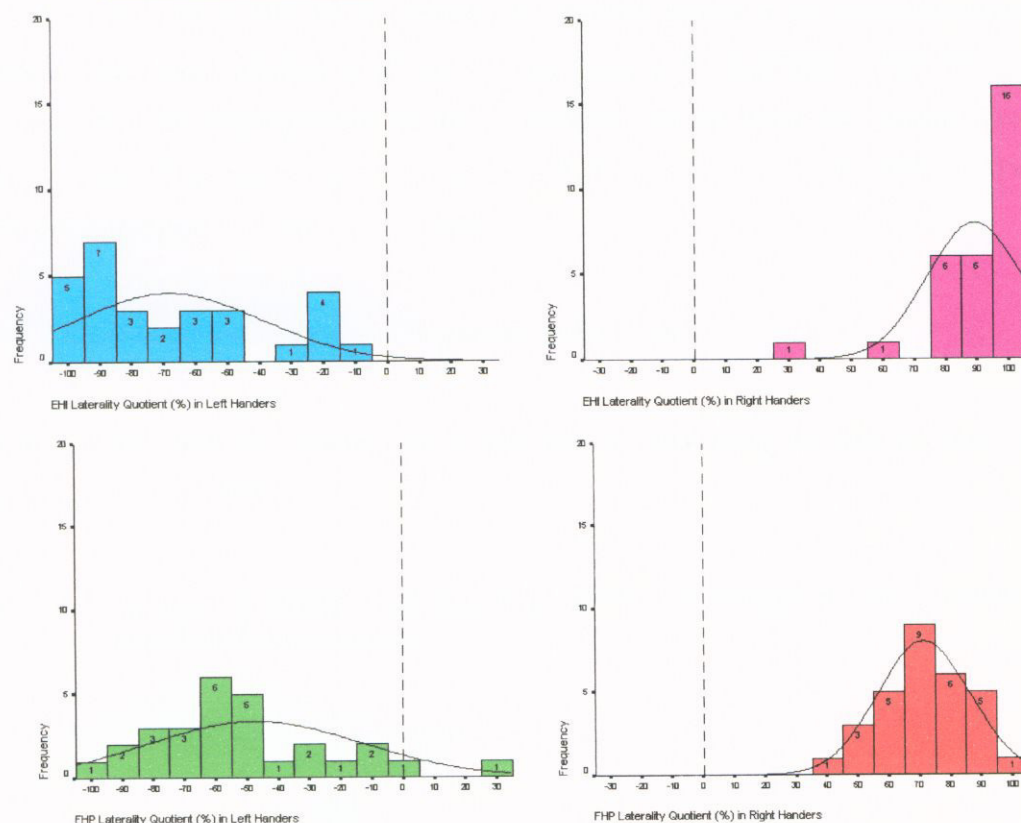


Table 4.5. Descriptive Information on Edinburgh Handedness Inventory (EHI) and Functional Hand Preference (FHP) Distributions in Left and Right Handers

	<i>Left EHI</i>	<i>Left FHP</i>	<i>Right EHI</i>	<i>Right FHP</i>
<i>Mean</i>	-67.35	-45.62	89.03	70.35
<i>SD</i>	28.53	34.07	14.80	15.51
<i>Skewness</i>	0.54	0.90	-2.42	-0.17
<i>Kurtosis</i>	0.42	0.86	7.79	-0.59

Left Handers.

The EHI demonstrated a higher mean (-67.35 ± 28.53) than the FHP (-45.62 ± 34.07). The FHP distribution was influenced by two left handers with positive LQ scores, indicating more frequent use of right than left hand during functional task performance (FHP LQ = +48% and +30% respectively), while the EHI reflected only left handed use (-80% and -10% respectively).

Right Handers.

Again the EHI demonstrated a higher mean (89.03 ± 14.80) than the FHP (70.35 ± 15.51), and a slightly wider spread. However, the EHI was negatively skewed (-2.42) and showed a strong positive kurtosis (7.79), whereas the FHP was not skewed and demonstrated only minimal negative kurtosis, thus displaying a more normal distribution.

Both the initial and modified tests showed a much wider spread in left handers than right handers. The overall distribution of the EHI was found to be abnormal, so the Wilcoxon nonparametric test was employed for the comparison between initial and modified tests. However, the Wilcoxon revealed that differences in means between the EHI and FHP were not significant ($z = -0.025$, $p = 0.980$).

4.3.1.2 Exploring Functional Hand Preference (FHP) Tasks

Figure 4.8 and Table 4.6 compare the distribution of Consistency between left and right handers, using the FHPT.

Figure 4.8. Comparison Between Left and Right Handers on Functional Hand Preference Test (FHPT) Consistency

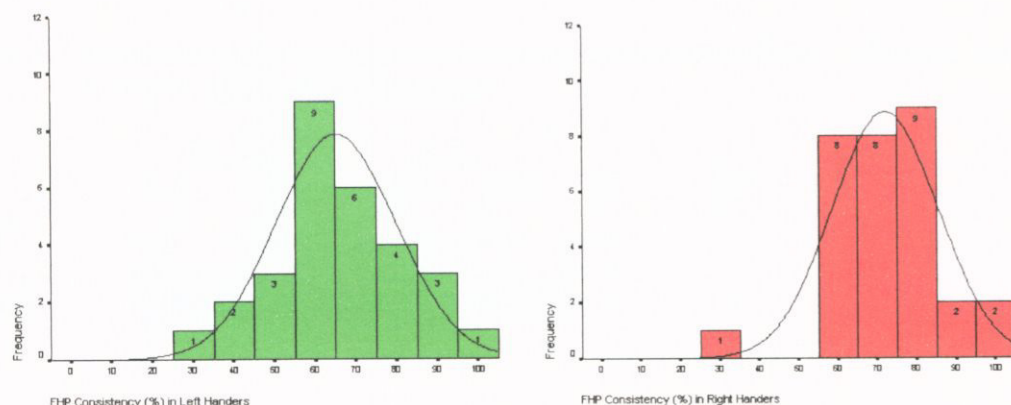


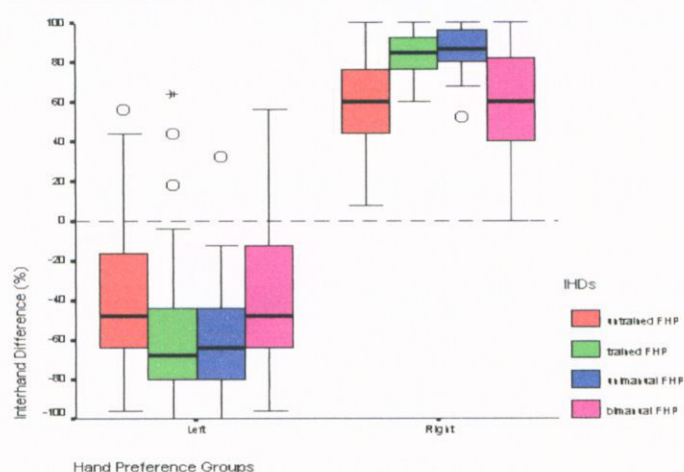
Table 4.6. Descriptive Information on Consistency Distribution in Left and Right Handers Using the Functional Hand Preference Test (FHPT)

	<i>Left</i>	<i>Right</i>		<i>Left</i>	<i>Right</i>
<i>Mean</i>	63.87	71.65	<i>Skewness</i>	-0.07	-0.28
<i>SD</i>	15.32	13.38	<i>Kurtosis</i>	-0.03	1.23

The left handed distribution of FHP scores was normal with a slightly lower mean (63.87 ± 15.32) than the right handers (71.65 ± 13.38). The right handed distribution was positively kurtosed, with more right handers clustering around the mean than left handers, indicating greater consistency in right handers.

The distributions of the four subtests of the modified FHP test, trained, untrained, unimanual and bimanual tasks are compared in left and right handers (see Figure 4.9 and Table 4.7).

Figure 4.9. Comparing Interhand Difference (IHD) Distributions in Left and Right Handers on the Four Functional Hand Preference (FHP) Subtests



Note. The horizontal line inside the boxes denotes the median; o = outlier; * = extreme value.

Table 4.7. Descriptive Information on Distributions of Functional Hand Preference (FHP) Subtests in Left and Right Handers

	<i>Untrained</i>		<i>Trained</i>		<i>Unimanual</i>		<i>Bimanual</i>	
	<i>Left</i>	<i>Right</i>	<i>Left</i>	<i>Right</i>	<i>Left</i>	<i>Right</i>	<i>Left</i>	<i>Right</i>
<i>Mean</i>	-33.8	56.0	-54.6	84.2	-55.5	85.4	-36.68	56.77
<i>SD</i>	44.0	25.4	40.7	11.2	30.5	11.4	37.81	26.32
<i>Skewness</i>	0.50	-0.68	1.40	-0.57	0.74	-0.87	0.42	-0.32
<i>Kurtosis</i>	-0.64	0.33	1.87	-0.43	0.62	0.95	0.29	-0.73

It is apparent from Figure 4.8 that left handers demonstrated greater variability and a lower mean in all four FHP categories compared to right handers. In addition, both left and right handers demonstrated greater variability and lower means for interhand differences in hand preference in untrained and bimanual tasks than trained and unimanual tasks. Interestingly, the only abnormal distribution was that of the left handers in trained tasks which was positively skewed (1.40) and kurtosed (1.87). The Wilcoxon test revealed no significant IHD differences between trained and untrained tasks in the entire sample ($z = -1.401, p = 0.159$), nor between bimanual and unimanual tasks ($z = -1.068, p = 0.285$).

Pearson's correlation disclosed significant correlations between all IHD measures. The correlations between untrained and bimanual subtests were the strongest in both left and right handers (left handers: $r = 0.697, p = 0.000$; right handers: $r = 0.850, p = 0.000$), whereas the Pearson's correlation between the other FHP subtests ranged between $r = 0.374$ ($p = 0.046$) and 0.496 ($p = 0.000$). This indicates a considerable overlap between the bimanual and untrained tasks in particular.

4.3.2 Hand Performance Tests

4.3.2.1 Comparing Initial and Modified Hand Performance Tests

Figure 4.10 and Table 4.8 compare the IHD distributions of left and right handers on the initial Motor Accuracy (MAcc) test and the modified Skill Test.

The overall IHD distributions of MAcc and Skill were normal. The left handed and right handed IHD distributions of the MAcc were similar, with less difference between the hands demonstrated in left handers compared to right handers. The Skill Test showed a wider spread of responses, with only two left handers exhibiting minimal IHD values and the right handed Skill distribution revealing a wider spread and variability with a positive kurtosis. Scores indicated some very large IHD values, and in one case, a superior left hand performance. However, paired t-tests disclosed no significant difference in IHD means between the initial and the modified test ($t = -0.470, p = 0.643$).

Figure 4.10. Comparing Interhand Difference (IHD) Distributions in Left and Right Handers on Initial and Modified Hand Performance Tests

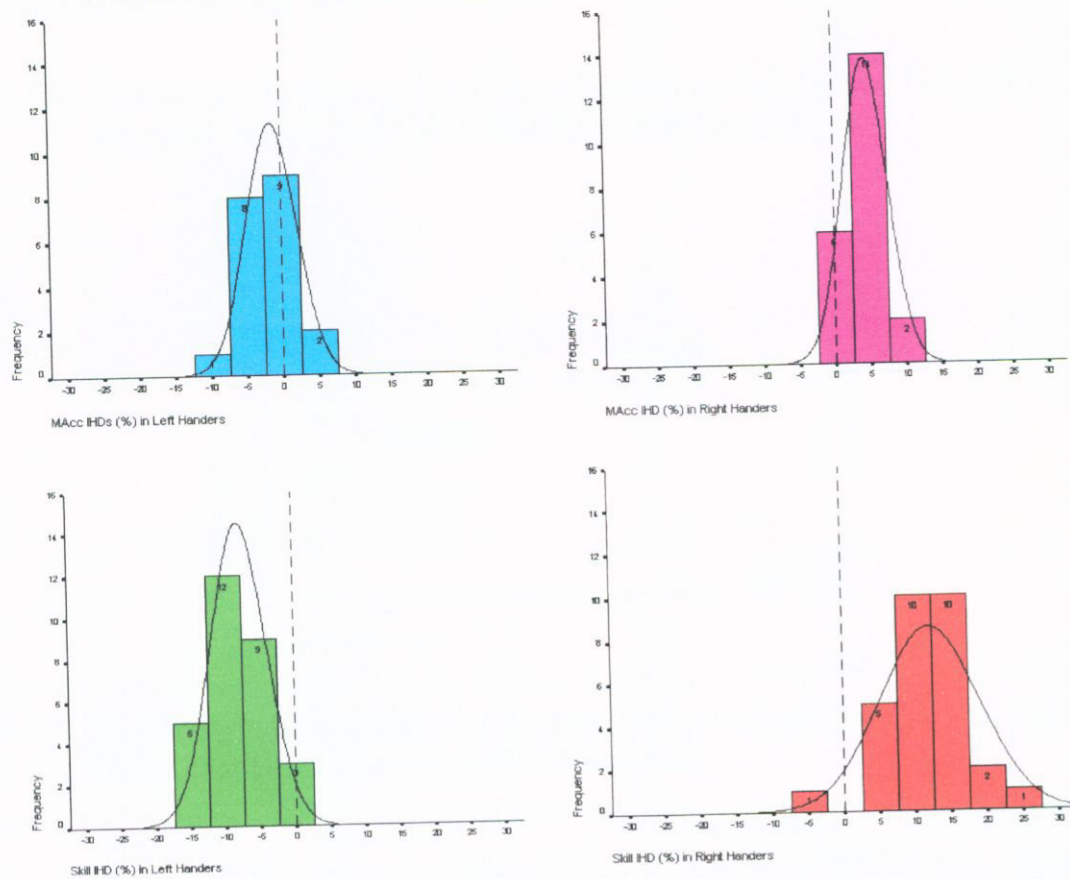


Table 4.8. Descriptive Information on Motor Accuracy (MAcc) and Skill Distributions in Left and Right Handers

	<i>Left MAcc</i>	<i>Left Skill</i>	<i>Right MAcc</i>	<i>Right Skill</i>
<i>Mean</i>	-1.43	-8.09	4.15	11.31
<i>SD</i>	3.37	3.94	3.20	5.48
<i>Skewness</i>	0.33	0.13	0.36	0.84
<i>Kurtosis</i>	0.48	-0.55	0.03	3.28

Distributions of performance levels (PL) were normal in both MAcc and Skill. The MAcc exhibited slightly higher means (left = 69.27 ± 4.45 ; right = 69.67 ± 2.83) than the Skill distribution (left = 64.61 ± 6.46 ; right = 64.04 ± 4.86). However, in contrast to both MAcc and Skill IHD values, paired t-tests detected significant differences in PL between the two tests ($t = 7.886, p = 0.000$).

4.3.2.2 Exploring Modified Hand Performance Tests, Ability and Skill

The Wilcoxon revealed significant differences between Ability and Skill PL values ($z = -2.072, p = 0.038$), but not in IHD values ($z = -0.685, p = 0.494$). Figure 4.11 and

Table 4.9 compare the two subtests of the modified Skill Test, the Bear Tracing Task (BTT) and the Bead Dotting Task (BDT).

Figure 4.11. Comparison Between Left and Right Handers in Bear Tracing Task (BTT) and Bead Dotting Task (BDT) Interhand Differences (IHD)

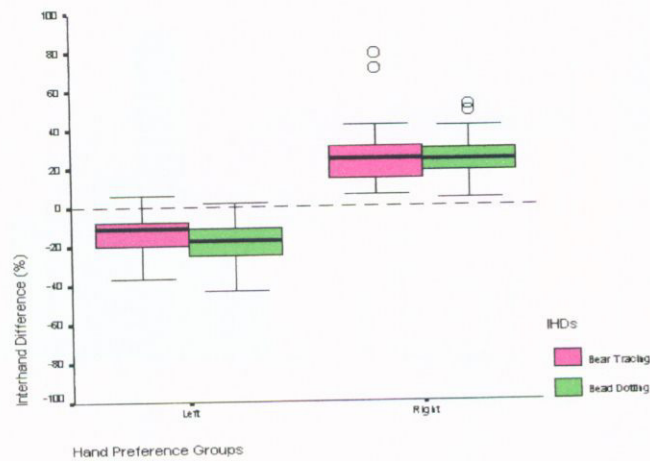


Table 4.9. Descriptive Information on Bear Tracing Task (BTT) and Bead Dotting Task (BDT) Interhand Difference (IHD) Distributions

	<i>Bear Tracing</i>		<i>Bead Dotting</i>		<i>Kurtosis</i>	<i>Bear Tracing</i>		<i>Bead Dotting</i>	
	<i>Left</i>	<i>Right</i>	<i>Left</i>	<i>Right</i>		<i>Left</i>	<i>Right</i>	<i>Left</i>	<i>Right</i>
<i>Mean</i>	-14.60	25.60	-18.59	24.97	0.17	3.94	-0.56	0.06	
<i>SD</i>	10.11	16.53	12.22	11.50	<i>Skewness</i>	-0.58	1.67	-0.17	0.47

Left handers demonstrated a lower mean in both the BTT and the BDT. In contrast to right handers who achieved an almost identical mean across the two subtests, left handers demonstrated greater variability of scores between the two subtest scores (mean BTT score = 14.76 ± 10.42 ; mean BDT score = -18.59 ± 12.22). The BTT distribution revealed a strong positive kurtosis in the right handers, indicating that most right handed children showed similar IHD variability. Since a few right handed children showed large IHD, the distribution was also positively skewed. The distribution of the BTT was abnormal while the BDT distribution appeared normal. Although the Wilcoxon test revealed that there was no significant IHD difference between BTT and BDT in the entire sample ($z = -0.557$, $p = 0.577$), Pearson's correlations were high in the entire sample ($r = 0.508$, $p = 0.000$ for right hand performance; $r = 0.644$, $p = 0.000$ for left hand performance). However, when the sample was divided into left and right handers, correlations were only significant in left handers (right hand: $r = 0.405$, $p = 0.029$; left hand: $r = 0.698$, $p = 0.000$), but not right handers (right hand: $r = 0.301$, $p = 0.100$; left hand: $r = 0.189$, $p = 0.309$).

Figure 4.12 and Table 4.10 illustrate the IHD distribution of hand performance Ability in left and right handers.

Figure 4.12. Distribution of Ability Interhand Differences (IHD) in Left and Right Handers

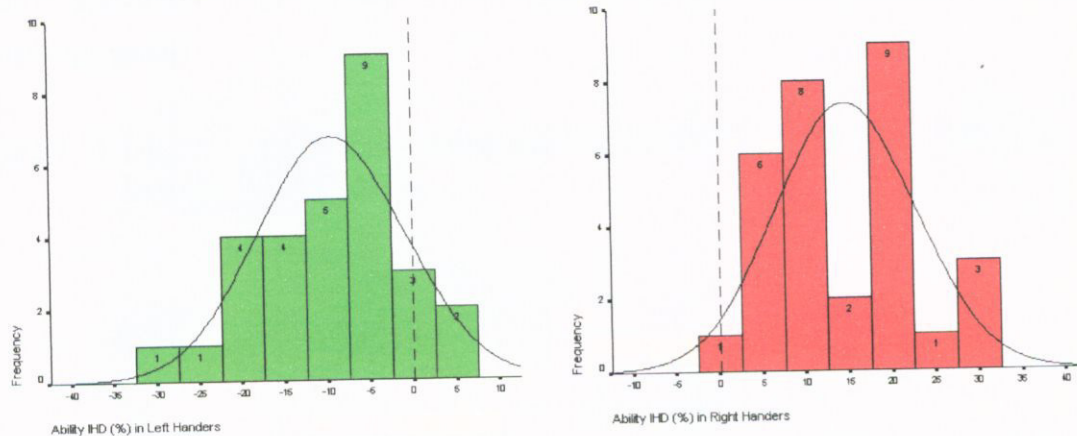


Table 4.10. Descriptive Information on Ability Interhand Difference (IHD) Distributions in Left and Right Handers

	<i>Left</i>	<i>Right</i>		<i>Left</i>	<i>Right</i>
<i>Mean</i>	-9.88	15.79	<i>Skewness</i>	-0.74	0.54
<i>SD</i>	8.36	8.05	<i>Kurtosis</i>	1.30	-0.53

The IHD distribution of left handers revealed a lower mean (-9.88 ± 8.36) than right handers (15.79 ± 8.05), and also demonstrated a wider spread of data. The distributions were not excessively skewed, but the left handed distribution showed a positive kurtosis (1.30), indicating that left handers' scores tended to cluster around similar IHD values. Two left handers performed better with their right hand and three performed equally well, compared to one right hander who demonstrated equal ability in either hand. Figure 4.13 and Table 4.11 depict the IHD distributions for hammering and tapping, the two subtests of Ability, in the form of box plots for left and right handers.

The left handed distribution of scores displayed a lower IHD mean than right handers in both hammering and tapping, with the mean for hammering being slightly higher than for tapping. These results indicated that left handers demonstrate a more equal performance with both hands. Distributions were normal for both hammering and tapping, and paired t-tests revealed that the overall difference between the two subtests was not significant ($t = 0.85, p = 0.396$). A significant correlation was found between hammering and tapping in right handers (Pearson's $r = 0.417, p = 0.020$) but not in left handers (Pearson's $r = -0.243, p = 0.213$). As both right and left handers achieved higher scores in

the hammering than the tapping task, rapid hammering movement appeared easier than rapid tapping movement. While the hammering distribution was slightly kurtosed (left = 0.91, right = 0.61) and not particularly skewed (left = -0.71, right = 0.00), the tapping distribution for left handers revealed a strong positive kurtosis (4.64) and a moderate positive kurtosis for right handers (1.41), suggesting a tight clustering around the mean for this age group.

Figure 4.13. Distributions for Hammering and Tapping Interhand Difference (IHD) in Left and Right Handers

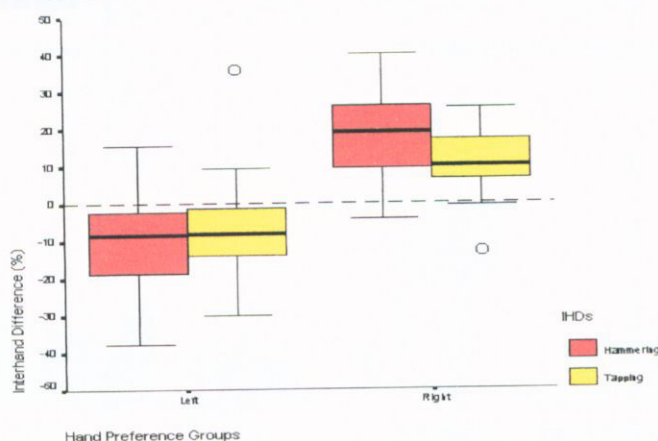


Table 4.11. Descriptive Information on Hammering and Tapping Interhand Difference (IHD) Distributions in Left and Right Handers

	<i>Hammering</i>		<i>Tapping</i>		<i>Kurtosis</i>	<i>Hammering</i>		<i>Tapping</i>	
	<i>Left</i>	<i>Right</i>	<i>Left</i>	<i>Right</i>		<i>Left</i>	<i>Right</i>	<i>Left</i>	<i>Right</i>
<i>Mean</i>	-11.15	18.27	-7.98	11.54	0.91	-0.61	4.64	1.41	
<i>SD</i>	15.34	11.04	12.37	8.06	-0.71	0.00	1.35	-0.61	

4.3.3 Midline Crossing Tests

4.3.3.1 Comparing Initial and Modified Midline Crossing Tests

Figure 4.14 and Table 4.12 compare the distributions of the initial and modified midline crossing tests, the Space Visualisation Contralateral Use (SVCU) test and the Midline Crossing Test (MCT), using the midline crossing quotient (MCQ) to assess IHD values. The mean in the initial SVCU test was notably lower in both left and right handers (-24.80 ± 17.35 and 27.22 ± 23.92) compared to the modified MCT, which, in turn, exhibited a significantly lower mean in left handers (-33.48 ± 48.71) than in right handers (54.97 ± 46.70) (see again Table 4.4).

Figure 4.14. Comparing Midline Crossing Quotient (MCQ) Distributions in the Initial Space Visualisation Contralateral Use (SVCU) Test and the Modified Midline Crossing Test (MCT) in Left and Right Handers

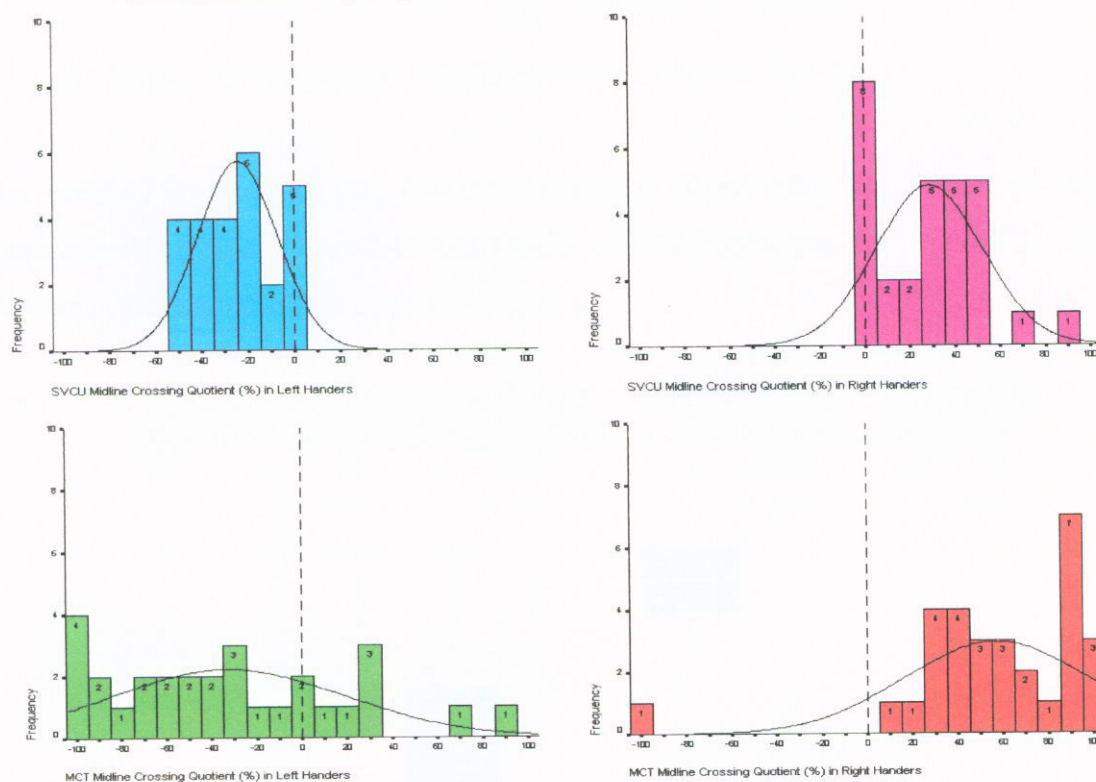


Table 4.12. Descriptive Information on Midline Crossing Quotient (MCQ) Using the Space Visualisation Contralateral Use (SVCU) and Modified Midline Crossing (MCT) Tests in Left and Right Handers

	<i>Left SVCU</i>	<i>Left MCT</i>	<i>Right SVCU</i>	<i>Right MCT</i>
<i>Mean</i>	-24.80	-33.48	27.33	54.97
<i>SD</i>	17.35	48.71	23.92	40.84
<i>Skewness</i>	0.04	0.53	0.53	-1.77
<i>Kurtosis</i>	-1.16	-0.37	-0.04	5.69

The MCQ distribution in right handers was strongly positively kurtosed and demonstrated negative skewness which indicates a ceiling effect. This effect was not seen in left handers, where the MCQ distribution was more normal. In contrast, the left handers' SVCU distribution on the SVCU was negatively kurtosed, indicating that left handers crossed the midline less than right handers during this test. If the hypothetical values of 100% had been achieved in left and right handers on the SVCU as was the case in the MCT, the SVCU distributions would have been more kurtosed (left = 7.52; right = 0.45) and skewed (left = 1.58; right = 0.78). Nevertheless, there was less of a floor effect in the SVCU distributions compared to the previous study, which may be related to the inclusion of 6-year old children exhibiting increased midline crossing behaviour. On the entire sample, the distributions of both tests were normal. Paired t-tests revealed that the

means were just significantly different between the SVCU and the MCT ($t = 1.97$, $p = 0.054$).

4.3.3.2 Exploring Subtests of the Modified Midline Crossing Test (MCT)

The modified Midline Crossing Test (MCT) consists of two subtests, proximal and distal contralateral reaching. Figure 4.15 and Table 4.13 demonstrate the distributions for these subtests in the form of a box plot.

Figure 4.15. Comparison of Proximal and Distal Contralateral Reaching During the Modified Midline Crossing Test (MCT) for Left and Right Handers

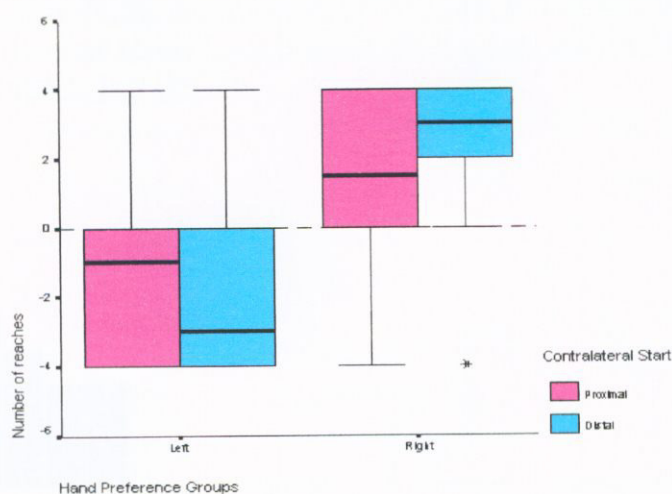


Table 4.13. Descriptive Information on the Distributions of Proximal and Distal Reaching Subtests of the Midline Crossing Test (MCT) in Left and Right Handers

	<i>Proximal</i>		<i>Distal</i>			<i>Proximal</i>		<i>Distal</i>	
	<i>Left</i>	<i>Right</i>	<i>Left</i>	<i>Right</i>		<i>Left</i>	<i>Right</i>	<i>Left</i>	<i>Right</i>
<i>Mean</i>	-1.20	1.60	-1.80	2.53	<i>Kurtosis</i>	0.12	-2.53	0.66	3.48
<i>SD</i>	2.04	2.31	2.24	1.96	<i>Skewness</i>	0.33	-1.96	1.04	-1.76

The proximal distribution revealed a similar mean and spread for left and right handers, but the right handed distribution was negatively kurtosed (-2.53) and negatively skewed (-1.96), indicating a ceiling effect for distal reach in right handers. Abnormal distributions were found for both proximal and distal reaches. However, the Wilcoxon test revealed that the difference between proximal and distal IHD was not significant in the entire sample ($z = -0.450$, $p = 0.653$). Correlations were significant in right handers (Pearson's $r = 0.551$, $p = 0.001$), and approaching significance in left handers (Pearson's $r = 0.318$, $p = 0.092$).

4.3.4 Bimanual Coordination

4.3.4.1 Comparing Initial and Modified Bimanual Coordination Tests

The initial Bilateral Motor Coordination (BMC) test and the modified Bimanual Coordination Test (BCT) were compared. Due to an irreparable breakdown of BCT test instrument and an inability to replace it within existing time constraints, only 38 children (18 left handers and 20 right handers) were assessed on both tests. Figure 4.16 and Table 4.14 illustrate the distributions of both tests for left and right handers.

Figure 4.16. Comparing Performance Levels (PL) in Left and Right Handers on the Initial Bilateral Motor Coordination (BMC) Test and the Modified Bimanual Coordination Test (BCT)

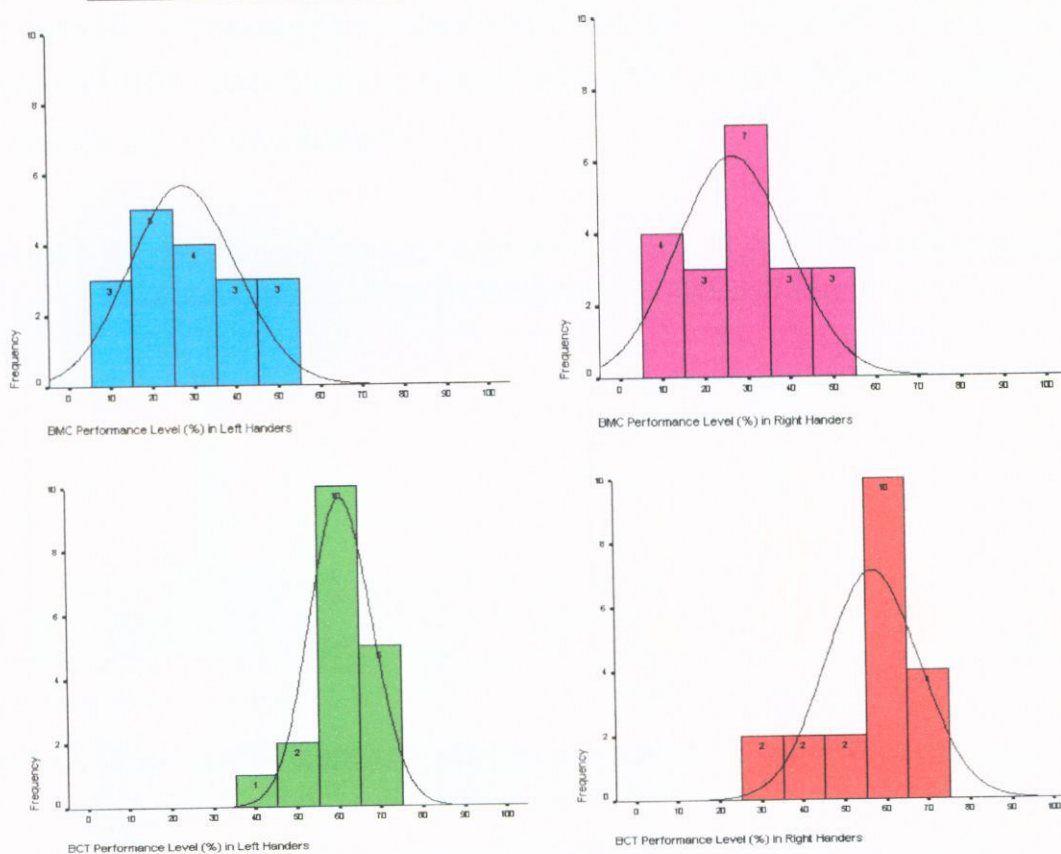


Table 4.14. Descriptive Information on Initial Bilateral Motor Coordination (BMC) and Modified Bimanual Coordination Test (BCT) Performance Level (PL) Distributions in Left and Right Handers

	Left initial BMC	Left modified BCT	Right initial BMC	Right modified BCT
Mean	27.22	60.57	26.50	56.70
SD	12.63	7.45	12.99	11.20
Skewness	0.25 (2.09)	-1.45 (-1.37)	-0.07 (1.81)	-1.10 (-0.82)
Kurtosis	-0.98 (6.63)	1.65 (6.30)	-0.86 (5.64)	-0.01 (3.65)

Note. Bracketed figures indicate skewness and kurtosis values when scores are viewed in relation to the total range possible.

The means of the modified BCT (left = 60.00 ± 7.67 ; right = 56.02 ± 11.07) were notably higher than those of the initial BMC test (left = 26.88 ± 11.24 ; right = 27.37 ± 12.73). Furthermore, the Wilcoxon statistic revealed significant differences between the two tests ($z = -5.512, p = 0.000$). These results indicate that unlike the initial BMC, the modified BCT did not yield a floor effect and it was easier for children to perform. In addition, when hypothetical values of 0% and 100% performance scores were added to each of the distributions, the real extent of skewness and kurtosis in the initial BMC test became evident (see values in brackets). Interestingly, kurtosis was particularly strong in left handers in both tests (BMC = 6.63; BCT = 6.30), showing similar performance patterns between the hands. Kurtosis was also present in right handers, with a smaller kurtosis in the BCT (BMC = 5.64; BCT = 3.65).

Apart from the performance level discussed above, the modified BCT test was also examined for IHD values. Figure 4.17 and Table 4.15 compare bimanual coordination IHD values in left and right handers.

Figure 4.17. Comparison of Bimanual Coordination Interhand Differences (IHD) in Left and Right Handers Using the Bimanual Coordination Test (BCT)

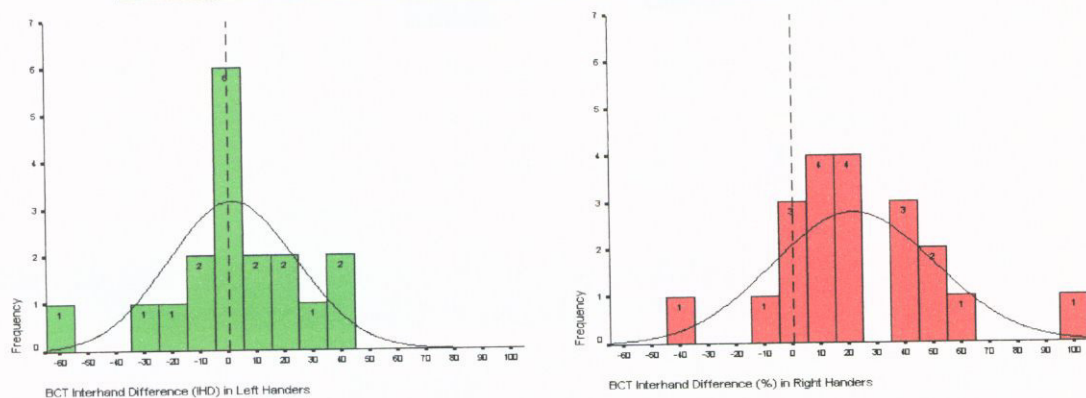


Table 4.15. Descriptive Information on Bimanual Coordination Interhand Differences (IHD) in Left and Right Handers Using the Bimanual Coordination Test (BCT)

	<i>Left</i>	<i>Right</i>		<i>Left</i>	<i>Right</i>
<i>No</i>	18	20	<i>Skewness</i>	-0.65	0.82
<i>Mean</i>	1.75	21.69	<i>Kurtosis</i>	1.38	2.09
<i>SD</i>	22.67	28.71	<i>95% CI</i>	-8.52; 12.02	8.25; 35.12

There was a wide spread of data in the modified BCT, with left and right handed scores extending into the negative and positive ranges between -60 and 100. An excessive lead with the non-preferred left hand, as was observed in Study II, was not found in this study.

Instead, eight left handers demonstrated greater IHD favouring the non-preferred right hand, compared to two children in the right handed group who demonstrated greater IHD favouring the left hand. Both distributions were positively kurtosed, more so in right handers (2.09) than the left handers (1.30), indicating that cases tended to cluster around the mean.

4.3.4.2 Exploring Modified Bimanual Coordination Subtests

The modified BCT consists of two subtests, homologous and heterologous bimanual movement, and the PL distributions of these subtests in left and right handers are depicted in Figure 4.18 and Table 4.16.

Figure 4.18. Interhand Differences (IHD) of Homologous and Heterologous Bimanual Movement Performance Level (PL) Distributions in Left and Right Handers

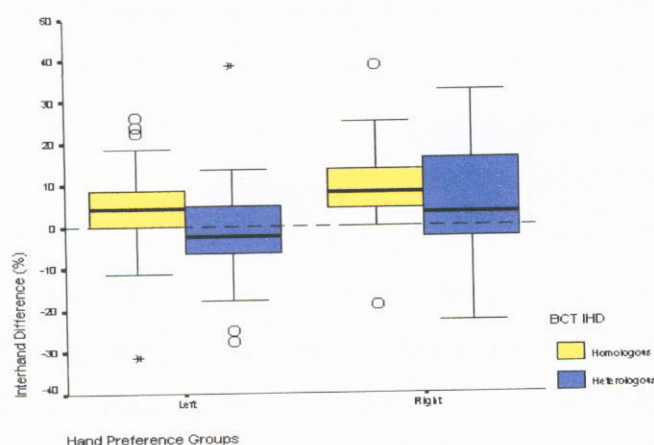


Table 4.16. Descriptive Information on Homologous and Heterologous Bimanual Movement Distributions in Left and Right Handers

	<i>Homologous</i>	<i>Heterologous</i>		<i>Homologous</i>	<i>Heterologous</i>
<i>Mean</i>	31.23	31.13	<i>Skewness</i>	1.69	0.52
<i>SD</i>	9.03	7.35	<i>Kurtosis</i>	2.77	0.65

The PL means of homologous (31.23 ± 9.03) and heterologous (31.13 ± 7.35) performance were almost identical. However, the homologous distribution was positively skewed (1.69) and showed positive kurtosis (2.77), whereas the heterologous distribution was fairly normal. This indicates that homologous movement yielded a ceiling effect, showing that homologous bimanual movement was too easy for the age groups in this study. The distributions for both homologous and heterologous bimanual movement were abnormal. The Wilcoxon test indicated no significant differences between the two bimanual coordination subtests ($z = -0.302, p = 0.762$).

4.4 Discussion

4.4.1 Discussion of Results

The results of this study have clearly revealed that all the modified tests demonstrate greater variability and spread compared to the initial tests within the same sample. Some of the differences between the initial and modified tests were significant (Experimental Hypothesis 1). Furthermore, the variability appeared sufficiently sensitive to detect degrees of handedness across the identified range of related neuromotor behaviours (Experimental Hypothesis 2). The two experimental hypotheses were thus achieved.

In the modified Functional Hand Preference Test the ceiling effect present in the Edinburgh Handedness Inventory was eliminated. While the lack of significant differences between the initial and modified tests suggests that the two tests assessed the same factors, the greater variability of the Functional Hand Preference Test indicated that it more sensitively evaluated unestablished or variable handedness. The superior sensitivity of the Functional Hand Preference Test was specifically illustrated by two left handers who scored overall in the right handed range on the Functional Hand Preference Test, while such diversity of hand preference behaviour was not detected by the Edinburgh Handedness Inventory. Untrained and bimanual tasks yielded the greatest variability, which is consistent with the literature (Bishop, 1990a; Longoni & DeGennaro, 1992). Because of the high correlation between untrained and bimanual tasks, only one distinction, namely the untrained-trained distinction, will be made in the forthcoming analysis. This decision is supported by the low correlation between the untrained/trained groups. In other words, untrained and trained Functional Hand Preference tasks will constitute the only two subtests of the Functional Hand Preference Test. Differentiating between untrained and trained, rather than unimanual and bimanual tasks is also more useful when comparing these with other handedness measures, such as 'untrained' Ability and 'trained' Skill. However, the unimanual-bimanual distinction might still provide useful qualitative information.

In hand performance, the modified Skill Test, based on tracing and dotting, identified more varied behaviour in right handers than the initial Motor Accuracy test, while also providing better opportunities for left handers to display their left handed skills. Although

the mean interhand differences were similar between the two tests, the performance levels differed significantly between Motor Accuracy and Skill due to greater variability in the latter. The Skill Test was thus successful in its modification to achieve a wider variability. The Ability Test, reflecting inherent rather than trained motor proficiency, also demonstrated a sufficiently wide variability with greater interhand differences than observed in the Skill Test, particularly in right handers. Left handers showed smaller interhand differences than right handers in both hammering and tapping. Also, performance levels in Ability and skill differed significantly from each other, indicating that each assesses different aspects of hand performance.

The modified Midline Crossing Test did not demonstrate the floor effect evident in the initial Space Visualisation Contralateral Use score. Instead, right handers (but not left handers), yielded a ceiling effect in the Midline Crossing Test, crossing almost exclusively with their preferred hand and more often than left handers. These findings are consistent with those of the previous study, and congruent with the literature (Gabbard, Helbig & Gentry, 2001).

In contrast, almost one third of left handers in the present study used the non-preferred right hand for contralateral reaching, rather than avoiding midline crossing altogether. These results differ from those of Stilwell (1987a), where left handers, although showing more use of the non-preferred right hand, did so in ipsilateral rather than contralateral responses. A study by Peters (2000) appears to provide an explanation for increased contralateral reaching with the non-preferred hand in left handers. Peters investigated contralateral reaching with temporal constraints and found that both left and right handers reacted faster with the right hand. This finding led Peters to suggest that left and right handers share the same hemispheric asymmetry, with superior temporal resolution in the left hemisphere. Although there was no official temporal constraint during the Midline Crossing Test administration, prompt and spontaneous reactions were encouraged to prevent boredom. Speed might thus be an aspect to be included or controlled to investigate its impact on midline crossing in greater detail.

Overall, the Midline Crossing Test revealed very different behaviours in left and right handers that were not evident from the Space Visualisation Contralateral Use measure. Furthermore, not only was the Midline Crossing Test able to identify more variable

handers, particularly in the left handed group, but it also demonstrated more explicit left and right handed contralateral reaching than the Space Visualisation Contralateral Use measure. The significant statistical difference between the two tests further reflects the improved variability of the Midline Crossing Test.

Finally, the performance level of the modified Bimanual Coordination Test substantially removed the floor effect evident in the initial Bilateral Motor Coordination test. The additional measure of the Bimanual Coordination Test interhand differences, an asymmetry measure unavailable in the Bilateral Motor Coordination, revealed only small interhand differences. This was expected since the task required *simultaneous* bimanual movement, and the task demands were not high. As a result, the distribution of the Bimanual Coordination Test performance level was kurtosed and skewed for the age groups involved. The greater lead of the non-preferred left hand in the majority of right handers observed in Study II was not seen in the present study, suggesting that this phenomenon might indeed reflect age-related neurological immaturity. Applying the Bimanual Coordination Test to an clinical sample with minimal neurological deficits might yield similar results to those of younger children.

Overall, there was a satisfactorily wide spread of Bimanual Coordination data since a few right handers and several left handers employed greater use of the non-preferred hand. The modified Bimanual Coordination Test thus appears to be more appropriate to assess bimanual coordination in younger age groups and more able to detect asymmetries between the hands than the initial Bilateral Motor Coordination test.

All five modified tests demonstrated superior performance in detecting variability compared to the initial tests, thereby supporting the proposed hypotheses. In addition, the modified tests also revealed useful additional details about handedness through their subtests. None of the pairs of subtests (untrained versus trained Functional Hand Preference; Bear Tracing versus Bead Dotting in Skill; hammering versus tapping in Ability; proximal versus distal Midline Crossing; and homologous versus heterologous Bimanual Coordination) showed significant differences between the two tasks, indicating that both subtests in each measure were assessing similar factors.

Whilst this may prompt a decision to choose one subtest and disregard the other, this option was rejected for several reasons. Firstly, although the differences were not significant, the subtest performances were not identical as indicated by a lack of correlation between several of the subtests, particularly when left and right handers were separated. It is thus likely that the inclusion of both subtests would contribute to the overall handedness variability and the analysis of an individual handedness profile. For example, based on a comparison of means and standard deviations, untrained tasks showed a much wider range of responses than trained tasks, the interhand differences were smaller in the Bear Tracing Task than the Bead Dotting Task, hammering appeared to be easier than tapping since the hammering mean was higher, and homologous bimanual movement seemed to require less skill than heterologous movement (a finding in agreement with those of Semjen, Summers and Cattaert (1995), since fewer errors were made during homologous than heterologous movement). These observed differences between the subtests might be useful when analysing individual handedness profiles in view of presenting problems and treatment.

Secondly, it has frequently been proposed that using a number of different tasks is preferable to a single task to obtain a more comprehensive representation of handedness (Beukelaar & Kroonenberg, 1983; Longoni & DeGennaro, 1992). This proposition supports the inclusion of all subtests of the five modified tests used in this study. Thirdly, the inclusion of all subtests might also detect useful information in *clinical* left and right handers, who might present with differences between the subtests not evident in a normative sample. Finally, since the overall testing time to administer the handedness profile with all the subtests was approximately one hour, the children were not exposed to excessively long assessment procedures compared to other paediatric assessments (e.g., the SIPT takes approximately two and a half hours). Overly long and laborious testing involved in the handedness profile would certainly warrant the removal of those subtests that appear to assess similar aspects of handedness. Future research to establish test validity and reliability will identify redundancy and appropriate adjustments will be made to the tests to ensure balanced representation of essential items without replication.

A lack of consistent hand use across the handedness measures, hereon referred to as *incongruence*, was observed in some children, particularly left handers. For example, numerous participants performed better with the non-preferred hand in untrained

Functional Hand Preference Tasks, the Ability Test, Midline Crossing Test and Bimanual Coordination Test. Similar findings of incongruence, or 'inconsistency', have been reported in other studies (e.g., Peters, 1985, 1987). However, the variability in these three modified tests was greater than expected. On the one hand, this suggests that the three modified tests might not be good predictors of the *direction* of handedness, whilst on the other hand, they appear sensitive enough to expose various *degrees* of handedness behaviour, obscured in the initial tests and not apparent in the trained Functional Hand Preference Test or Skill Test. It would be important, then, to employ the complete set of five modified tests of the Handedness Profile Battery, in order to examine both the *direction* and the *degree* of handedness, as proposed by McManus, Sik, Cole, Mellon, Wong and Kloss (1988). In this context, just as Ability and Skill represent the more innate and the more trained aspects of handedness respectively, untrained and trained subtests of the Functional Hand Preference Test should also be reported separately.

Findings of this study indicate a statistically significant difference between left and right handers on all modified tests assessing interhand differences, whereby the interhand difference was generally smaller in left handers. This is congruent with a wide range of literature (e.g., Annett, 1970a, 1985; Peters, 1990). Similarly, the finding that right handers were more consistent than left handers is also in accordance with findings in the previous study and with other research (Bryden, 1982; Herron, 1980; Steenhuis & Bryden, 1989). Conversely, there was a lack of a significant difference between left and right handers for the performance levels. Similar performance in left and right handers was expected, since there is sufficient evidence that familial left handers do not display inferior motor performance (e.g., Bishop, 1984, 1990a, 1990c; Gillberg & Rasmussen, 1982; Hugdahl, Synnevag & Satz, 1990; Kaufman, Zalma & Kaufman, 1978; Tan, 1985. See Section 1.2.1.3 in Chapter 1 for review on the impact of pathological influences on left handedness). Furthermore, the modified handedness measures were able to sensitively detect a much greater diversity of differences between left and right handers compared to the initial tests.

As discussed previously, the tasks of the modified Handedness Profile Test Battery have a prospective drawback, since they are all essentially repetitive and monotonous in nature. Furthermore, the Handedness Profile Test Battery aims to assess *spontaneous* neuromotor behaviour, and undue awareness of task performance might interfere with the

desired spontaneity. Engaging in repetitive, monotonous tasks is likely to result in boredom, decreased attention span and a lack of motivation, particularly in young children. This response, in turn, might distort and diminish their performance abilities. For this reason, the researcher had included imagination and humour into the design of the modified tests, using the teddy bear theme as a continued focus throughout the assessment. It was observed that all children appeared to enjoy participating in the Handedness Profile Test Battery. Moreover, numerous requests were made to repeat some of the 'teddy bear games'. The apparent pleasure and sustained concentration span demonstrated by most children during their engagement in the modified assessment tasks, was seen as anecdotal evidence for successfully overcoming the potential drawback of the Handedness Profile Test Battery.

There were more boys than girls in the left handed groups recruited for this study, which would be in agreement with the literature citing greater incidence of left handedness amongst males (e.g., Brito, Lins, Paumgarten & Brito, 1992; Hardyck, Goldman & Petrinovich, 1975; McManus, 1981). However, in the present study neither the modified tests nor the initial ones revealed specific gender differences in interhand differences or performance levels. Whilst Study I also failed to reveal gender differences, Study II, based on a normative sample with three age groups, detected significantly different measures between boys and girls. It is possible that these gender differences might be more apparent when related to age. Larger samples of different age groups with equal numbers of boys and girls as well as left and right handers would be required to investigate gender differences based on the modified tests more accurately. The inconclusive findings on gender across the three studies, however, suggest that gender differences are not central to the construction of a basic normative handedness profile. Therefore, for the purpose of this thesis, gender will not be considered as a factor in the forthcoming statistical analyses.

4.4.2 Conclusion

The present study has revealed that the modifications of the handedness tests have fulfilled the hypotheses of sufficient variability and sensitivity to assess degrees of handedness. Varying degrees of handedness across a range of related neuromotor behaviours in normal children can provide an index, or a standard handedness profile,

against which children with variable and unestablished handedness can be measured. It must be cautioned, however, that for the number of variables the sample was relatively small. Findings from this study suggest that such a normative handedness profile can now be constructed, whereby the five modified tests will provide a structure that enables the various degrees of individual handedness behaviours to be categorised and an overall handedness classification to be obtained. The following chapter will describe and discuss the construction of such a normative handedness profile.

CHAPTER 5

CONSTRUCTING A NORMATIVE HANDEDNESS PROFILE

5.1 Introduction

This chapter describes the construction of a normative handedness profile based on the data of the previous study using the Handedness Profile Test Battery that finally exhibited the desired variability in the various handedness measures. Percentiles were computed for each handedness measure of the Handedness Profile Test Battery, namely the Functional Hand Preference Test, Ability Test, Skill Test, Midline Crossing Test, and Bimanual Coordination Test. Furthermore, the categorisation of percentiles is described according to a multiple point or category scale so that the overall handedness of each participant could be classified at some point on this scale. Investigation of the most suitable number of categories for the multiple point scale is reported along with statistical procedures to determine cluster membership and predictive factors of handedness. A typical normative profile was constructed for each of the categories in left and right handers, and the characteristics and differences between the handedness groups is addressed in the Discussion.

5.1.1 Categorisation of Handedness

Continuous data in the form of percentages (e.g., the laterality quotient), provide the most accurate measure for determining *degrees* of handedness. However, the *direction* of handedness (i.e., left or right) also needs to be established, particularly in relation to writing, and for this purpose the continuous data (i.e., handedness degrees) was converted to nominal or categorical data (i.e., handedness direction). In order to achieve this, multiple categories were employed that differentiated between “strong” and “flexible” left and right handers. An effective handedness profile to be used for clinical decision making should be able to sensitively identify and *classify* presenting handedness in terms of interhand differences (IHD) and performance levels (PL) for each of the handedness measures. Reporting test performance by classifying ability is common practice in psychometric procedures. As Lezak (1995) explains,

“In the standard classification system, each ability level represents a statistically defined range of scores. Both percentile scores and standard scores can be classified in terms of ability level. Test performances communicated in terms of ability levels have generally accepted and relatively clear

meanings... This method also enables the examiner to report clusters or scores that may be one or two score points apart that probably represent a normal variation of scores around a single ability level" (p.159).

Furthermore, the principle of basing average performance around quartiles is an accepted basis for classification in psychological and related measurements. The norm lies between the 25th and 75th percentiles, above average performance is demonstrated by the top quartile, and below average or subaverage performance is reflected in the lowest quartile (Lezak, 1995; Munro, 1997). A test used frequently in paediatric occupational therapy based on a percentile evaluation system is the Test of Visual Motor Integration (Beery, 1982).

Such a classification system would enable the normative handedness profile (hereon synonymous with *normative profile*) to effectively categorise aspects of handedness that present as continuous data (i.e., raw scores in percentages) derived from the modified tests. No *standard* guidelines for such categories exist (Annett, 1970b, 1992a; Bishop, 1990a, 1990c). In the normative studies described in the previous chapters, three types of classifications had been extracted from continuous hand preference scores, namely *2-group classification* (i.e., left and right handers), *3-group classification* (i.e., left, 'mixed' and right handers) and *5-group classification* (i.e., definite left, tendency left, 'mixed', tendency right, and definite right handers, as termed in the parent questionnaire).

At first glance, a 5-group handedness classification appeared to be sufficient as the basis of this profile. This could be derived in a normative sample from quartile ranges for each handedness test, where the top 25 percent constitutes one quartile (i.e., definite left and right handers), the middle 50 percent another two quartiles (i.e., moderate left and right handers), and the lowest 25 percent the final quartile (i.e., variable handers). However, whilst a five-point scale would be able to differentiate well established or *explicit* left/right handers from established or *moderate* left/right handers, the variable handers would remain undifferentiated in the middle category. As the purpose of a normative profile is to provide a scale for classifying the *variability* of handedness in particular, it was deemed important to differentiate between the *extent* of variability, and larger numbers of categories would be desirable to reflect the multidimensional and continuous nature of handedness.

Unlike the classification based on quartiles frequently used in psychometric measures, (i.e., using 75th, 50th and 25th percentiles as divisions), the 50th percentile was not deemed to be an important separation, since the range between the 25th and the 75th percentile is generally assumed to be the norm. Instead, a distinction between *small* interhand differences / *subaverage* performance levels (10th to 25th percentile), and *slight* interhand differences / *poor* performance levels (0 to 9th percentile) could provide valuable additional information on the child's handedness in relation to occupational performance. In this way, the extent of the direction and degrees of handedness are obtained (i.e., interhand differences) and these can be compared with co-existing performance levels.

Assembling information on the *extent* of subaverage scores might not only assist therapists in obtaining a more accurate handedness classification, but also provide a context for understanding each individual handedness presentation, since there could be several reasons for variable handedness (see Section 1.4 on proposed causes for variable handedness in Chapter 1). Using these criteria, a handedness profile consisting of an *eight point* scale (included the 10th percentile for both left and right handed responses) was constructed as an appropriate basis for handedness classification.

Eight categories of handedness is not a new concept. Annett (1970a, 1976, 1985, 1994) has repeatedly advocated the use of initially eight (prior to 1985) and thereafter seven handedness groups. Annett's classification system of *hand preference* was based on 6 'primary actions', similar to trained/skilled tasks (e.g., writing, throwing), and 6 'non-primary actions', comparable to untrained/unskilled tasks (e.g., dealing cards, using a broom), derived from a factor analysis of those items (Annett, 1994). Subjects were classified according to a decision tree (see Appendix 5A), depending on the number and type of actions executed with each hand.

Unlike Annett, who based her classification solely on the nature of the selected hand preference items, the 8-group classification for the handedness profile was based on the four percentile groups outlined above and applied to all five modified handedness tests. Categories based on percentiles provided a framework for handedness scores to indicate whether a child performed above, at, below or well below average for any specific aspect of handedness. Assuming that normal handedness presentation is a *continuum*, ranging from explicit left to explicit right handedness, it would be expected that normal

individuals with relatively established handedness would fall into all categories, although it is unlikely that the middle categories would contain many cases. This should, however, not deter from using an 8-group system, since individuals with variable handedness in a clinical population would, by definition, dominate the middle categories to varying extents.

5.1.2 Summarising the Handedness Profile Test Battery

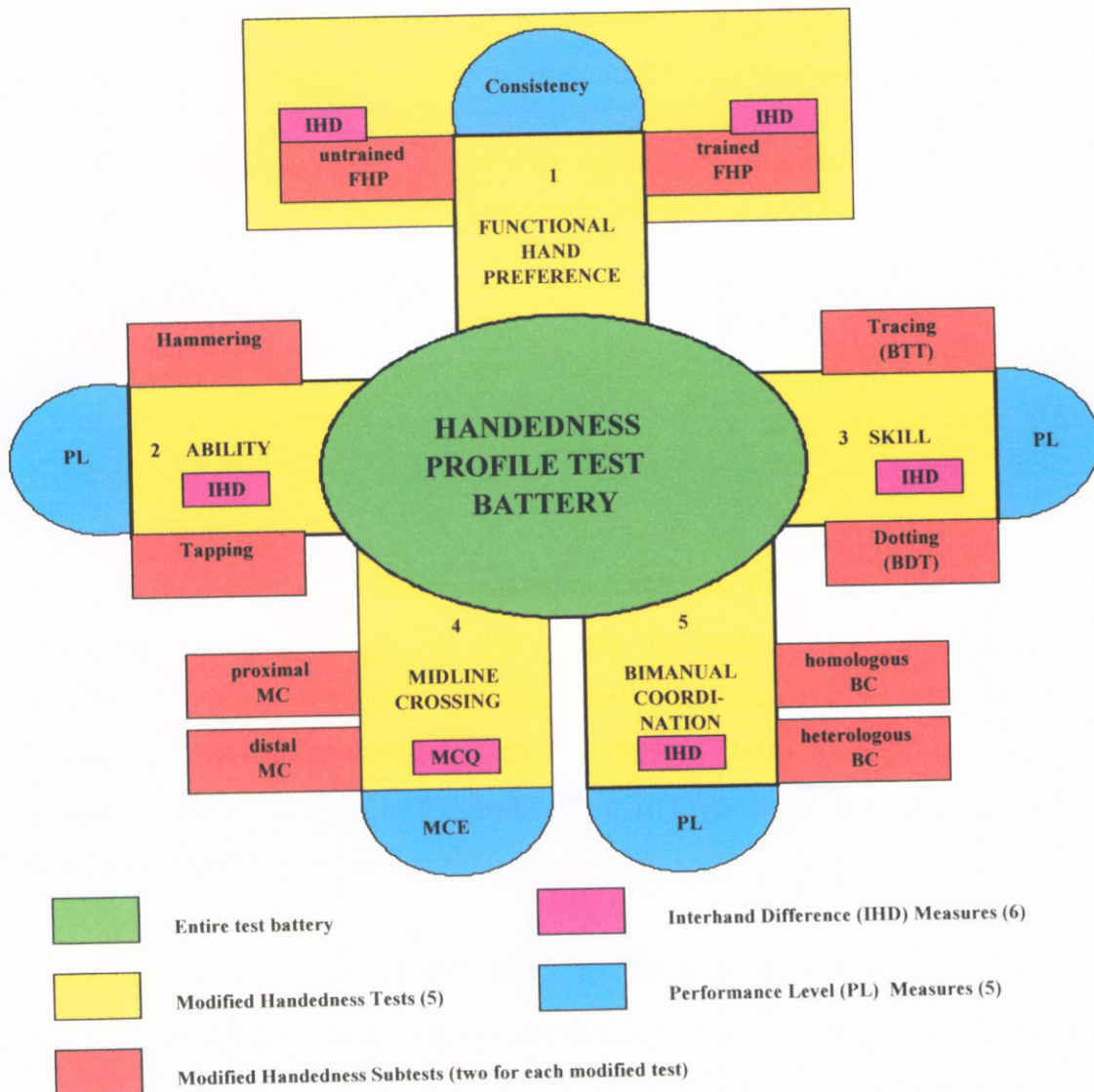
The Handedness Profile Test Battery, on which the normative profile was based, consists of the five modified tests, Functional Hand Preference Test (FHPT), Ability Test, Skill Test, Midline Crossing Test (MCT), and Bimanual Coordination Test (BCT). Each of these modified tests comprises of two subtests: untrained and trained FHP tasks for the FHPT, hammering and tapping for Ability Test, tracing and dotting for Skill Test, proximal and distal contralateral reaching for MCT, and homologous and heterologous bimanual movement for BCT. As outlined earlier, the individual raw scores of these subtests were averaged for a combined raw score in all modified tests except FHPT, which retained the untrained/trained distinction since valuable information might be lost if the two were collapsed. Every modified test yielded an interhand difference (IHD) measure (the FHPT was the only test with a separate IHD measure for its two subtests) and a performance level (PL) measure.

In total, the handedness profile thus consists of six IHD measures and five PL measures, also referred to in combination as the eleven *handedness measures*. The IHD measures demonstrate the magnitude of interhand differences whilst the PL measures provide information on the quality of the performance, regardless of the extent to which one hand outperformed the other. Consistency is taken as the PL measure for both untrained and trained FHPT, and Midline Crossing Extent is the PL measure for midline crossing. The PL measures of the remaining tests consist of the superior raw score of one hand over the other.

Figure 5.1 provides a summary of the Handedness Profile Test Battery, with the five modified tests (FHPT, Skill, Ability, Midline Crossing and Bimanual Coordination tests), each with their two subtests, as well as their separate IHD and PL measures. Functional Hand Preference Tasks is the only test where the two subtests, untrained and trained

FHPT, are taken as two separate measures. This is in contrast to the subtests of the other four tests, which are combined and the average of the two comprises the raw score of each test.

Figure 5.1. Interhand Difference (IHD) and Performance Level (PL) Measures
Derived from the Modified Tests of the Handedness Profile Test Battery



Note. Figures in brackets indicate the total number of tests.

5.1.3 Specification of Handedness Categories

Since the previous studies found evidence for a significant difference between left and right handers, quartiles were computed separately for left and right handers for all interhand differences (IHD) and performance levels (PL). The eight handedness

categories indicating handedness ‘strength’ are based only on the IHD measures. Table 5.1 defines these categories and relevant percentile ranges.

Table 5.1. Summary of Categorising Handedness into Eight Groups Using Percentiles

<i>Abbreviation</i>	<i>Percentile range</i>	<i>Terminology</i>
L+	-75% to -100%	EXPLICITLY left (above average IHD/exceptionally large)
L	-25% to -74%	MODERATELY left (average IHD)
L-	-10% to -24%	MILDLY left (below average/subaverage IHD)
Vl	0% to -9%	VARIABLE (left) (exceptionally small IHD)
Vr	0% to 9%	VARIABLE (right) (exceptionally small IHD)
R-	10% to 24%	MILDLY right (below average/subaverage IHD)
R	25% to 74%	MODERATELY right (average IHD)
R+	75% to 100%	EXPLICITLY right (above average IHD/exceptionally large)

As mentioned earlier, the average range was defined between the 25th and 74th percentile, leaving 25 percent above and 25 percent below the average range (see Table 5.2 under Section 5.3.1 further on for more detail on computing percentiles.)

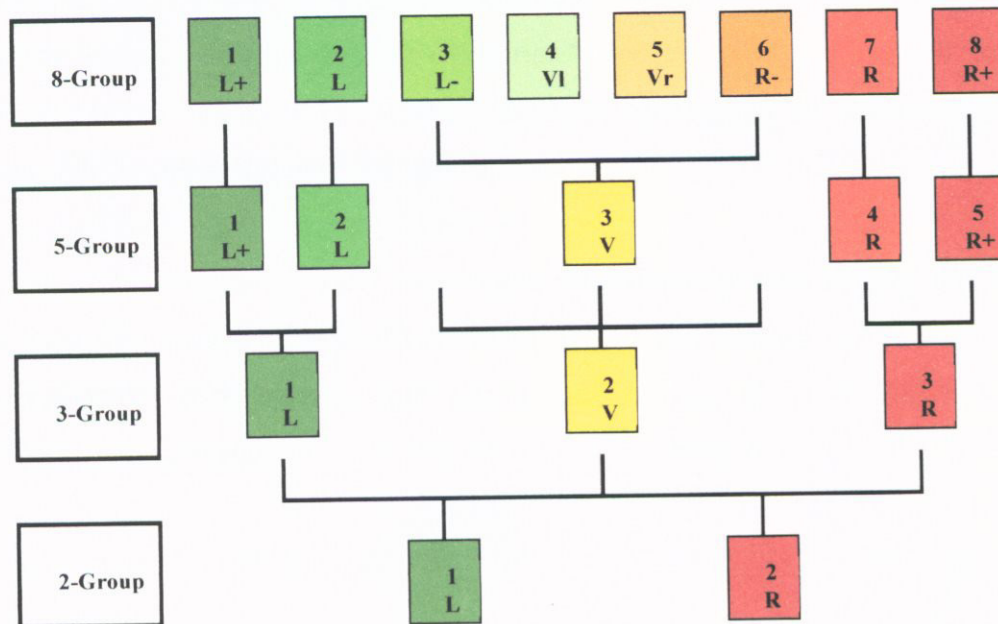
The researcher considered it to be important that the descriptive terminology of the categories should be neutral. For this reason, the terms *explicit*, *moderate*, *mild* and *variable* were chosen over commonly used terms such as ‘strong’, ‘weak’ and ‘undecided’ handedness, which qualify the direction of handedness in a positive or negative manner. (See Table 5.9 under Section 5.3.5 further on for a more detailed definition of each handedness category.)

While eight handedness categories based on the percentiles seemed to be a necessary basis for the handedness profile, it appeared unlikely that a *normative* sample of the present size would yield sufficient cases for each of the eight categories. In other words, a discriminant function analysis employing eight categories requires a sufficiently large normative sample for predictive factors to emerge. Therefore, for the purpose of this chapter, scores were collapsed into a maximum of five categories.

In addition, some statistical comparisons or analyses might require fewer groups, as was evident in the previous studies (e.g., established left handers, established right handers and unestablished handers in a 3-group classification). It is even more frequent to examine comparisons between left and right handers (2-group classification). A category

tree illustrates how the 5-group classification can be derived from the 8-group classification (Figure 5.2).

Figure 5.2. Diagrammatic Representation of a Category Tree Deriving Lesser Handedness Groups from the 8-Group Classification



Note. L = left, R = right, + refers to explicit and - to mild, V denotes variable handedness.

The 5-group classification was derived from the 8-group classification by collapsing categories L-, V, Vr and R-, whilst each of the categories L+, L, R and R+ remained separate. The 3-group classification combined the L+ and L groups, and the R+ and R groups. Finally, the 2-group classification consisted of two groups, where all four left categories and all four right categories were each collapsed into one group. However, since the purpose of this profile is to investigate groups based on various degrees of handedness, the 3-group classification with one variable group is not useful in the context of constructing a handedness profile and will thus not be included in the forthcoming analysis.

5.1.4 Experimental Hypotheses

A suitable normative handedness profile would need to satisfy the following three experimental hypotheses.

Experimental Hypothesis 1: The normative handedness profile would display various degrees of left and right handedness within the 8-group classification, or there would be relatively few cases in the variable categories.

Experimental Hypothesis 2: In the discriminant analysis, the modified tests would clearly distinguish between five handedness categories based on the degree of left or right handed tendency (i.e., explicit left handers, moderate left handers, variable/mild handers, moderate right handers, and explicit right handers).

Experimental Hypothesis 3: Those handedness measures related to training and learnt, skilled tasks (i.e., trained FHP, Skill) are likely to be strong handedness factors because of environmental reinforcement and would thus emerge as predictive factors of handedness establishment.

5.2 Method

5.2.1 Participants, Tests and Instruments, Procedures and Scoring of the Handedness Profile Test Battery

The data analysis in this chapter was based on the data of the previous study using the Handedness Profile Test Battery on a normal sample of 5- to 6-year old children (i.e., 31 left and 31 right handers; see Sections 4.2.1, 4.2.3, and 4.2.5 on details of participants, test administration and scoring procedures in Chapter 4).

5.2.2 Procedures

5.2.2.1 Obtaining a Normative Handedness Profile Classification

Scoring of the handedness profile to obtain a profile classification involved a 6-step scoring procedure.

- (i) *Raw scores* of IHD and PL values were obtained as percentages from each of the five modified tests, whereby untrained and trained FHP received separate IHD raw scores (see Sections 3.2.5 and 4.2.5 in Chapters 3 and 4 respectively).
- (ii) Each of the eleven raw scores was assigned to the appropriate *percentile range* for raw scores available for each handedness measure. Each percentile range defined one of the eight categories (see Table 5.2 under Section 5.3.1 further on regarding computing percentiles). For example, if a child scored -80% in untrained FHP, the appropriate handedness category for that measure would be Category L+ (75th to 100th percentile with scores ranging between -75% to -100%).
- (iii) The percentile range/category for IHD measures provided a predetermined *category score* that had been assigned to each category (see Figure 5.3).

Figure 5.3. The 8-Group Handedness Classification with Corresponding Category Scores

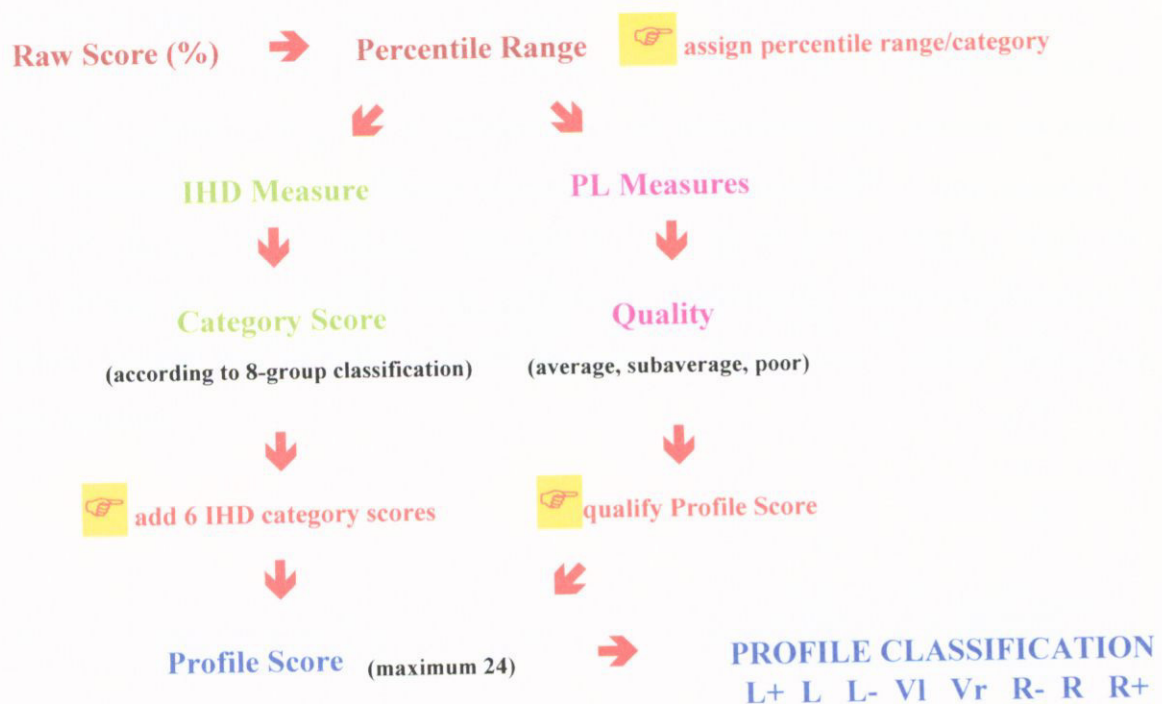
L+	L	L-	Vl	Vr	R-	R	R+
Score = -4	Score = -3	Score = -1.5	Score = -0.5	Score = 0.5	Score = 1.5	Score = 3	Score = 4

For each handedness measure a child could receive a maximum category score of 4 points and a minimum of 0.5 points. The explicit categories L+ and R+ were allotted the highest score of 4 points each, showing the strongest extent of lateralisation above the 75th percentile. Scores in the moderate categories L and R falling between the 25th and 75th percentiles were assigned 3 points. The mild categories L- and R- were allocated 1.5 points (i.e., half of the moderate category) for falling below the 25th percentile, while scores falling in categories V1 and Vr of the variable responses were awarded half a point, reflecting a performance level below the 10th percentile. The allocation of scores was based on the tenet that high variability (i.e., mild and variable categories) should be 'penalised' by providing only 0.5 points, whilst still acknowledging the tentative direction of preferred hand use by scoring these categories at all. Consistent with other left handedness scoring procedures, the left category scores carried a negative sign.

- (iv) By adding the category scores for each IHD handedness measure, an overall *profile score* was obtained. Since a maximum category score of 4 points could be achieved, the maximum profile score would be 24 points (i.e., 6 IHD handedness measures times 4 points). If the sum of left category scores exceeded right ones, the overall profile score would be negative.
- (v) The percentile range/category for PL measures indicated performance to be average, subaverage or poor, providing a *qualitative* aspect irrespective of direction of handedness. Performance levels were examined to assess if any delays or strengths in these performance-based measures might qualify the above IHD-based handedness classification. For example, a child scoring overall in the *variable* categories, V1 or Vr, may not show any motor problems (i.e., achieved high performance level scores), indicating that variable handedness did not necessarily influence motor skills. Another child presenting with variable handedness might also demonstrate motor delays (i.e., obtaining low performance scores), and in such a case there might be a relationship between motor skill and handedness establishment, although the *direction* of a causal relationship might not be evident.

- (vi) Based on the above process, the final *profile classification* was obtained. One of the following profile classifications was assigned: explicit left hander (L+), moderate left hander (L), mild left hander (L-), variable left hander (VI), variable right hander (Vr), mild right hander (R-), moderate right hander (R), or explicit right hander (R+). Figure 5.4 summarises the 6-point scoring process for the handedness profile.

Figure 5.4. Scoring Process for Obtaining a Handedness Profile Classification



There are two possible reasons for a profile classification resulting in the mild or variable categories. First, all six IHD measures fall in the mild/variable categories of either the left or right side (e.g., all measures show a left tendency, indicating that the measures are compatible in their direction of handedness, hereon referred to as *congruence*). Second, some measures might present on the left side (i.e., in L+, L, L- or VI) and others on the right side (i.e., R+, R, R- or Vr), a phenomenon that has previously been defined as *incongruence* for the purpose of this thesis. This means that even if some measures are classified in moderate or explicit categories, other measures on the opposite side will result in a lower overall profile classification.

5.2.3 Data Analysis

The data analysis for constructing the normative handedness profile consists of several parts. Firstly, the raw scores were divided into categories based on the percentile groups as shown in Table 5.1 for all handedness measures. This allowed for an overall profile score (from the summed category scores) providing the basis of each child's overall profile classification. Comparative statistics were employed to assess the number of cases in each handedness group. Secondly, in order to measure the significance of differences between the percentile groups, a K-means cluster analysis based on the profile scores was performed for all IHD measures to confirm group membership of the participants for the 2-group, 5-group and 8-group classifications. Cross-tabulations were executed to display the correspondence between clusters and categories. One-way ANOVA was employed to examine the extent of differences between the handedness groups. Finally, sequential discriminant function analyses were performed to establish the existence of predictive factors amongst the modified tests for the 2-group, 5-group and 8-group handedness classifications.

5.3 Results

5.3.1 Computing Percentiles and Comparing 8-Group Categories

The values falling into the percentile range for each handedness measure are summarised in Table 5.2, according to the 8 categories defined above. The interhand difference (IHD) values reflect the *degree* and *direction* of preferred hand use and the performance level (PL) values exhibit the *level of proficiency*. Since the categories already indicate a left or right direction of handedness, left and right handed scores are both reported as positive percentages for the purpose of this table.

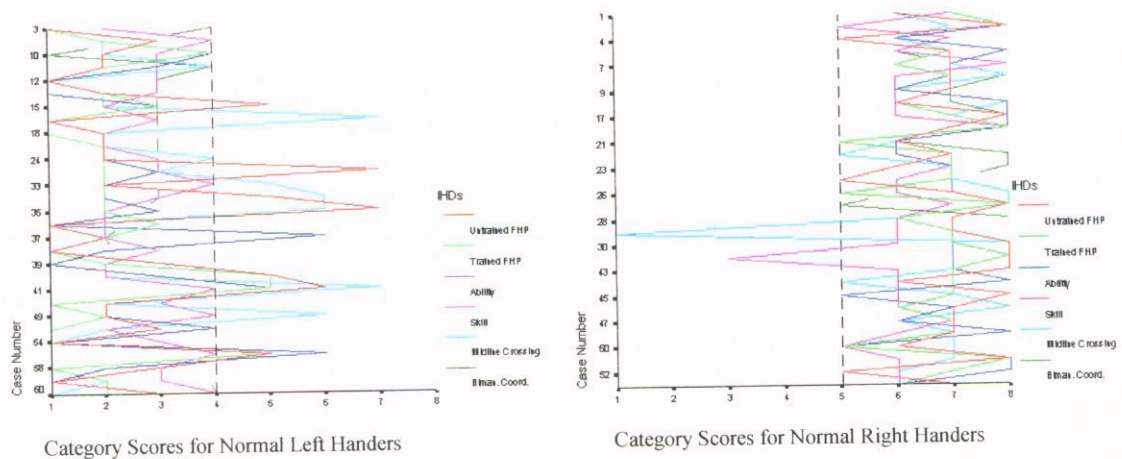
Table 5.2. Handedness Raw Scores of All Handedness Measures and Percentile Ranges According to the Eight Handedness Categories

<i>Category</i>	<i>L+</i>	<i>L</i>	<i>L-</i>	<i>VI</i>	<i>Vr</i>	<i>R-</i>	<i>R</i>	<i>R+</i>
<i>Percentile Range</i>	<i>75th-100th</i>	<i>25th-74th</i>	<i>10th-24th</i>	<i>0-9th</i>	<i>0-9th</i>	<i>10th-24th</i>	<i>25th-74th</i>	<i>75th-100th</i>
<i>Interhand Difference (IHD)</i>								
Untrained FHP	76-100	40-75	3-39	0- 2	0-26	27-47	48-75	76-100
Trained FHP	80-100	42-79	18-41	0-17	0-69	70-77	78-93	94-100
Ability IHD	13-100	6-12	2- 5	0- 1	0- 3	4- 9	10-18	19-100
Skill IHD	17-100	10-16	4- 9	0- 3	0- 4	5-13	14-21	22-100
Midline Crossing Quotient	81-100	19-80	3-18	0- 2	0-23	24-46	47-93	94-100
Bimanual Coordination IHD	48-100	23-47	4-22	0- 3	0- 3	4- 7	8-35	36-100
<i>Performance Level (PL)</i>								
Consistency	75-100	58-74	47-57	0-46	0-57	58-61	62-82	83-100
Ability PL (preferred hand)	71-100	58-70	48-57	0-47	0-56	57-59	60-74	75-100
Ability PL (non-preferred hand)	57-100	49-56	39-48	0-38	0-35	36-45	46-54	55-100
Skill PL (preferred hand)	67-100	61-66	57-60	0-56	0-54	55-58	59-66	67-100
Skill PL (non-preferred hand)	60-100	51-59	46-50	0-45	0-29	30-46	47-55	56-100
Midline Crossing Extent	94-100	31-93	3-30	0- 2	0-18	19-24	25-87	88-100
Bimanual Coordination PL	66-100	59-65	49-58	0-48	0-33	34-45	46-62	63-100

The PL values of Ability and Skill were computed as percentiles of the preferred hand and the non-preferred hand to detect the magnitude of the difference between the two. Each profile score was categorized according to the eight categories resulting in a final *profile score*.

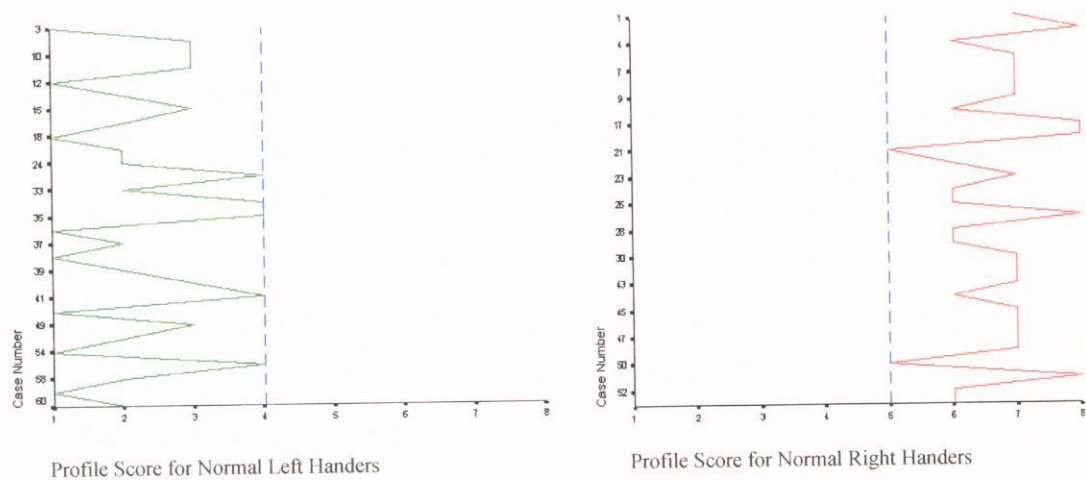
Figure 5.5 illustrates the difference in category scores in the six IHD measures between normal left and right handers.

Figure 5.5. Comparing Category Scores of Interhand Differences (IHD) in Normal Left and Right Handers



The line graphs of Figure 5.6, based on the overall (average) profile score, indicate that left handers tended to be more extreme in their presentation by being either more explicit or variable than right handers. Conversely, right handers were more inclined to cluster around the moderate and mild categories.

Figure 5.6. Comparing the Overall Profile Score Between Normal Left and Right Handers Based on Profile Classifications



5.3.2 Comparative statistics

Cross-tabulations on all handedness measures revealed that 83% of left handers displayed negative scores and 85% of right handers demonstrated positive scores, confirming that the measures express of handedness reliably. More specifically, as summarised in Table 5.3, cross-tabulations of the 8-group classification demonstrated similar percentages of

cases for left and right handers in some categories (i.e., explicit left handers, $n = 7$; explicit right handers, $n = 5$; mild left handers, $n = 5$; mild right handers, $n = 8$).

Table 5.3. Summarising the Prevalence of Normal Left and Right Handedness Groups and Performance Levels (PL)

<i>Handedness Classification</i>	<i>Left Handers (n=29)</i>		<i>Right Handers (n=30)</i>	
	<i>Frequency</i>	<i>Percentage</i>	<i>Frequency</i>	<i>Percentage</i>
Explicit Handers	7	24	5	17
Moderate Handers ♦	10	34	16	53
Mild Handers	5	17	8	27
Variable Handers ♦	7	24	1	3
<i>Performance Particulars</i>				
No subaverage PL	8	28	7	23
Only preferred hand PL poor	5	17	3	10
Only non-preferred hand PL poor	2	7	4	13
Midline Crossing avoidance	5	17	5	17
Subaverage Bimanual Coordination	5 (n=18)	36	4 (n=20)	20
Inconsistency	8	28	9	30
Incongruence ♦	9	31	2	7

Note. ♦ = difference between left and right handers that is greater than 3 cases.

However, moderate right handers ($n = 16$, 53%) exceeded the percentage of moderate left handers ($n = 10$, 34%). In addition, left handers were more likely to score in the variable category ($n = 7$, 24%) than right handers ($n = 1$, 3%). Left handers were also more frequently incongruous ($n = 9$, 31%) than right handers ($n = 2$, 7%). Only 13.6% ($n = 8$) of all cases were classified as variable handers. There were no notable differences in percentages between left and right handers with regard to the performance level (PL), both with the preferred and non-preferred hands.

5.3.3 Cluster Analysis

Classically, a cluster analysis classifies data into two or more groups that are mutually exclusive (Tabachnick & Fidell, 2000). In order to assess if the handedness groups based on the system described above were statistically different, the *profile* scores were subjected to a K-means cluster analysis to differentiate between left and right handers. The following F-values denoting the magnitude of difference between clusters were found: 2-group, $F = 505.492$; 5-group, $F = 841.467$; and 8-group, $F = 837.035$. For the

2-group classification, the final cluster centres of -14.3 and 15.8 showed 100% correspondence with the left and right handed classification. Table 5.4 illustrates the percentage of association between clusters and handedness categories for the 8-group classifications (see Appendix 5B for the 5-group classification).

Table 5.4. Correspondence Between Clusters and Handedness Categories for the 8-Group Classification Based on Profile Scores

	Cluster 3 L+ n = 8 CC: -21.1	Cluster 5 L n = 10 CC: -16.9	Cluster 8 L- n = 6 CC: -10.8	Cluster 7 V(l) n = 4 CC: -3.3	Cluster 4 V (r) n = 2 CC: 8.7	Cluster 2 R- n = 10 CC: 12.8	Cluster 1 R n = 13 CC: 17.3	Cluster 6 R+ n = 5 CC: 21.3
Category L+	7 88%							
Category L	1 12%	7 70%	1 17%					
Category L-		3 30%	5 83%					
Category V(l)				4 100%				
Category V(r)					1 50%	2 20%		
Category R-					1 50%	6 60%		
Category R						2 20%	13 100%	2 40%
Category R+								3 60%

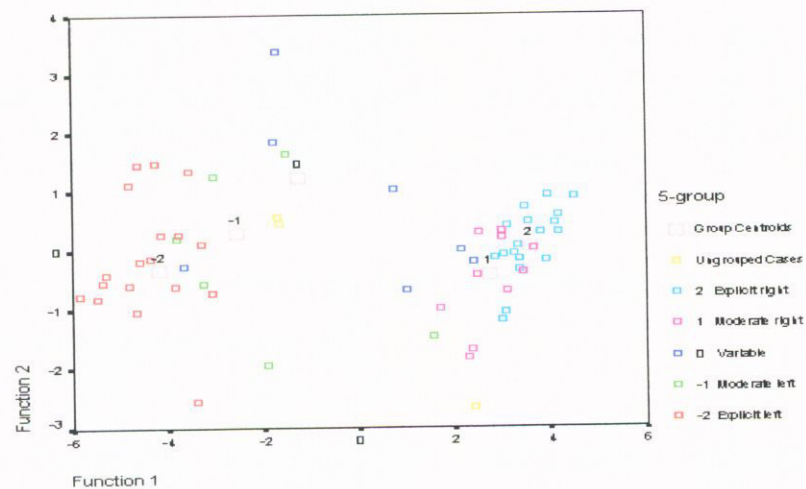
Note. The top figure denotes the number of cases showing correspondence between cluster and category, and the figure underneath illustrates the corresponding percentage. CC = cluster centre. L+ = explicit left, L = moderate left, L- = mild left, V(l) = variable left, V(r) = variable right, R- = mild right, R = moderate right, R+ = explicit right. Figures in bold donate the majority of overlapping cases, the orange squares indicate 100% correspondence between clusters and categories, and the yellow squares the remaining cases.

In the moderate right and variable left categories there was 100% agreement between clusters and categories. The overall agreement for the 8-Group classification was 82% between clusters and categories, and the remaining cases that did not show 100% cluster-category correspondence were classified in categories immediately adjacent.

As cluster analyses are frequently used in conjunction with discriminant function analyses (Tabachnick & Fidell, 2000), the 5-group classification, which formed the basis for the discriminant function analysis, was also used for a cluster analysis on the eleven handedness measures (i.e., 6 IHD measures and 5 PL measures). Some measures showed highly significant differences and high F-values, while others did not (see Table 5.5 for a summary). Whereas IHD measures showed significant differences between clusters with high F-values on all the measures except Bimanual Coordination, the PL measures failed

60.0% in moderate right handers, and 77.8% explicit right handers. Figure 5.7 displays a canonical discriminant function graph of the 5-group handedness classification based on the IHD measures.

Figure 5.7. Canonical Discriminant Function Graph of the 5-Group Handedness Classification Based on Interhand Difference (IHD) Measures



Note. Functions refer to predictive factors. Function 1 = trained FHP; Function 2 = untrained FHP.

The canonical discriminant function graph displays few explicit right handers particularly in regard to untrained FHP (Function 2). Conversely, left handers displayed more explicit and more variable behaviour compared to right handers for both predictive factors.

5.3.5 Summary of the Handedness Profile

In order to present a more precise overview of the average profiles achieved for the handedness groups, the *mean* IHD and PL measures of each of the eight categories (i.e., ranging from 1 to 8) are listed in Table 5.8.

Table 5.8. Summary of Mean Profile Categories in Interhand Difference (IHD) and Performance Level (PL) Measures Across all Handedness Categories

IHD Measures	Mean Category Scores							
	L+ (n=8)	L (n=10)	L- (n=6)	Vl (n=5)	Vr (n=2)	R- (n=10)	R (n=13)	R+ (n=5)
uFHP	1.25	2.30	3.17	6.00	6.00	6.20	7.15	7.80
tFHP	1.38	1.70	3.00	3.20	5.00	6.30	6.92	7.80
Ability	1.13	2.40	2.83	3.80	5.50	6.90	6.85	8.00
Skill	2.63	2.80	3.00	3.20	5.50	6.10	6.15	6.40
MCQ	1.38	2.80	3.00	5.40	6.50	5.80	7.08	7.40
BC	3.50	3.00	2.67	3.00	6.00	7.67	7.25	7.00

(table continues)

Table 5.8 (continued)

<i>PL Measures</i>	<i>Mean Category Scores</i>							
	L+ (n=8)	L (n=10)	L- (n=6)	VI (n=5)	Vr (n=2)	R- (n=10)	R (n=13)	R+ (n=5)
Cons	1.50	1.80	2.83	2.80	6.00	7.10	7.08	7.80
Ability	1.50	1.60	2.50	2.20	7.00	6.70	6.77	7.20
Skill	1.75	1.60	2.50	1.80	7.00	7.00	7.23	7.20
MCE	1.38	2.10	2.50	2.20	6.50	6.80	7.15	7.40
BC	2.25	1.86	2.25	2.67	8.00	7.43	6.75	6.75

Note. IHD = Interhand Differences; PL = Performance Level; uFHP = untrained Functional Hand Preference; tFHP = trained Functional Hand Preference; MCQ = Midline Crossing Quotient; MCE = Midline Crossing Extent; BC = Bimanual Coordination; Cons = Consistency.

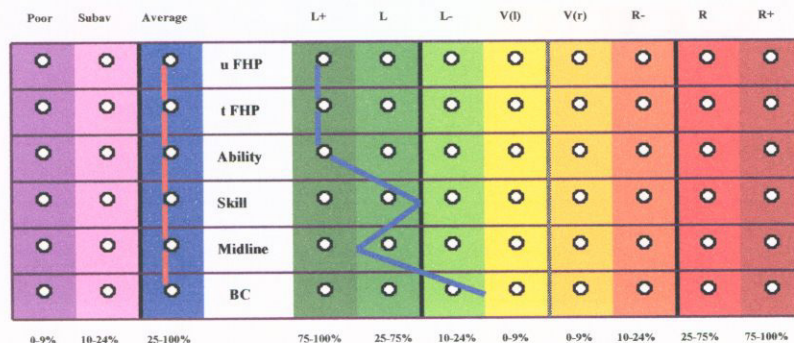
These means of the profile categories were plotted as profile charts (see Figure 5.8), a process hereon referred to as *profiling*.

The left three columns (blue, pink and purple) display the PL. The blue column contains both the above average range (76th to 100th percentile) and the average performance range (25th to 75th percentile), the pink column represents the subaverage range (24th to 10th percentile) and the purple column the poor range (0 to 9th percentile). Consistency was taken as the performance measure on both untrained and trained Functional Hand Preference (FHP). The white column lists the handedness measures, to the right of which the coloured columns depict the eight IHD-based handedness categories ranging from explicit left to explicit right.

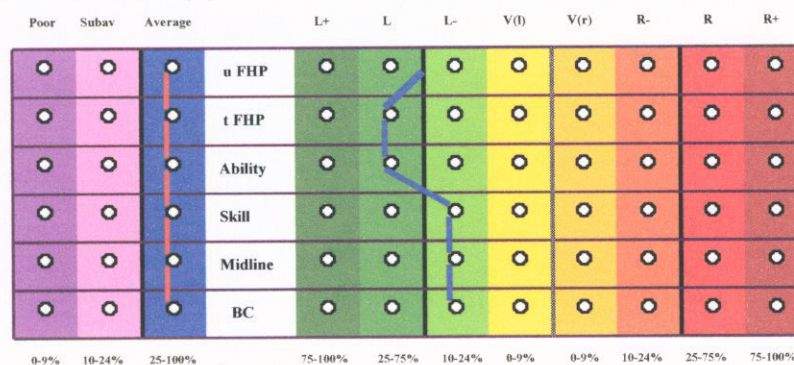
Percentages at the bottom of the columns indicate the percentile ranges for each category. Category scores from 0.75 were rounded upwards (e.g., 1.75 was plotted in the Moderate Left category, L) whilst values of 0.25 were rounded downwards (e.g., 5.25 was plotted in the Variable Right category, Vr). Category scores between 0.26 and 0.74 were plotted between the categories (i.e., on the line dividing the columns).

Figure 5.8. Normative Handedness Profiles Based on Mean Profile Categories for All Handedness Measures Plotted as a Chart

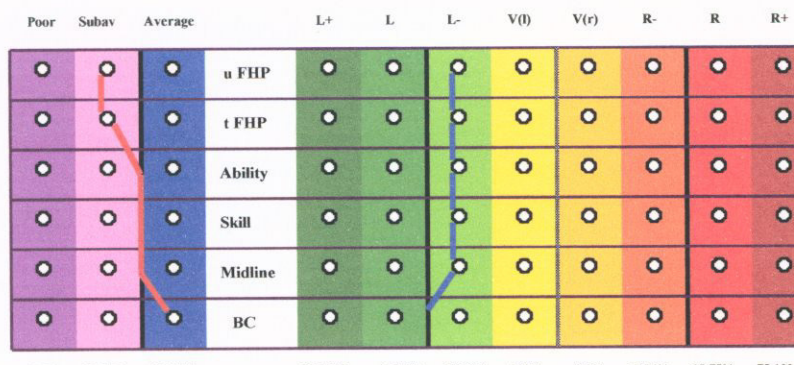
Explicit Left Handers (L+)



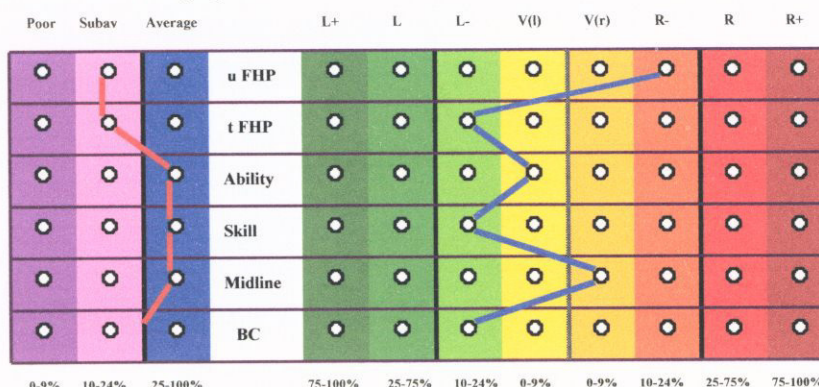
Moderate Left Handers (L)



Mild Left Handers (L-)



Variable Left Handers (Vl)



(figure continues)

Figure 5.8. (continued)

Variable Right Handers (Vr)



Mild Right Handers (R-)



Moderate Right Handers (R)



Explicit Right Handers (R+)



The normative profile charts illustrate a clear shift from the explicit left to the explicit right category, with a reasonable correspondence between the overall handedness classification and the individual category scores. Only mild left handers displayed a perfect correspondence apart from Bimanual Coordination, which exhibited the least agreement with the overall classification. Variable left handers clearly showed the greatest incongruence. Interestingly, the Skill IHD values tended to be smaller than other IHD values in both explicit groups. For explicit and moderate handers all PL values were in the average range. Consistency, the performance level measure for FHP tasks, presented in the subaverage range for mild left handers and variable left and right handers, but not for mild right handers. Even though some performance levels bordered on the subaverage range in the mild and variable groups, apart from FHP (Consistency) none were categorized in the subaverage or poor ranges.

In the absence of absolute measure for handedness, and the presence of other factors influencing handedness presentation, an *approximate* range of profile scores and a typical description was provided as a guideline and a basis for confirming the final profile classification. This information was based on previous normative data and discussion of different handedness measures to assist the overall classification process (see Table 5.9). Thus, the capacity of the handedness profile to classify handedness requires not only the ability to categorise scores, but also the means to investigate individual scores within the assigned categories in relation to normal and irregular handedness development.

Table 5.9. Description of Typical Handedness Presentation in the Eight Handedness Categories as Guidelines for a Handedness Profile Classification

<i>Handedness Category</i>	<i>Typical Presentation</i>
Explicit Left Hander L+ <i>Approximate range of profile scores: -17 to -24</i>	<ul style="list-style-type: none"> - Scores uFHP, tFHP and MC should be in L+ - Ability, Skill and BC can be scored in L+, L or L- - No scores except BC should be in VI - There should be no incongruence
Moderate Left Hander L <i>Approximate range of profile scores: -10 to -16</i>	<ul style="list-style-type: none"> - Scores uFHP, tFHP and MC should be in L+ or L - Ability, Skill and BC can be scored in L+, L, L- or VI - There should be no incongruence, or if yes, only up to Vr
Mild Left Hander L- <i>Approximate range of profile scores: -5 to -9</i>	<ul style="list-style-type: none"> - Two scores of uFHP, tFHP and MC should be in L or L- - Ability, Skill and BC can be scored in categories up to R- - There may be incongruence up to R- but not beyond - At least 4 scores should fall between L+ and VI

(table continues)

Table 5.9. (continued)

<i>Handedness Category</i>	<i>Typical Presentation</i>
Variable (left) Hander Vl <i>Approximate range of profile scores: 0 to -4</i>	- At least two of uFHP, tFHP and MC should be in L, L- or Vl, if not, then 'variable hander' without left hand tendency might apply - Ability, Skill and BC can be scored in any category - There may be large incongruencies up to R+
Variable (right) Hander Vr <i>Approximate range of profile scores: 0 to 4</i>	- At least two of uFHP, tFHP and MC should be in R, R- or Vr, if not, then 'variable hander' without right hand tendency might apply - Ability, Skill and BC can be scored in any category - There may be large incongruencies up to L+
Mild Right Hander R- <i>Approximate range of profile scores: 5 to 9</i>	- Two scores of uFHP, tFHP and MC should be in R or R- - Ability, Skill and BC can be scored in categories up to L- - There may be incongruence up to L- but not beyond - At least 4 scores should fall between R+ and Vr
Moderate Right Hander R <i>Approximate range of profile scores: 10 to 16</i>	- Scores uFHP, tFHP and MC should be in R+ or R - Ability, Skill and BC can be scored in R+, R, R- or Vr - There should be no incongruence, or if yes, only up to Vl
Explicit Right Hander R+ <i>Approximate range of profile scores: 17 to 24</i>	- Scores uFHP, tFHP and MC should be in R+ - Ability, Skill and BC can be scored in R+, R or R- - No scores except BC should be in Vr - There should be no incongruence

Note. L+ to R+ refer to categories of handedness ranging from explicit left to explicit right. FHP = Functional Hand Preference; u = untrained; t = trained; MC = Midline Crossing; BC = Bimanual Coordination. If a child receives a score of 0, this would be classified in both Vl and Vr categories.

5.4 Discussion

5.4.1 Discussion of Results

The analyses performed in this chapter indicate that all three experimental hypotheses were accomplished. The first experimental hypothesis, that the Handedness Profile Test Battery would unambiguously distinguish left handers from right handers, was clearly demonstrated in virtually all cases and handedness measures, with only a few cases falling in the variable category. Overall, profiling the data demonstrated similar patterns of performance in left and right handers, but at the same time, it also indicated differences sensitively. For example, profiling detected more instances of incongruence in left handers who employed the non-preferred hand to a greater extent than their right handed counterparts for certain tasks. Others have referred to incongruence, as defined in this thesis, as ‘inconsistency’, which has frequently been reported as a typical characteristic in left handers (e.g., Bryden, Bulman-Fleming & McDonald, 1996; Cherry & Kee, 1991; Dunaif-Harris, 1984; Peters & Servos, 1989). In the present study, the 8-group handedness classification of the profile revealed a large number of left handers congregating in the variable category, whilst most right handers were grouped in the moderate category.

The second experimental hypothesis stating that the modified tests of the normative profile would distinguish between multiple handedness categories (i.e., 5-group and 8-group classification) based on the degree of handedness, was also fulfilled, as revealed in the cluster analysis. Schachter (2000) also compared multiple categories of handedness to the left/right distinction in a study using the Edinburgh Handedness Inventory, where the laterality quotients based on a binominal classification (i.e., left versus right) were compared to those of a 5-group classification (i.e., always left, usually left, no preference, usually right, always right). The author concluded that the 2-group classification was distinctive of the *direction* of ‘handedness’, whereas the 5-group classification reflected the *degree* thereof.

As predicted for a normative sample, multiple classifications in the present study resulted in the mild and variable categories containing very few cases, because of the diminished likelihood of many variable/unestablished handers in a normative sample at an age when

handedness is fairly well established. However, the present analysis of a normative sample was not aimed at assessing *if* an 8-group system would be a viable option for handedness classification. Had this been the case, the inevitable conclusion would have been that there are not sufficient cases in the middle categories to warrant an 8-group classification system. Instead, the underlying assumption has been that variable handers, particularly those present in clinical populations, require a specific method of classification that reflect their *degrees* of handedness within the variable category. The present analysis was merely employed to indicate the range of normal variable handers. However, because of the limited number of cases, the results are preliminary and should be interpreted with caution.

All interhand difference measures, apart from Bimanual Coordination, showed significantly different clusters between left and right handers, whilst the performance level measures did not display such a pattern. This indicates that the difference between the hands was more consistent with the overall profile classification than the performance level of each hand. In other words, there was no strong relationship between interhand differences and performance levels. A child might score high or low on the performance measures regardless of the extent of interhand differences. It is thus likely that interhand difference and performance level measures have different underlying factors.

The third experimental hypothesis, that some measures or components would emerge as predictive factors for handedness, was also achieved. However, the predictive factors evolving from the normative profile differed according to the categorisation of the sample. When the sample was divided into left and right handers (2-group classification), trained Functional Hand Preference and Skill emerged as predictive factors. The literature abounds with studies suggesting that trained and skilled items such as writing and cutting are the most reliable tasks (Chapman & Chapman, 1987; Raczkowski, Kalat & Nebes, 1974) and appear to indicate the *direction* of handedness (Schachter, 2000). In this context, the 'trained' nature of the two predictive factors is not unexpected. It is conceivable that the interplay between a predisposed preferred hand and the development of motor skill through practice and repetition would result in the strongest handedness presentation.

However, when the sample was analysed according to the 5-group classification, the two strongest predictive factors from the profile were trained and untrained Functional Hand Preference tasks. It is possible that more variable handers require predictive factors that extend beyond trained and skilled tasks and contain elements of handedness reflecting a more inherent or predisposed aspect. These results appear to confirm that untrained Functional Hand Preference tasks comprise of elements that are relatively free from environmental influence, representing an aspect of handedness that has been considered by several authors substantial in determining handedness (Coren, 1992; Harris, 1990; Olsson & Rett, 1989; Porac, Coren & Searleman, 1986; Richberg, 1987; Sakano, 1982; Sattler, 1998, 1999; 2001, 2002).

Moreover, the ability of the handedness profile to reveal greater variability in left handers than right handers was facilitated by the division between trained and untrained Functional Hand Preference tasks. Moderate and mild left handers frequently used the right non-preferred hand for *trained* tasks, a behaviour not seen in right handers. Instead, left handers showed more consistent left hand use in *untrained* tasks. Conversely, right handers showed the opposite pattern by displaying greater variability in hand use during untrained tasks and more consistency in trained tasks. The separation of trained and untrained hand preference tasks in the profile thus appears justified, and lends further support to the proposition stressing environmental influences with a right-handed bias on certain hand preference tasks (Coren, 1992; Olsson & Rett, 1989; Porac, Coren & Searleman, 1986; Sattler, 1998, 2001, 2002; Stutte, Schilling & Weber, 1977). Interestingly, Skill interhand difference did not feature as a predictive factor in the 5-group classification, suggesting that the superior skill performance of one hand above the other is not necessarily strongly indicative of differentiating between varying extents of left or right handedness.

Bimanual Coordination was the only interhand difference measure that did not show a significantly different cluster between left and right handers in the 5-group cluster analysis. This may be due to different motor system organisation for this particular bimanual simultaneous tasks where one hand entrains to the other (Kelso, 1984; Mudie, 2000; Mudie & Matyas, 1996; Scholz & Kelso, 1990; Turvey, 1990; Zanone & Kelso, 1992), and interhand difference would not be an obvious feature since the two hands act as a unit. Research has revealed that interhand differences in bimanual simultaneous

tasks are dramatically reduced compared to the large differences often observed in unimanual performance (Kelso, 1984; Mudie & Matyas, 1996, 2000; Scholz & Kelso, 1990; Turvey, 1990; Zanone & Kelso, 1992). This appears to be particularly true for left handers. Research by Gorynia and Egenter (2000) revealed that less pronounced left handers (probably comparable to the mild to variable categories of the normative handedness profile) not only showed smaller interhand differences in a bimanual tasks than their right handed counter parts but also a higher level of bimanual coordination.

However, these findings contrast with those studies displaying a definite asymmetry in bimanual tasks where the preferred hand takes a leading role (e.g., Carson, Thomas, Summer, Walters & Semjen, 1997; Semjen, Summers & Cattaert, 1995). A temporal component (i.e., executing the bimanual movement as fast as possible) and a greater number of repetitions constitute two major differences between these studies and the present one. It is thus possible that greater asymmetry between the hands, or increased interhand differences, might be revealed during faster and more prolonged bimanual circular movement.

Alternatively, it is possible, that significant interhand differences might only become apparent in a clinical sample, where children have difficulty performing bimanual coordinated movement and the right and left neural systems are less entrained. Thus, Bimanual Coordination interhand differences might be an important feature when applying the handedness profile to a clinical sample of children with unestablished handedness. Furthermore, it is worthwhile noting that Bimanual Coordination performance levels were significant when the sample was analysed according to the 2-group classification of left and right handers, suggesting that Bimanual Coordination is related to the other handedness measures when the *direction* of handedness is emphasised.

The normative profile did not detect significant differences in *performance levels* of Ability, Skill or Bimanual Coordination between left and right handers. This finding is not unexpected, since the analyses were based on a normative sample where many cases of subaverage motor performance would be unlikely. However, on closer investigation, the profile was sufficiently sensitive to detect a difference in performance levels between explicit and moderate/mild left handers, even though it did not reach statistical

significance. Explicit left handers were least likely perform below average on the motor tasks, while moderate left handers were most prone to subaverage motor performance. Similar results were observed when Consistency and Midline Crossing were investigated separately.

Whilst explicit left and right handers showed similar performance in all aspects of handedness, the normative profile disclosed a greater difference between explicit and moderate left handers than between explicit and moderate right handers. Similarly, Annett repeatedly found a stronger asymmetry in left handed scores than in right handed scores (Annett, 1992a, 1993; Annett & Kilshaw, 1984; Annett & Manning, 1989, 1990), as did Gorynia and Egenter (2000), who combined a distinction between familial/non-familial and 'strong/weak' left handers. The finding that strong and consistent left handers highly resemble right handers is also in accordance with the literature (Annett, 1970; Harris & Carlson, 1988; Peters & Murphy, 1992; Peters & Servos, 1989).

Furthermore, according to the normative profile, *moderate* left handers scored even lower on motor-based tasks (i.e., Skill, Ability and Bimanual Coordination), Midline Crossing and Consistency than *variable* handers, and any other category in the 5-group classification. One interpretation could be that a handedness profile with low scores in motor-based tasks, Midline Crossing and Consistency, is 'normal' in the moderate left hander. Alternatively, moderate left handers as a group may be more likely to display subaverage performance on the handedness profile. This finding requires further investigation using a larger normative sample than the present study.

5.4.2 Conclusion

This chapter confirmed that the handedness profile developed on a normative sample is capable of clearly differentiating degrees of handedness on a continuum from explicit left through variable to explicit right handedness on all handedness measures. Furthermore, the manifestations of handedness as revealed by the profile is consistent with the current literature. The normative profile disclosed a distinction between interhand differences and performance levels. These results indicate a possible division between environmentally influenced aspects of handedness (e.g., trained Functional Hand Preference tasks and Skill), and more innate, predisposed elements (e.g., untrained

Functional Hand Preference tasks), as revealed by the discriminant analyses. So far, these tentative distinctions between aspects of handedness reflect unique individual differences that have not been routinely identified in existing tests.

The normative handedness profile confirmed the more heterogenous behaviour and higher incidence of incongruence in left handers compared to right handers, as frequently cited in the literature (e.g., Bryden, Bulman-Fleming & MacDonald, 1996). In addition, the profile's ability to distinguish specifically between explicit and moderate left handers, revealed greater homogeneity in each of these two left handed groups compared to the two right handed counterparts. At the same time, a greater variability was found in moderate and mild right handers than their left handed counterparts. These differentiated findings further support the importance of classifying the various aspects of handedness into multiple categories in a handedness profile. For example, discriminant analysis exposed different additional predictive factors (e.g., untrained Functional Hand Preference tasks and Midline Crossing) with multiple categories compared to a binomial left-right analysis. It is possible that similar, or altogether different predictive factors might emerge from profiling children with unestablished handedness presenting for therapy.

In summary, the normative handedness profile constructed in this chapter provides unique details on the degrees of various handedness dimensions, and the use of an 8-group classification system as a basis for the normative profile seems to be justified. The profile appears to be a promising measure against which the individual handedness profiles of a sample of children presenting with unestablished handedness can be investigated. The usefulness of the normative profile will thus be explored further by applying it to a clinical sample in the following chapter. Implications for treatment are discussed in the final chapter.

CHAPTER 6

THE APPLICATION OF THE NORMATIVE HANDEDNESS PROFILE TO A CLINICAL SAMPLE

6.1 Introduction

This chapter is based on a fourth study where the constructed normative handedness profile, based on the Handedness Profile Test Battery, was applied to a clinical sample of children with minimal dysfunction and variable handedness establishment. The aim of this chapter is to evaluate how well the normative handedness profile detects degrees of handedness based on the modified measures, and to what extent children with variable handedness differ from the norm. Evaluation of the variability of the handedness profiles in a clinical sample compared to the normative profile, and examination of predictive factors for a clinical sample, are presented and discussed. The nature of clinical handedness profiles, and how they diverged from the norm, was investigated. In this context, different factors or *features* of handedness were explored in several case studies.

6.1.1 Experimental Hypotheses

Three experimental hypotheses were identified for the present study.

Experimental Hypothesis 1: The application of the normative profile would detect a wide range of responses and various degrees of handedness according to the 8-group classification system in all handedness measures in the clinical sample.

Experimental Hypothesis 2: The strongest predictive factor identified through the discriminant functional analysis in the normative profile (i.e., trained FHP) would also emerge as a predictive factor in the clinical sample. However, there would be different predictive factors to the normative profile when larger numbers of categories are subjected to the analysis. These predictive factors would be sensitive to greater variability, reflected in those handedness measures that are less subjected to training and environmental influence, such as midline crossing and bimanual coordination.

Experimental Hypothesis 3: The handedness profiles of most children with variable handedness would clearly differ from the normative profiles, particularly in regard to an increased presence of identified handedness features indicative of specific types of problems with the establishment of handedness.

6.2 Method

6.2.1 Participants

The present study involved 68 children (13 girls, 55 boys) aged 4 years ($n = 22$), 5 years ($n = 22$), 6 years ($n = 20$) and 7 years ($n = 4$) attending occupational therapy. All children were reported by parents, teachers and/or therapists to have variable hand preference. Parents and teachers were asked to rate the child's handedness according to a 5-point scale on the initial questionnaire (see Appendix 2B). All presenting children were included in the study, and some of their ages exceeded those of the normative profile. However, the inclusion of 4- and 7-year old children was deemed acceptable for the following reasons. Firstly, the normative profile in its present form does not provide age norms but a cross-section of handedness presentation in school-entry children. Therefore, the normative profile can be applied to any age group since it compares the child's individual performance to a standard measurement of handedness establishment at 5 to 6 years. Secondly, results in Study II (Chapter 3) indicated that there was no age effect in the interhand difference (IHD) measures, the basis for the profile classification. This supports the use of the normative profile in 4-year old children. Some of the performance level (PL) measures, however, were significantly different between age groups (e.g., Skill). This would mean that when the profile score is interpreted together with the level of performance in a 4-year old child, subaverage or poor PL scores might be attributed to immaturity. Thirdly, there were only four 7-year old children. Since the normative handedness profile was based on a younger age group, identification of handedness variability and performance delays in an older child would only emphasise the magnitude of the child's problems.

This study focused on *minimally* affected children, so children diagnosed with disorders other than, or additional to, minimal brain dysfunction, developmental coordination deficit, perceptual motor deficit, sensory integration disorders or mild developmental delay were excluded from the study. Almost all children had fine and gross motor coordination deficits, a third showed sensory integrative related disorders, another third had mild speech and language delays, and approximately three quarters presented with learning disabilities. This information was obtained from the doctors' referral notes, and it was not analysed or related to the particular handedness profiles since this exceeded the scope of this study. Instead, the

clinical sample was analysed as a group with a common denominator, namely variable handedness coexisting with different types of minimal dysfunction that are addressed by occupational therapy intervention. Participants were recruited by obtaining parental permission through informed consent (see again Appendix 2A for an example of the Informed Consent Form). None of the subjects had received specific occupational therapy for establishing handedness. Ethics approval for all procedures conducted was obtained from La Trobe University (see Appendix 6A).

6.2.2 Tests and Instruments, Procedures, and Scoring of Modified Tests

Tests and instruments, procedure and scoring of modified tests were identical to those described under Sections 4.2.2 and 4.2.3 on tests, instruments and procedures in Chapter 4. Scoring of the handedness profile was discussed under Section 5.2.2 in Chapter 5.

6.2.3 Data Analysis

Scores on the individual handedness measures of the clinical group were classified according to the eight normative profile percentile ranges. Based on the results of the handedness profile, children were classified as *profiled* left handers (i.e., those achieving a negative profile score), or *profiled* right handers (i.e., those obtaining a positive profile score). As in the previous chapter, a K-means cluster analysis was performed to establish group membership using the profile scores. This analysis included ANOVA to investigate if the handedness groups differed significantly from each other. Descriptive statistics were employed to obtain the means (SD) of the different categories, and frequency distributions were performed to compare distributions of the handedness measures between children with variable handedness and the normative profile. Sequential discriminant function analyses were then executed to determine the predictive factors for the clinical sample. Furthermore, one-way ANOVA was used with specific handedness features to determine whether groups based on these features were significantly different. Finally, key handedness features were identified and refined. The identification process of handedness features emerged as an integral part of the Results section to provide an analytic basis for the presentation of individual handedness profiles illustrating key handedness features.

6.3 Results

6.3.1 Comparative Statistics

6.3.1.1 Comparing the Distributions of the Handedness Measures in the Clinical Sample to the Normative Profile

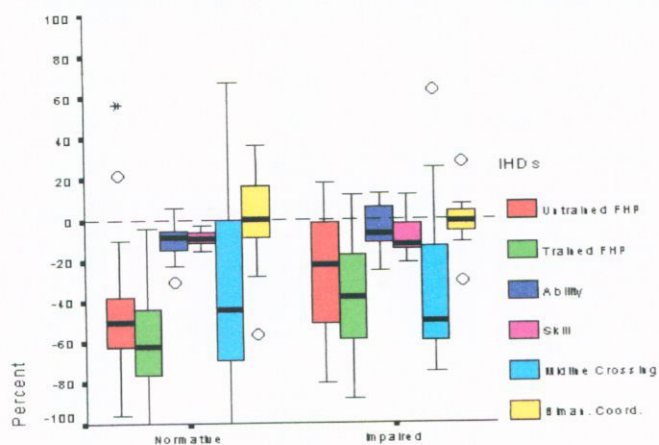
Profiling of the clinical sample resulted in 11 profiled left handed classifications and 57 profiled right handed classifications. When the minimally dysfunctional children with variable handedness are compared to the normative profile (also referred to as the *norm*), they are termed *clinical* sample or *clinical* left/right handers. The presentation of the following analyses is based on these groups.

Interhand Differences (IHD).

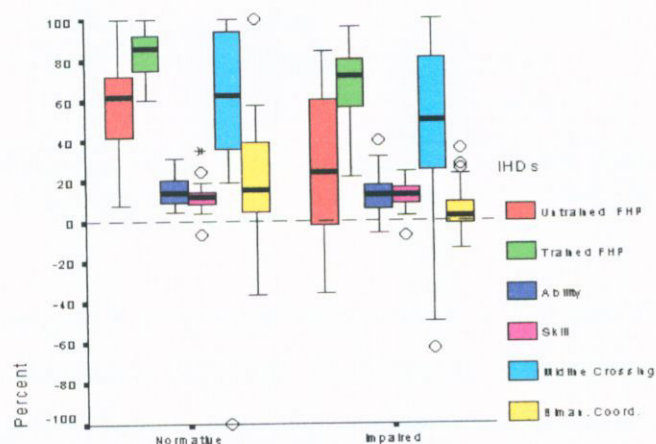
The distributions of interhand difference (IHD) measures in left and right handers comparing the clinical sample to the normative profile are displayed in Figure 6.1 and Table 6.1. It is apparent that clinical handers showed greater variability in all measures except 'Midline Crossing. Trained Functional Hand Preference (FHP), untrained FHP and Midline Crossing displayed the greatest IHD values in both the clinical sample and the normative profile. Conversely, Bimanual Coordination, Ability and Skill demonstrated the smallest IHD values across the samples.

With the exception of Skill IHD, Midline Crossing and Bimanual Coordination in left handers, all other measures showed a lower mean in the clinical sample compared to the normative profile, indicating smaller IHD values. Clinical left handers also showed greater variability in Ability IHD and Skill IHD relative to the normative profile, while such a difference was not apparent in the two right handed groups. Furthermore, compared to the normative profile, clinical left handers displayed a wider range in Midline Crossing and Bimanual Coordination, while this was not observed in clinical right handers. Bimanual Coordination IHD values in clinical left handers were strongly kurtosed (2.49), indicating a narrow range of performance not displayed by clinical right handers who demonstrated a wider range of IHD values (kurtosis = 0.30).

Figure 6.1. Interhand Difference (IHD) Distributions in Clinical Left and Right Handers Compared to the Normative Profile



Comparing Clinical Left Handers to Normative Profile



Comparing Clinical Right Handers to Normative Profile

Note. The horizontal line inside the box plot is the *median*. * = extreme value; O = outlier; IHD = interhand difference; FHP = Functional Hand Preference; Biman. Coord. = Bimanual Coordination.

Table 6.1. Descriptive Statistics for Interhand Difference (IHD) Distributions in Clinical Left and Right Handers Compared to the Normative Profile

	Left Handers <i>Normative Profile</i>	Handers <i>Clinical Sample</i>	Right Handers <i>Normative Profile</i>	Handers <i>Clinical Sample</i>
<i>Mean (SD)</i>				
uFHP	-41.33±40.15	-27.20±34.82	58.00±23.31	24.25±35.20
tFHP	-61.44±24.25	-37.40±30.65	84.00±12.40	67.82±17.06
Ability	-9.88±8.36	-4.80±13.17	15.79±8.05	12.33±8.79
Skill	-8.46±3.88	-7.93±11.51	12.46±8.24	12.57±6.47
Midline Crossing	-33.17±48.71	-32.50±44.56	58.20±46.70	44.11±40.41
Bimanual Coord.	1.39±22.67	-0.500±14.77	21.69±28.71	5.00±10.67

(table continues)

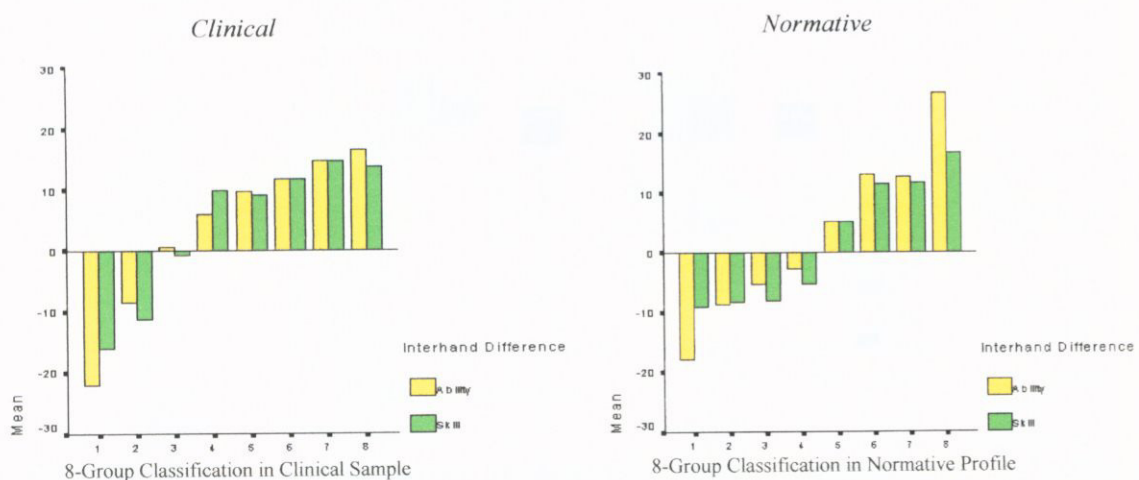
Table 6.1. (continued)

	Left Normative Profile	Left Handers Clinical Sample	Right Normative Profile	Right Handers Clinical Sample
<i>Skewness</i>				
uFHP	1.12 •	-0.16	-0.47	0.10
tFHP	0.60	0.07	-0.66	-0.77
Ability	-0.74	-0.23	0.54	0.41
Skill	-0.01	0.70	0.58	-0.30
Midline Crossing	0.34	1.42 •	-2.10 ♦	-0.70
Bimanual Coord.	-0.63	-0.20	0.82	0.49
<i>Kurtosis</i>				
uFHP	0.88	-1.63 •	0.09	-1.24 •
tFHP	0.50	-0.67	-0.62	-0.01
Ability	1.30 •	-1.27 •	-0.53	0.75
Skill	-1.08	-0.93	2.98 ♦	0.41
Midline Crossing	-0.69	1.19 •	6.30 ♦	-0.04
Bimanual Coord.	1.30 •	2.49 ♦	2.09 ♦	0.30

Note. uFHP = untrained Functional Hand Preference tasks; tFHP = trained Functional Hand Preference. Coord. = Coordination. \pm = standard deviation; • = skewness and kurtosis greater than 1; ♦ = skewness and kurtosis greater than 2.

Interestingly, BCT displayed a much more narrow range of data and a lower IHD mean in the clinical sample compared to the norm. To determine if the clinical sample contained more cases with large IHD values suggesting that one hand performs significantly poorer than the other, Skill and Ability were compared (see Figure 6.2) to the normative profile.

Figure 6.2. Ability and Skill Interhand Differences (IHD) in the 8-Group Classification of the Clinical Sample and the Normative Profile

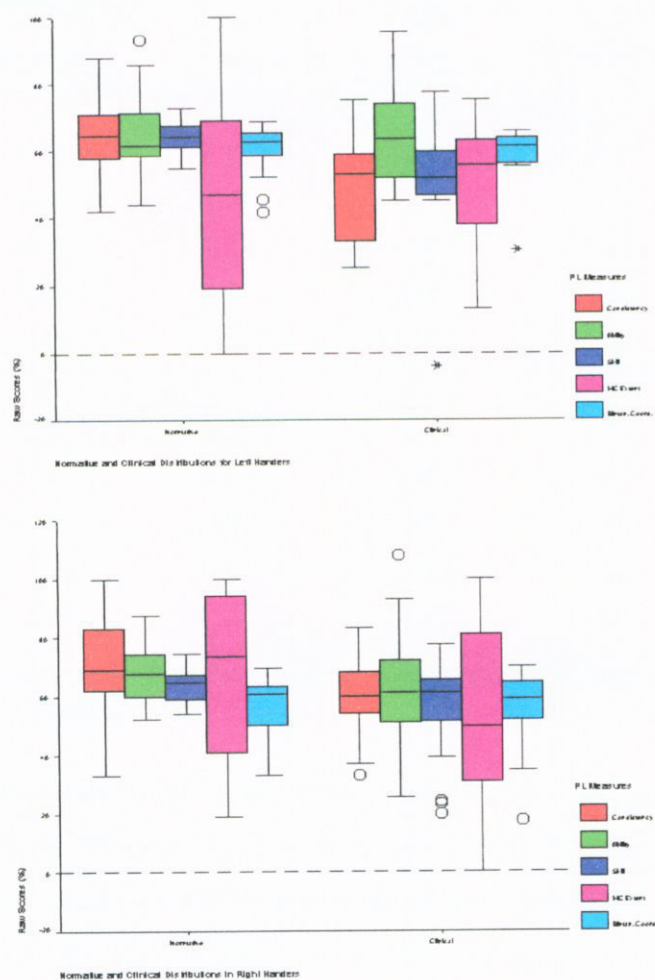


Only clinical explicit and moderate left handers and clinical variable right handers showed higher IHD means in Ability and Skill. The Ability IHD values were similar in explicit and moderate handers across clinical and normative samples, but clinical explicit right handers showed smaller Ability IHD values compared to the normative profile. In other words, whilst IHD values demonstrate a decrease from the explicit to the variable categories in the normative profile, this was not clear in the clinical sample.

Performance Levels (PL).

The distributions of the performance level (PL) measures of clinical left and right handers were compared to that of the normative profile (see Figure 6.3 and Table 6.2).

Figure 6.3. Comparing Performance Level (PL) Distributions in Clinical Left and Right Handers to the Normative Profile



Note. The horizontal line inside the box plot denotes the median. * = extreme values, O = outlier; PL = performance level; MC = Midline Crossing; Biman. Coord. = Bimanual Coordination.

Apart from a wide variety of Midline Crossing in the normative profile displayed in the above figure, only clinical left handers showed greater variability in the other PL measures. The variability in clinical right handers appeared to be similar to that of the normative profile.

Table 6.2. Descriptive Statistics for Performance Level (PL) Distributions in Clinical Left and Right Handers Compared to the Normative Profile

	Left Handers		Right Handers	
	<i>Normative Profil</i>	<i>Clinical Sample</i>	<i>Normative Profil</i>	<i>Clinical Sample</i>
<i>Mean (SD)</i>				
Consistency	65.56±11.79	49.80±16.03	70.95±15.28	60.35±12.37
Ability	64.95±12.00	65.45±15.80	67.53±9.75	61.55±15.67
Skill	64.52±4.64	49.67±21.46	63.50±5.31	57.37±12.49
Midline Crossing	47.50±33.89	50.10±19.24	68.20±29.17	52.53±28.36
Biman. Coord.	60.57±7.45	57.84±10.39	56.70±11.20	57.14±10.11
<i>Skewness</i>				
Consistency	0.14	-0.31	-0.22	-0.08
Ability	0.79	0.62	0.34	0.22
Skill	0.00	-1.77 •	-0.22	-1.14 •
Midline Crossing	0.09	-0.91	-0.32	0.06
Biman. Coord.	-1.15 •	-2.43 ♦	-1.10 •	-1.52 •
<i>Kurtosis</i>				
Consistency	0.20	-0.74	0.99	-0.44
Ability	0.88	-0.24	-0.56	0.68
Skill	0.01	4.92 ♦	-0.42	1.33 •
Midline Crossing	-1.16 •	0.09	-1.55 •	-1.00 •
Biman. Coord.	1.65 •	6.58 ♦	0.01	3.17 ♦

Note. Biman. Coord. = Bimanual Coordination; ± = standard deviation; • = skewness and kurtosis greater than 1, ♦ = skewness and kurtosis greater than 2.

On examining Skill and Consistency means, clinical left handers performed notably lower than the normative profile. Meanwhile, clinical right handers displayed lower means of Midline Crossing, Consistency and Ability compared to the norm. Thus, Consistency was lower in both clinical left and right handers, and Ability and Skill showed larger standard deviations in clinical handers, indicating a wider range of PL values compared to the normative profile. Midline Crossing also demonstrated a wide range in all groups except in

clinical left handers. There were no obvious differences in Bimanual Coordination PL values. Whilst Bimanual Coordination and Midline Crossing revealed some skewness and kurtosis in the profile, there was markedly more skewness and kurtosis in the clinical sample, particularly in Bimanual Coordination and Skill, indicating abnormal distributions.

6.3.1.2 Significant Differences Between the Clinical Sample and the Normative Profile

The clinical sample was compared with the normative profile to determine significant differences on all individual handedness measures. The Mann-Whitney U test was used because of unequal numbers on left and right handers in both samples (see Table 6.3).

Table 6.3. Significant Differences in Handedness Measures Between the Clinical Sample and the Normative Profile

<i>Handedness Measures</i>	Left Handers		Right Handers	
	<i>z-score</i>	<i>p</i>	<i>z-score</i>	<i>p</i>
Untrained FHP	-0.873	0.383	-3.881	0.000**
Trained FHP	-1.949	0.051*	-4.502	0.000**
Consistency	-2.467	0.014*	-3.723	0.000**
Ability IHD	-1.015	0.310	-1.424	0.154
Ability PL	-0.337	0.505	-2.175	0.030*
Skill IHD	-1.159	0.247	-0.572	0.567
Skill PL	-2.839	0.005**	-2.870	0.004**
Midline Crossing Quotient	-0.086	0.932	-1.287	0.198
Midline Crossing Extent	-0.874	0.382	-0.863	0.388
Biman. Coord. IHD	-0.413	0.680	-3.085	0.002**
Biman. Coord. PL	-1.115	0.265	-0.047	0.963

Note. IHD = interhand difference; PL = performance level; FHP = Functional Hand Preference; Biman. Coord. = Bimanual Coordination; * = significant at 0.05; ** = significant at 0.01.

The difference in Skill PL values was highly significant in left and right handers, with clinical left handers demonstrating a mean of 49.7 ± 21.4 for the clinical sample, in comparison to the normative profile mean of 64.5 ± 4.6 . The mean of 57.4 ± 12.5 for clinical right handers was also lower than the normative mean of 63.5 ± 5.3 . Both trained FHP and Consistency were significantly different at the 0.05 level in left handers, and at an even higher significance level ($p \leq 0.01$) in right handers.

Whilst none of the remaining measures were significantly different from the normative profile in left handers, right handers displayed highly significant differences in untrained

FHP, with an clinical sample mean of 24.2 ± 35.2 against the profile mean of 58.0 ± 23.3 . Similarly, clinical right handers demonstrated a Bimanual Coordination IHD mean of 5.0 ± 10.7 , which differed significantly from normative right handed mean of 21.7 ± 28.7 . Finally, Ability PL also revealed significant differences in right handers (clinical sample mean: 61.6 ± 15.7 ; normative mean: 67.5 ± 9.8). Once again, the means were lower in the clinical sample. Performance levels in Midline Crossing, Skill, Ability and Bimanual Coordination did not demonstrate significant differences between the clinical and normative means.

6.3.1.3 Comparing Incongruence of the Clinical Sample to the Normative Profile

Incongruence is reflected when one hand scores in the left categories (i.e., L+, L, L- or VI), and the other in the right categories (i.e., R+, R, R- or Vr). More specifically, these should be at least one category between the incongruent categories (i.e., adjacent VI and Vr are not considered incongruent since the difference between them is too small, but VI and R-, or Vr and L- would be incongruent). Since there was minimal incongruence in the normative profile (i.e., mainly amongst variable left handers), incongruence could be an important aspect indicating problems with established handedness in a clinical sample. Table 6.4 summarises how the clinical sample compares to the normative profile.

Table 6.4. Incongruence of Interhand Difference (IHD) Measures in the Clinical Sample Compared to the Normative Profile

IHD Measures	<i>Left Handers</i>			<i>Right Handers</i>		
	Clinical I	Normative N	Difference %	Clinical I	Normative N	Difference %
<i>Untrained FHP</i>	27.3	22.6	I +4.7	31.6	3.2	I +28.4
<i>Trained FHP</i>	9.1	9.7	N +0.6	0.0	0.0	None
<i>Skill</i>	27.3	0.0	I +27.3	1.8	3.2	N +1.4
<i>Ability</i>	36.4	9.7	I +26.7	8.8	0.0	I +8.8
<i>Midline Crossing</i>	18.2	29.0	N +10.8	15.8	0.0	I +15.8
<i>Bimanual Coord.</i>	45.5	19.4	I +26.1	36.8	6.5	I +30.3

Note. IHD = interhand difference; FHP = Functional Hand Preference; Coord. = Coordination. The numbers in the clinical and normative columns indicate the percentage of cases showing incongruence. The + in the Difference columns denotes a higher percentage in either the Clinical group (I) or the Normative profile (N).

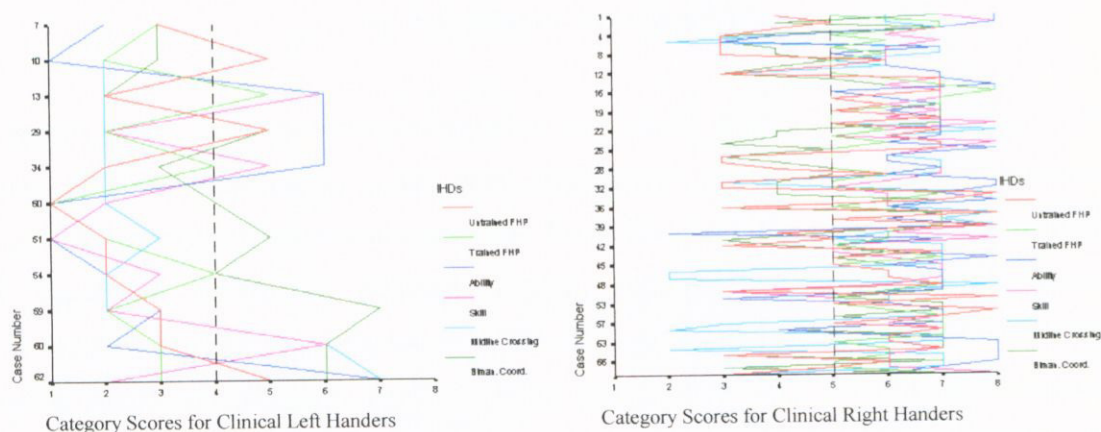
Overall, 28 (41%) of clinical handers demonstrated incongruous behaviour, compared to 14 (24%) of the normative sample making up the profile. There was considerably more incongruence amongst *clinical left handers* in Skill, Ability and Midline Crossing compared to the normative profile. All clinical left handers showed greater incongruence in untrained than trained FHP tasks, unlike the normative profile which demonstrated the opposite pattern in left handers. However, clinical left handers were more congruent in Midline Crossing than the normative profile.

Clinical right handers were also considerably more incongruent in untrained FHP tasks compared to the normative profile, but none of the right handers showed any incongruence on trained FHP. Clinical right handers were also more incongruent in Ability and Skill, but particularly in Bimanual Coordination.

6.3.2 Profile Classification of the Clinical Sample

To illustrate the comparison between clinical/profiled left and right handers in IHD measures using category scores, multiple line graphs were constructed (see Figure 6.4).

Figure 6.4. Comparing Category Scores of All Handedness Measures in Clinical Profiled Left and Right Handers

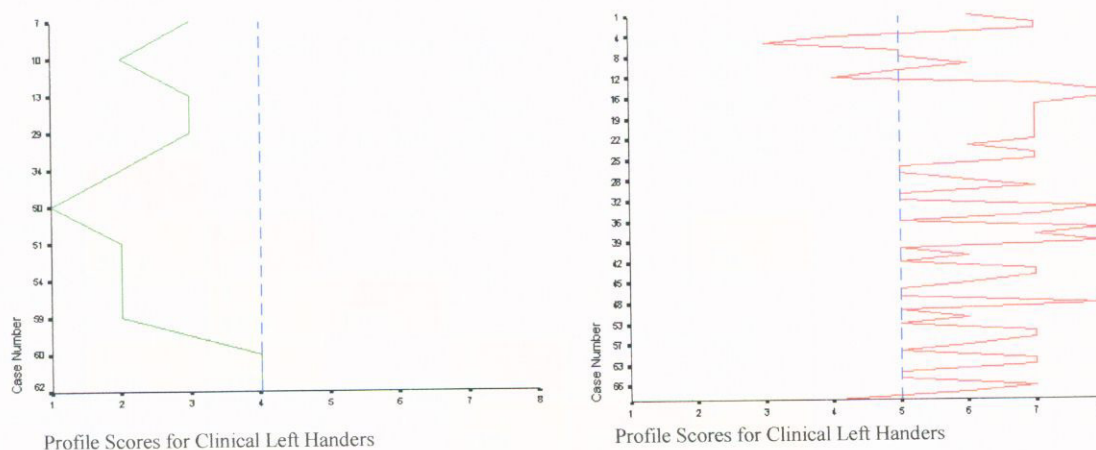


Note. The y-axis depicts individual cases and the x-axis displays the 8 handedness categories.

In both profiled left and right handers a wider scatter of IHD category scores was apparent due to greater incongruence in the clinical sample compared to the normative profile (see

again Figures 5.5 and 5.6 in Chapter 5 for comparison). Figure 6.5 compares the profile scores of the clinical sample in profiled left and right handers by means of line graphs.

Figure 6.5. Comparing Profile Scores Between Clinical Profiled Left and Right Handers



Note. The Y-axis depicts individual cases and the x-axis displays the 8 handedness categories.

Compared to the line graphs illustrating the normative sample (Figures 5.5 and 5.6), it is clear that there is a shift towards mild and variable categories and the definition between left and right, while still apparent, is less well defined.

6.3.3 K-Means Cluster Analysis

K-means cluster analyses were performed in the clinical sample using profile scores. Once again, different classification groups were employed to assess if the number of handedness groups determined or influenced clustering. The following F-values denoting the magnitude of significant differences between clusters emerged in the 2-group classification: $F = 563.744$; 5-group classification: $F = 763.906$; and 8-group classification: $F = 1242.035$. For the 2-group classification, the final cluster centers were -12.5 and 12.4 , and the majority of handedness measures showed 100% correspondence with the left and right handed classification. Of the 11 profiled left handers, ten (91%) corresponded with the clusters, and of the 57 profiled right handers, 53 (93%) could be matched with corresponding clusters. The association between clusters and handedness categories for the 8-group classifications is

displayed in Table 6.5 (see Table 5.5 in Chapter 5 for comparison; see also Appendix 6B and Appendix 5B for the 5-group classifications).

Table 6.5. Correspondence Between Clusters and Handedness Categories Based on Profile Scores for the 8-Group Classification

	<i>Cluster 1</i> <i>L+</i> <i>n = 4</i> <i>CC: -16.3</i>	<i>Cluster 8</i> <i>L</i> <i>n = 9</i> <i>CC: -11.5</i>	<i>Cluster 4</i> <i>L-</i> <i>n = 1</i> <i>CC: -6.0</i>	<i>Cluster 7</i> <i>VI</i> <i>n = 12</i> <i>CC: 7.6</i>	<i>Cluster 6</i> <i>Vr</i> <i>n = 11</i> <i>CC: 10.6</i>	<i>Cluster 2</i> <i>R-</i> <i>n = 20</i> <i>CC: 13.7</i>	<i>Cluster 5</i> <i>R</i> <i>n = 9</i> <i>CC: 16.5</i>	<i>Cluster 3</i> <i>R+</i> <i>n = 2</i> <i>CC: 21.0</i>
<i>Category L+</i>	1 25%							
<i>Category L</i>	2 50%	2 22%				1 5%		
<i>Category L-</i>		4 45%	1 100%					
<i>Category VI</i>	1 25%	3 33%		0 0%				
<i>Category Vr</i>				9 75%	3 27%	4 20%		
<i>Category R-</i>				3 25%	4 36.5%	2 20%	1 12%	
<i>Category R</i>					4 36.5%	13 65%	4 44%	
<i>Category R+</i>						4 44%	2 100%	

Note. The top figure denotes the number of cases showing correspondence between cluster and category, and the figure underneath illustrates the percentage of corresponding cases. CC = cluster center. L+ = explicit left, L = moderate left, L- = mild left, VI = variable left, Vr = variable right, R- = mild right, R = moderate right, R+ = explicit right. Squares containing the highest percentage were printed bold. Orange squares indicate a hypothetical 100% correspondence, and yellow squares the deviations thereof.

The overall agreement for the 8-Group classification was 82%. Compared to the K-means cluster analysis of the normative profile, which showed a high correspondence between clusters and handedness categories, the overlap was notably less in the clinical sample, with a general shift towards the right. In other words, in six of the eight categories, the majority of cases within a cluster were classified one category to the right. For example, Cluster 7 (variable left handers) was classified as predominantly variable right handers (75%), and even mild right handers (25%). This could be reflective of the right handed environmental bias on clinical children presenting with variable handedness.

All handedness measures were submitted individually to a 5-group classification cluster analysis with ANOVA for comparison with the normative profile (see Table 6.6 for a summary).

Table 6.6. Summary of the 5-Group Cluster Analysis with ANOVA on All Handedness Measures in the Clinical Sample and the Normative Profile

<i>Handedness Measures</i>	<i>F-Value</i>		<i>Significance (p)</i>	
	<i>Clinical</i>	<i>Normative</i>	<i>Clinical</i>	<i>Normative</i>
Untrained FHP	68.079	56.956	0.000**	0.000**
Trained FHP	110.209	144.566	0.000**	0.000**
Consistency	◆4.503	1.989	◆0.003**	0.119
Ability IHD	9.151	22.583	0.000**	0.000**
Ability PL	1.889	1.030	0.407	0.124
Skill IHD	19.290	23.446	0.000**	0.000**
Skill PL	◆2.629	0.411	◆0.043*	0.799
Midline Crossing Quotient	44.107	39.997	0.000**	0.000**
Midline Crossing Extent	46.232	41.856	0.000**	0.000**
Bimanual Coordination IHD	◆5.293	1.729	◆0.001*	0.167
Bimanual Coordination PL	0.381	0.690	0.822	0.604

Note. Figures in brackets denote F-values and significance levels of the same cluster analysis of the normative study from Chapter 5. * denotes significance level of 0.05, and ** indicates significance level at 0.01. ◆ = those values that differ significantly across the two samples.

Interestingly, compared to the normative profile, three additional measures demonstrated significant separation between the 5-group classifications in the clinical sample, namely Consistency, Skill PL and Bimanual Coordination IHD. The other measures yielded similar significance levels, with larger F-values in the clinical sample for untrained FHP, and in the normative sample for trained FHP, Skill IHD and Ability IHD.

6.3.4 Sequential Discriminant Function Analyses

The 2-group, 5-group and 8-group handedness classifications were used in the discriminant analysis to assess if different predictive factors would emerge according to these classifications. The results are summarised in Table 6.7. Only one predictive factor, trained FHP, emerged for the 2-group classification when all measures were entered, compared to three predictive factors for the normative profile (trained FHP, Bimanual Coordination IHD and Skill IHD). As in the normative profile, untrained FHP was also the predictive factor when only IHD measures were entered. None of the PL measures qualified for the discriminant analysis.

Table 6.7. Summary of Sequential Discriminant Function Analysis Using Interhand Difference (IHD) Measures in a 2-Group Handedness Classification

Measures entered/removed	Wilks' Lamda
<i>All measures</i>	
Trained FHP	0.208
Predicted group membership	Left = 100%; Right = 100%

Note. Wilks' Lamda tests the mean difference, and the closer the Lamda is to zero, the greater the measure's contribution to the discriminant function. The maximum partial F to enter was 3.84.

Further discriminant function analyses were performed on all IHD measures, using the 5-group and 8-group classifications, to assess if the same predictive factors would emerge as in the 2-group classification. Findings are summarised in Table 6.8.

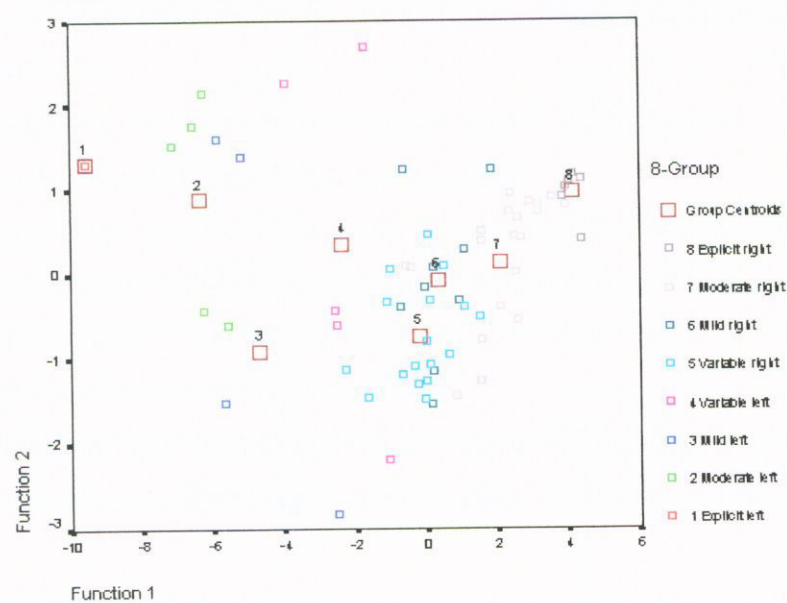
Table 6.8. Summary of the Discriminant Function Analyses of the Interhand Difference (IHD) Measure in 5-Group and 8-Group Handedness Classifications

Predictors	Wilks' Lamda	Predicted Group Membership
<i>5-Group</i>		
Midline Crossing	0.256	Explicit Left: 75.0%; Moderate Left: 100%
Trained FHP	0.097	Variable: 75.9%
		Moderate Right: 62.5%; Explicit Right: 83.3%
<i>8-Group</i>		
Trained FHP	0.242	Explicit Left: 100.0%; Moderate Left: 80.0%
Midline Crossing Quotient	0.114	Mild Left: 50.0%; Variable Left: 80.0%
Untrained FHP	0.062	Variable Right: 64.7%; Mild Right: 55.6%
		Moderate Right: 66.7%; Explicit Right: 100%

Similar to the analysis of the normative profile, trained FHP emerged as a main predictive factor in the clinical sample across all classifications. Skills IHD and untrained FHP also featured as predictive factors in the normative discriminate analysis when applied to IHD measures in the 2-group and 5-group classifications respectively. Midline Crossing, however, was revealed as a major predictive factor only in the clinical sample within the 5-group and 8-group classifications, but not in the 2-group classification.

Figure 6.6 illustrates the 8-group handedness classification based on IHD measures. (Appendix 6C displays canonical discriminant function graphs of the 5-group classification for comparison with the normative profile.)

Figure 6.6. Canonical Discriminant Function Graph of the 8-Group Handedness Classifications Based on Interhand Difference (IHD) Measures



Note. Functions refer to predictive factors. Function 1 = trained FHP; Function 2 = Midline Crossing.

The canonical discriminant function graph depicts a tighter clustering in profiled right handers around moderate and mild IHD values, compared to profiled left handers who demonstrate a wider scatter.

6.3.5 Identification of Handedness Features

Certain distinctive characteristics appeared typical of variable handedness and will hereon be referred to as *handedness features*. Handedness features were deemed to indicate dysfunction related to handedness establishment in the clinical sample. Moreover, patterns or aggregations of handedness features typical of variable handedness might provide valuable information on a particular constellation of problems associated with variable handedness. For the sake of clarity, the definition of emergent handedness features and their impact on the clinical sample will be presented together with the statistical analysis providing empirical evidence for the existence of these handedness features.

6.3.5.1 Defining Handedness Features

Six features were identified, based on the frequency of their occurrence in the clinical sample compared to the normative profile. The handedness features furthermore, draw on the reviewed literature associating atypical handedness presentation to a variety of problems (see Section 1.4 on proposed reasons for variable handedness and Appendix 6D for a diagrammatic summary).

- (i) Congruous versus incongruous behaviour (all IHD measures);
- (ii) Consistent versus inconsistent handers (FHP);
- (iii) Excessively large IHD in Skill, Ability and Bimanual Coordination, or excessively small IHD in untrained and trained FHP and Midline Crossing;
- (iv) Subaverage/poor unimanual motor performance in both hands versus average motor performance (Ability and Skill);
- (v) Average Midline Crossing versus avoidance (MCT); and
- (vi) Average versus subaverage/poor Bimanual Coordination performance (BCT).

(i) *Incongruence*.

The handedness feature, incongruence, is based on the premise that the preferred hand is used predominantly across all handedness measures, and when this is not the case, incongruence results. Four types of *incongruence* were identified and defined. Two of the four types were further divided into severe and minor incongruence, depending on whether the non-preferred hand shows superior performance in trained and skilled aspects (severe) or in untrained/ability-based tasks (minor).

1. *FHP Incongruence* – (i) severe: non-preferred hand engages predominantly in *trained* FHP tasks, or (ii) minor: non-preferred hand engages predominantly in *untrained* FHP tasks.
2. *Motor Incongruence* – non-preferred hand shows superior performance in *Ability and Skill*.
3. *Ability/Skill Incongruence* – incongruence *between* Ability and Skill. (i) severe: non-preferred hand shows superior performance in Skill, and preferred hand in Ability, or (ii) minor: non-preferred hand shows superior performance in Ability, and preferred hand in Skill.

4. *MC Incongruence* - non-preferred hand predominantly engages in midline crossing.

(ii) *Inconsistency.*

Within-task inconsistency is reflected in subaverage/poor *performance levels* of untrained and trained FHP measures, whilst *across-task* inconsistency is indicated by subaverage IHD (i.e., categories 3 to 6) for the FHP measures (see Section 1.2.3.3 on consistency).

(iii) *Excessive Interhand Differences (IHD).*

Excessive IHD are based on percentiles. IHD values above the 75th percentile would be excessively large, and below the 25th percentile excessively small. Some measures yield large interhand differences in the normative profile (i.e., untrained and trained FHP, Midline Crossing), and other measures normally demonstrate small interhand differences (i.e., Ability, Skill and Bimanual Coordination). If the normally large IHD values present as excessively small, and the normally small IHD values are excessively large, they are considered to demonstrate an excessive IHD handedness feature.

(iv) *Subaverage/Poor Unimanual Motor Performance Level (PL).*

Unimanual motor performance refers to both Ability and Skill, and a distinction was made between subaverage/poor performance (i.e., below the 25th percentile) of either the *preferred* hand, the *non-preferred* hand, or *both* hands.

(v) *Midline Crossing.*

A low Midline Crossing Quotient can be achieved by employing both hands equally during contralateral reaching (i.e. small IHD values), or by avoiding midline crossing altogether. It would be important to note the difference.

(vi) *Bimanual Coordination.*

Subaverage/poor bimanual coordination was deemed to be indicative of dysfunction. The type of response would also reflect the type of problem (e.g., reversions, alternating movement) (see again Section 2.2.4.3 for interpretation of the Bimanual Coordination Test) and should be recorded.

6.3.5.2 The Impact of Handedness Features on Performance in the Clinical Sample

A one-way ANOVA with Tukey's B was performed on the clinical sample using the handedness features as factors. Table 6.9 summarises the F-values and significance levels between the groups based on the handedness features.

Table 6.9. Comparing Feature Groups for Incongruence, Inconsistency, Excessive Interhand Differences (IHD), Subaverage Performance Levels (PL), Midline Crossing Avoidance, and Subaverage Bimanual Coordination

	Congruence vs		Incongruence		Consistent vs		Inconsistent	
	<i>F-value</i>		<i>Significance</i>		<i>F-value</i>		<i>Significance</i>	
uFHP	41.204		0.000**		12.527		0.001**	
tFHP	1.833		0.180		5.669		0.020**	
Consistency	3.485		0.066		◆ 107.346		◆ 0.000**	
Skill IHD	2.948		0.091		3.123		0.082"	
Skill PL	0.241		0.625		5.312		0.024*	
Ability IHD	1.677		0.200		5.455		0.023*	
Ability PL	2.302		0.134		2.438		0.123	
Midline Crossing	4.007		0.049*		6.315		0.014**	
Biman. Coord. IHD	1.524		0.001**		3.671		0.060	
Biman. Coord. PL	0.009		0.924		2.029		0.159	
	Excessive vs		Average IHD		Average Perform. vs Subaverage			
	<i>large</i>	<i>small</i>	<i>large</i>	<i>small</i>	<i>F-value</i>		<i>Significance</i>	
uFHP	0.818	0.202	0.369	0.654	0.722		0.398	
tFHP	1.735	0.180	0.192	0.673	0.100		0.753	
Consistency	0.270	0.247	0.605	0.621	6.606		0.012**	
Skill IHD	◆ 3.496	◆ 5.869	◆ 0.066	◆ 0.018*	0.521		0.473	
Skill PL	1.466	0.085	0.230	0.771	◆ 1.713		◆ 0.195	
Ability IHD	◆ 18.801	◆ 0.054	◆ 0.000**	◆ 0.816	0.751		0.389	
Ability PL	4.229	0.106	0.044*	0.745	◆ 35.820		◆ 0.000**	
Midline Crossing	0.040	1.292	0.842	0.260	1.994		0.163	
Biman. Coord. IHD	0.036	0.411	0.851	0.524	1.176		0.282	
Biman. Coord. PL	0.917	0.216	0.342	0.644	3.803		0.055*	
	Midline Crossing		vs Avoidance		Average BC vs		Subaverage BC	
	<i>F-value</i>		<i>Significance</i>		<i>F-value</i>		<i>Significance</i>	
uFHP	6.995		0.010**		0.000		0.988	
tFHP	1.090		0.300		2.634		0.109	
Consistency	3.763		0.057*		0.159		0.691	
Skill IHD	0.005		0.942		1.328		0.253	
Skill PL	0.022		0.883		0.095		0.759	
Ability IHD	0.885		0.350		2.484		0.120	
Ability PL	1.189		0.280		2.156		0.147	
Midline Crossing	◆ 3.282		◆ 0.075		3.521		0.065	
Biman. Coord. IHD	1.193		0.279		0.252		0.618	
Biman. Coord. PL	1.887		0.174		◆ 68.316		◆ 0.000**	

Note. uFHP = untrained Functional Hand Preference; tFHP = trained Functional Hand Preference; IHD = Interhand Differences; PL = Performance Level. Perform. = performance; BC and Biman. Coord. = Bimanual Coordination * indicates 0.05 significance and ** illustrates 0.01 significance level. ◆ = measures on which the particular feature is based, thus a relationship between these is to be expected.

According to one-way ANOVA (whereby the measures with a ♦-symbol were excluded), the following means and standard deviations were significantly different.

- *Incongruent* handers compared to their congruent counterparts, showed significantly lower means at ($p \leq 0.05$) in untrained FHP (incongruent = -15.84 ± 20.92 ; congruent = 34.51 ± 35.76), Consistency (incongruent = 54.76 ± 10.90 , congruent = 60.91 ± 14.19), Midline Crossing (incongruent = 16.72 ± 49.90 , congruent = 40.88 ± 46.87), and Bimanual Coordination (incongruent = -1.70 ± 11.28 , congruent = 7.35 ± 10.19).

- *Inconsistent* handers demonstrated a significantly lower mean than consistent handers in the following handedness measures: Skill PL (consistent = 60.67 ± 9.25 , inconsistent = 52.82 ± 16.43); Ability PL (consistent = 13.14 ± 10.14 , inconsistent = 6.82 ± 11.64); Midline Crossing (consistent = 48.69 ± 45.90 , inconsistent = 19.59 ± 48.17) and Bimanual Coordination IHD approaching significance (consistent = 7.03 ± 12.15 , inconsistent = 1.78 ± 10.41).

- *Excessively large IHD* differed significantly from average IHD values in Ability PL (large IHD = 58.88 ± 15.60 , average IHD = 68.44 ± 13.76). Whilst not significant, children displaying excessively large IHD also demonstrated higher scores in both FHP subtests. Excessively small IHD values revealed no significant differences. However, children displaying excessively small IHD values also showed lower scores in FHP scores.

- *Subaverage hand performance* (particularly Ability) showed significantly lower scores in Consistency (55.98 ± 13.26) compared to average performers (64.62 ± 11.70), as was Bimanual Coordination Performance (average = 60.71 ± 7.29 , subaverage = 55.70 ± 10.71).

- *Midline Crossing avoidance* versus midline crossing demonstrated significant differences in untrained FHP tasks (MC = 24.66 ± 42.35 , avoidance = -0.96 ± 26.43); and Consistency (MC = 60.84 ± 12.62 , avoidance = 54.35 ± 13.92).

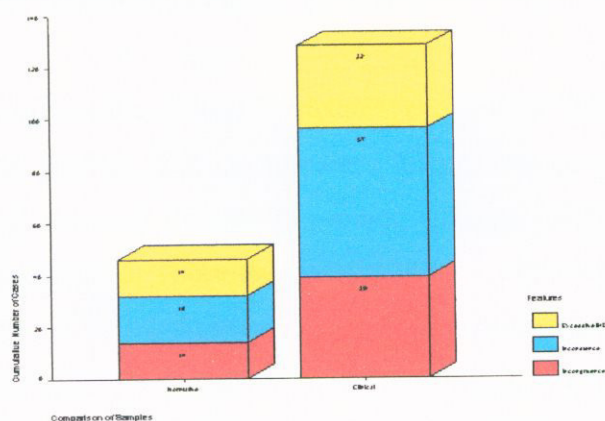
- *Bimanual Coordination PL* did not make any difference in most handedness measures except for Midline Crossing where the differences approached significance (average BC = 37.83 ± 46.28 , subaverage BC = 11.40 ± 54.61).

Collectively, these handedness features yielded significant differences between groups on all handedness measures, supporting the proposition that the identified features are indicative of dysfunction associated with variable handedness. More specifically, the following could be concluded from these results:

- (i) *Incongruent handers* were more likely to avoid Midline Crossing, perform more poorly in Bimanual Coordination, and were less consistent (particularly regarding untrained FHP tasks) than congruent handers.
- (ii) *Inconsistent handers* were more likely to demonstrate poorer Ability and Skill performance levels, and also showed more Midline Crossing avoidance and subaverage Bimanual Coordination PL.
- (iii) *Excessive IHD (large)* seemed to negatively affect performance levels (especially Ability) but yielded higher laterality quotients. Excessively small IHD, on the other hand, did not appear to be associated with lower performance levels but did demonstrate lower means in FHP (especially untrained FHP).
- (iv) *Subaverage/poor unimanual performance* (hereon referred to collectively as *Motor*), appeared to bear some relationship with inconsistency and poor bimanual coordination, particularly Ability.
- (v) *Avoidance of Midline Crossing* seemed to coincide with lower scores in untrained FHP tasks and greater inconsistency.
- (vi) *Subaverage/poor Bimanual Coordination* suggested an association with Midline Crossing avoidance.

The above summary denotes anecdotal evidence that the identified handedness features were able to provide information on one or more of the other handedness measures, indicating possible associated problem areas. However, this is a preliminary analysis, and empirical evidence based on larger clinical samples is required to substantiate the value of the handedness features and their impact on function. As discussed in Chapter 5, performance levels appear to be less distinctive in obtaining a handedness classification than interhand difference measures, since they may exist independently of variable handedness. For this reason, handedness features based on performance levels are considered to play a *peripheral* role by providing additional and qualitative information to the handedness profile. Conversely, the *key* handedness features are based in IHD measures, consisting of incongruence, inconsistency and excessive IHD values. Figure 6.7 displays the difference between the normative profile (n = 62) and the clinical sample (n = 68) on these three key handedness features.

Figure 6.7. Comparing Key Handedness Features Incongruence, Inconsistency and Excessive Interhand Differences (IHD) Between Clinical and Normative Samples



The number of cases displaying incongruence, inconsistency and excessive interhand differences were more than double in the clinical sample. It is important to interpret the data of the handedness features with caution, since the present studies provide only preliminary evidence. Nevertheless, despite limited quantitative data, the handedness features provide descriptive information, illustrating how the handedness profile can be interpreted. It might also assist therapists in identifying underlying reasons for variable handedness, and they might provide points of departure for future research. For this reason, the three key handedness features will be investigated with reference to individual case studies in the following section.

6.3.5.3 Exploring Handedness Features in the Clinical Sample

Since the analysis was based on the means of the entire sample, it was unlikely that *individual* handedness features would be revealed. Thus, individual handedness profiles were carefully examined for deviations from the norm and for the presence of handedness features. For the exploration of individual handedness profiles, a summary sheet was compiled to include both the interhand differences and the performance levels for each of the measures in the form of plotting charts, similar to those displayed in the previous chapter (Figure 5.8 under Section 5.3.5 in Chapter 5). In addition, relevant background information provided by the initial parent questionnaire was included (e.g., birth-related stress, familial left handedness, injury to the upper limb or hemispheres, developmental delay, etc., see

Figures 6.8 to 6.11). Finally, a summary checklist of significant handedness features impacting on performance was added for easier comparison.

The key handedness features of the clinical handedness profiles are illustrated with examples of individual handedness profiles. The incongruence feature was analysed according to its four different types since this was deemed to provide valuable information, illustrated by four detailed handedness profiles. These case examples were selected on the premise that they illustrate at least one of the handedness features under discussion. Furthermore, twelve additional case examples with abbreviated handedness profiles are included in Appendix 6E. (The examples in the appendix also display comments on clinical decision making, which will be covered in greater detail in Chapter 7.) The number of cases in the clinical sample presenting with *similar* features were reported (the constellation of individual handedness profiles was usually unique). Identifying patterns or aggregations of handedness features would require larger samples of variable handers, which is beyond the scope of this thesis.

FHP Incongruence.

DEFINITION (i) Severe: Non-preferred hand executes more trained, preferred hand more untrained tasks.

Only one profiled left handed child demonstrated severe FHP incongruence, and the right hand also scored better in motor skills (see Figure 6.8 for Case 13). This feature possibly reflects the environmental influence on some left handers, who have learnt to imitate or were taught to perform skilled and socially important tasks with the right hand. No severe FHP Incongruence was found in profiled right handers.

DEFINITION (ii) Minor: Non-preferred hand executes more untrained, preferred hand more trained tasks.

In the clinical sample, 3 of 11 (27%) profiled left handers and 18 of 58 profiled right handers (31%) demonstrated minor FHP incongruence. Whilst this might be an indication of switched handedness in some cases, its occurrence in a normative sample, though to a lesser extent, precludes it from being a severe FHP Incongruence.

Motor Incongruence.

DEFINITION Non-preferred hand demonstrates higher performance level in Ability *and* Skill.

There was only one profiled left hander (see Appendix 6E for Case 60) and one profiled right hander displaying Motor Incongruence. This appears to be a rare feature which might be a strong indicator of switched handedness.

Ability/Skill Incongruence.

DEFINITION (i) Severe: Non-preferred hand shows superior performance in Skill, and preferred hand performs better in Ability.

No children demonstrated superior Skill performance with the non-preferred hand without also displaying superior Ability performance (i.e., motor incongruence). Either this feature does not exist, or it is rare. Its hypothetical existence can only be confirmed or disputed by conducting further research based on larger clinical samples.

DEFINITION (ii) Minor: Non-preferred hand shows superior performance in Ability and preferred hand in Skill.

Four left handers (36%) showed a higher performance level in Ability with the non-preferred right hand. Two of these cases were in the average range (see again Figures 6.8 and 6.9 for Cases 62 and 13, and Appendix 6E for Cases 29 and 60 respectively). This type of profile might coexist with average or above average motor proficiencies in both hands, which possibly differ in regard to the nature of the task. It could be normal in some left handers and might also be task dependent and/or environmentally influenced. Five right handers (9%) showed a higher performance level in Ability with the left non-preferred hand, and four of these cases demonstrated subaverage/poor performance in both Ability and Skill (see Appendix 6E for Cases 4, 5 and 58). This incongruence feature might, together with a FHP Incongruence, strengthen the case for a switched hander.

Midline Crossing Incongruence.

DEFINITION Non-preferred hand is used predominantly for contralateral reaching.

Two left handers (18.2%) employed their right hand for contralateral reaching, scoring in the average range for Midline Crossing (see again Figure 6.9 for Case 62, and Appendix 6E for Case 60). Eleven right handers (19%) employed their left hand for contralateral reaching (categories 3 and 4), seven of which scored in the average range for midline crossing (see Appendix 6E for Cases 4, 5, and 31). Seven of the eighteen right handers demonstrating

minor FHP Incongruence also exhibited Midline Crossing Incongruence. This feature might strengthen the case of a switched hander. Alternatively, it might be reflective of other aspects of contralateral reaching and information processing that were not controlled in the present studies (e.g., temporal or visuospatial aspects).

Inconsistency.

DEFINITION (i) Within-tasks: A subaverage Consistency score is achieved

Three (27%) left handers and 26 (45%) right handers showed inconsistency within-tasks (see Figure 6.10 for Case 12 and Appendix 6E for Cases 58, 68 and 9).

DEFINITION (ii) Across-tasks: Untrained and trained FHP tasks demonstrate excessively small interhand differences (i.e., in the mild to variable categories).

Three (27%) left handers and 34 (59%) right handers demonstrated across-task inconsistency (see Figure 6.10 for Case 12 and Appendix 6E for Case 4). Only one of the three left handers showed both within and across task inconsistency compared to 16 right handers. Since all children in the clinical sample have been observed to display variable or ambiguous hand use, it is not surprising to find a high level of inconsistency. It is interesting to note the higher incidence of inconsistent right handers compared to left handers.

Excessive Interhand Differences.

DEFINITION (i) Excessively large interhand differences in Ability and Skill, and possibly Bimanual Coordination.

Three of 11 profiled left handers (27.3%) showed interhand differences above the 75th percentile, with one displaying poor and subaverage performance in Ability and Skill, while the other two scored in the average range (see Figure 6.11 for Case 10). It was usually the non-preferred hand that was considerably less able. This feature suggests the possibility of pathological left handedness. Seventeen of 58 profiled right handers (29.3%) showed interhand differences above the 75th percentile in either Ability (n = 11), or Skill (n = 4), or both (n = 2).

Figure 6.8. Handedness Profile of Case 13

Case: 13

Age: 4.11 years

Gender: Male

Background Information

Draws / writes with Left Right Either

Main reasons for referral

Clumsiness, concentration, motor skills, social skill

Familial left handedness

Don't know No Yes: *Brother, grandparents, uncle*

Birth-related stress

Maybe No Yes: *Induced but no problems*

Developmental delay

Don't know No Yes:

Injury to upper limb / hemisphere

Don't know No Yes: L R

Evidence of socio-cultural pressure

Don't know No Yes:

Early hand use

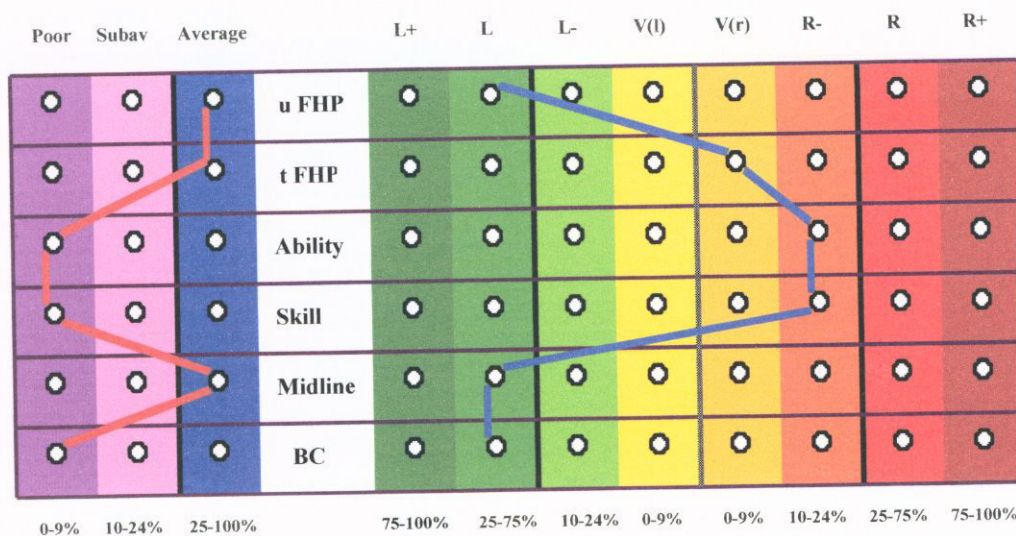
Left Right Mixed Changed at age:

Parental estimation of handedness

Very left More left Mixed More right Very right

Performance Level (PL)

Interhand Differences (IHD)



Handedness Features

Profile Score: -5.5

Profile Classification: L-

Incongruence

No

Yes: FHP Ability/Skill Motor MC

Inconsistency

No (*untr. FHP*)

Yes: within-tasks across-tasks (*trained FHP*)

Excessive IHDs

No

Yes: above average below average

Poor motor performance

No

Yes: preferred (*Skill*) non-preferred both (*Ability*)

Midline Crossing avoidance

No

Yes: avoids preferred hand non-preferred either

Poor Bimanual Coord.

No

Yes: reversions steps strong *left* deviations

Figure 6.9. Handedness Profile of Case 62

Case: **62**

Age: **6.4 years**

Gender: **Male**

Background Information

Draws / writes with Left Right Either

Main reasons for referral

Fine motor difficulties, visual perceptual problems, speech

Familial left handedness

Don't know No Yes: *Cousin, uncle*

Birth-related stress

Maybe No Yes: *Caesarian, 2 weeks early*

Developmental delay

Don't know No Yes:

Injury to upper limb / hemisphere

Don't know No Yes: L R

Evidence of socio-cultural pressure

Don't know No Yes:

Early hand use

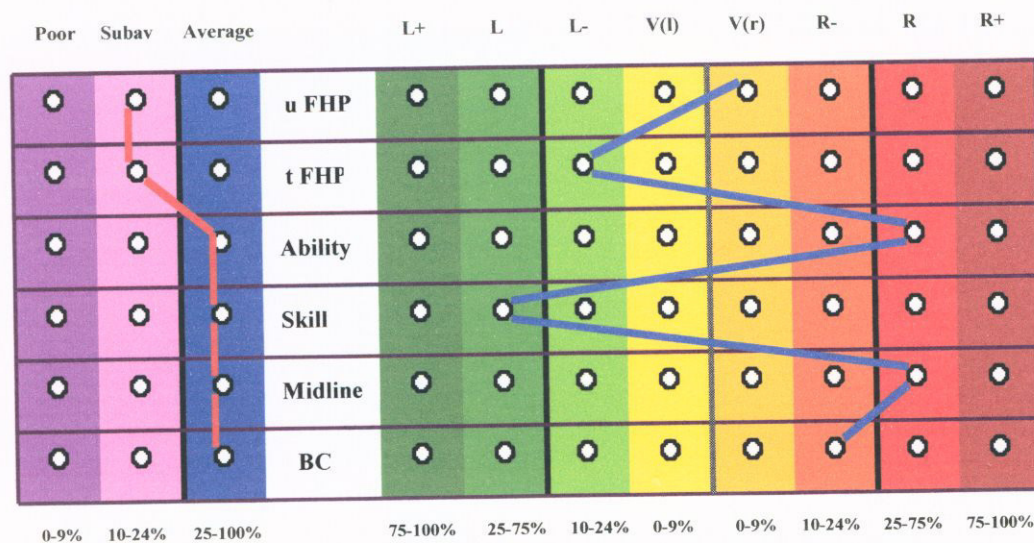
Left Right Mixed Changed at age:

Parental estimation of handedness

Very left More left Mixed More right Very right

Performance Level (PL)

Interhand Differences (IHD)



Handedness Features

Profile Score: **-3.5**

Profile Classification: **V1**

Incongruence No

Yes: FHP Ability/Skill Motor MC

Inconsistency No

Yes: within-tasks across-tasks

Excessive IHDs No

Yes: above average below average

Poor motor performance No

Yes: preferred hand non-preferred both hands

Midline Crossing avoidance No

Yes: avoids preferred hand non-preferred either

Average Bimanual Coord. No

Yes: reversions steps strong left/right deviations

Figure 6.10. Handedness Profile of Case 12

Case: 12

Age: 6.3 years

Gender: Male

Background Information

Draws / writes with Left Right Either

Main reasons for referral

Fine and gross motor problems, visual perception

Familial left handedness

Don't know No Yes: *Father, sister (both switched)*

Birth-related stress

Maybe No Yes: *Umbilical cord, blue*

Developmental delay

Don't know No Yes: *General mild developmental delay*

Injury to upper limb / hemisphere

Don't know No Yes: L R

Evidence of socio-cultural pressure

Don't know No Yes: *Father believes in switching*

Early hand use

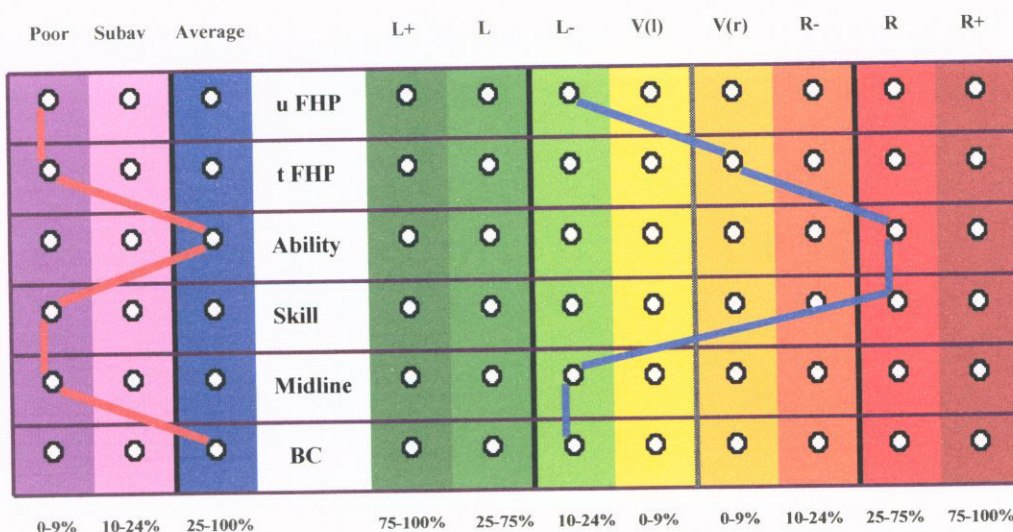
Left Right Mixed Changed at age:

Parental estimation of handedness

Very left More left Mixed More right Very right

Performance Level (PL)

Interhand Differences (IHD)



Handedness Features	Profile Score: -2.0	Profile Classification: VI
Incongruence <input type="checkbox"/> No	<input checked="" type="checkbox"/> Yes: <input checked="" type="checkbox"/> FHP <input type="checkbox"/> Ability/Skill <input type="checkbox"/> Motor <input checked="" type="checkbox"/> MC	
Inconsistency <input type="checkbox"/> No	<input checked="" type="checkbox"/> Yes: <input checked="" type="checkbox"/> within-tasks <input checked="" type="checkbox"/> across-tasks	
Excessive IHDs <input checked="" type="checkbox"/> No	<input type="checkbox"/> Yes: <input type="checkbox"/> above average <input type="checkbox"/> below average	
Poor motor <input checked="" type="checkbox"/> No (<u>Ability</u>)	<input checked="" type="checkbox"/> Yes: <input type="checkbox"/> preferred <input type="checkbox"/> non-preferred <input checked="" type="checkbox"/> both hands (<u>Skill</u>)	
Midline Crossing avoidance <input type="checkbox"/> No	<input checked="" type="checkbox"/> Yes: <input checked="" type="checkbox"/> avoids <input type="checkbox"/> preferred hand <input checked="" type="checkbox"/> non-preferred <input type="checkbox"/> either	
Poor Bimanual Coord. <input checked="" type="checkbox"/> No	<input type="checkbox"/> Yes: <input type="checkbox"/> reversions <input type="checkbox"/> steps <input type="checkbox"/> strong left/right deviations	

Figure 6.11. Handedness Profile of Case 10

Case: 10

Age: 5.8 years

Gender: Male

Background Information

Draws / writes with Left Right Either

Main reasons for referral

Fine motor difficulties

Familial left handedness

Don't know No Yes: *Mother, brother, cousin*

Birth-related stress

Don't know No Yes:

Developmental delay

Don't know No Yes:

Injury to upper limb / hemisphere

Don't know No Yes: L R

Evidence of socio-cultural pressure

Don't know No Yes:

Early hand use

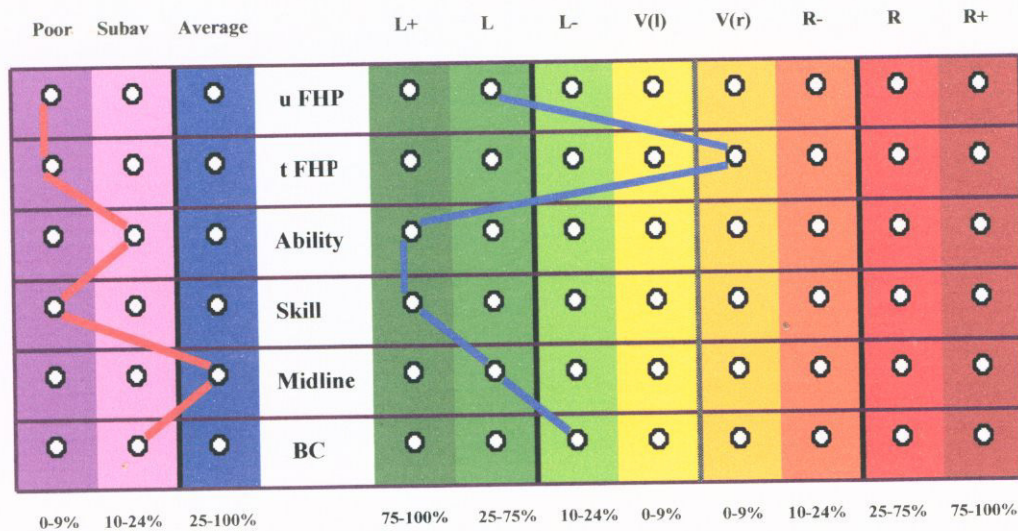
Left Right Mixed Changed at age:

Parental estimation of handedness

Very left More left Mixed More right Very right

Performance Level (PL)

Interhand Differences (IHD)



Handedness Features

Profile Score: **-15.0**

Profile Classification: **L**

Incongruence No

Yes: FHP Ability/Skill Motor MC

Inconsistency No

Yes: within-tasks across-tasks (*trained FHP*)

Excessive IHDs No

Yes: above average (*both hands*) below average

Poor motor No (*Ability*)

Yes: preferred (*Skill*) non-preferred both hands

Midline Crossing avoidance No

Yes: avoids preferred non-preferred either

Poor Bimanual Coord. No

Yes: reversions steps strong left/right deviations

Only five of the seventeen cases (29.4%) scored in the subaverage/poor range (see Appendix 6E for Cases 31, 32, 65 and 68). In most profiled right handers, it was also the non-preferred hand that performed significantly poorer than the preferred hand. It seems possible that some minor neurological insult to the right hemisphere is related to this type of profile, and pathological right handedness, although rare, should be considered.

DEFINITION (ii) Excessively small interhand differences (IHD) in untrained and trained FHP and/or Midline Crossing.

Excessively small IHD values were apparent in five profiled left handers (45%) with subaverage scores in Ability and/or Skill (both preferred and non-preferred hands), small interhand differences in trained FHP, untrained FHP and Midline Crossing (see Figure 6.8 Case 13, and Appendix 6E for Cases 7, 13, 34 and 60). In comparison, twelve profiled right handers (20.7%) demonstrated small IHD values in untrained FHP and/or trained FHP tasks. Only one of these cases exhibited Midline Crossing avoidance (see Appendix 6C for Cases 4, 5 and 9). This type of profile indicates subaverage motor performance in both hands coexisting with variable handedness, and a causative relationship might exist between the two.

6.4 Discussion

6.4.1 Discussion of Results

The three proposed experimental hypotheses were fulfilled to varying degrees. The first hypothesis, stating that the application of the handedness profile would detect various degrees of handedness across all handedness measures in the clinical sample, with significant differences between the eight handedness categories, was achieved. The clinical profiles showed a general trend towards the middle variable categories and much wider scatter due to higher levels of incongruence and inconsistency. The differences between the eight categories were even larger compared to the normative profile, supporting the proposed need for a multiple classification system.

The second hypothesis suggested that the strongest predictive factor of the normative profile, trained Functional Hand Preference, would also emerge as a main predictive factor in the clinical sample. This was indeed the case in the 2-group and 8-group classifications, and in the 5-group classification trained Functional Hand Preference also featured as a secondary predictor. This finding suggests that performance of trained everyday tasks can strongly predict the direction of handedness regardless of whether a sample is normative or clinical. Furthermore, it supports the literature that has repeatedly found trained tasks such as writing, drawing or cutting, to have the highest reliability (e.g., Annett, 1992a). The second hypothesis also envisaged that the clinical sample would exhibit different predictive factors in the 5-group and 8-group classifications than the normative profile, reflecting a greater variability in those handedness measures that are less subjected to training and environmental influence. This prediction was partially fulfilled since Midline Crossing, but not Bimanual Coordination, emerged as a primary predictive factor in the 5-group classification, and as a secondary factor in the 8-group classification. In addition, Skill interhand differences and untrained Functional Hand Preference tasks also presented as predictive factors in the multiple classifications of the clinical sample, as was the case in the normative profile.

The emergence of Midline Crossing as a predictive factor in the clinical sample and not in the normative profile invites an interesting interpretation. It is possible that children

experiencing problems with contralateral reaching are those exhibiting inconsistency and incongruence in addition to general poor motor ability. This proposal is in accordance with a significantly lower midline crossing performance in inconsistent and incongruent handers, as well as those children performing in the subaverage range in Ability. Several authors have stressed the importance of assessing contralateral reaching in clinical populations as a diagnostic factor (Giotakos, 2001; Surburg & Eason, 1999). However, when the clinical sample was compared to the normative profile, Midline Crossing did not reveal any significant differences between left and right handers. Overall, the results of this study thus indicate that while Midline Crossing is one of the predictive factors for handedness establishment *within* an clinical sample, particularly in regard to Consistency and Ability, it does not appear to be a decisive factor in *identifying* variable handedness. Rather, Midline Crossing as a diagnostic factor might be more reflective of other types of problems or features related to contralateral reaching that were not assessed in this study but that have been addressed in the literature, such as visual perception (Weissman & Banich, 2000) and language-based deficits (Hill & Bishop, 1998).

The third hypothesis proposing that the handedness profiles of most clinical children would clearly differ from those of the normative ones, was partially met as important differences emerged in addition to similarities. The performance levels of Skill were considerably lower in the clinical group (particularly in profiled left handers), as were Ability performance means (particularly in profiled right handers). In addition, there were significantly higher levels of inconsistency and incongruence in the clinical sample. In fact, as would be expected, all performance means except Bimanual Coordination were lower in the clinical sample. Furthermore, all interhand differences except for Skill were smaller in the clinical sample. This finding could be taken to support the argument that variable handers fail to gain superior proficiency of one hand over the other. Since performance levels were also lower in the clinical sample, it is possible that the decreased interhand differences was due to a lack of development of the preferred hand rather than an elevated performance of the non-preferred hand. This argument is in accordance with Flowers (1975) who reported 'ambilateral' individuals to demonstrate lower proficiency and smaller interhand differences than well established handers.

The finding that Skill interhand differences remained the same across normative and clinical sample, despite displaying a lower performance mean in the latter, stands in contrast to the decreased interhand differences in the other measures. One explanation for this discrepancy could be that Skill, related to pen and paper tasks such as drawing and writing, is subjected to practice and environmental influence to a greater extent than the other handedness measures. This means that most children with variable handedness and subaverage motor performance would also have learnt to use the preferred hand for drawing and writing tasks, resulting in an interhand difference comparable to the norm. Interestingly, Skill interhand difference was one of the predictive factors in the normative profile but not in the clinical sample, indicating that it only differentiates well *between* the handedness categories in normal development. However, it could be concluded that Skill interhand differences would not feature as a good *diagnostic* measure in identifying impairment, since children could perform within or below the average range, regardless of the extent of interhand differences.

Bimanual Coordination was another measure that yielded no significant difference overall when compared to the normative profile, and displayed great variability in the normative sample. It was already apparent in the previous chapter that Bimanual Coordination did not appear to show significant differences between left and right handers in the entire sample. Also, there was no difference in the other handedness measures when children with subaverage Bimanual Coordination performance levels were compared to those with average performance levels. This might be related to the ceiling effect achieved in the homologous subtest.

However, Bimanual Coordination interhand differences were significantly lower in clinical right handers compared to the norm. Furthermore, similar to findings in Study II with younger normal right handers, clinical profiled right handers were more incongruent in Bimanual Coordination than their left handed counterparts, tending to lead or deviate more with the non-preferred left hand. These results are congruent with those of Gladstone, Best and Davidson (1989), who argued that a possible left hemispheric inhibition was responsible for increased left handed involvement during bimanual coordination in their clinical sample of right handed dyslexic boys. Thus, whilst the Bimanual Coordination Test might not display strong agreement with the other handedness measures and presents with a great variability in the norm, it appears to sensitively detect bimanual asymmetry in clinical

variable handers by displaying smaller interhand differences and greater incongruence. In addition, Bimanual Coordination performance level emerged as the second strongest predictive factor for the normative profile in the 2-group discriminant analysis, validating it as a handedness measure when determining the direction of handedness. Nevertheless, the apparent ceiling effect in homologous bimanual movement, constituting half of the Bimanual Coordination raw score, might compromise its sensitivity, particularly in older children. It would therefore be useful to include two or more additional items that involve higher levels of bimanual skill, cognitive involvement and visual attention, such as tracing a given slope of 67° and 33° as suggested by Brown (1991). Adapting the Bimanual Coordination Test in this way could possibly assist to increase its sensitivity in detecting more subtle information related to bimanual coordination as a handedness measure.

The third hypothesis suggesting that some clinical profiles would reveal similar features and patterns, was partially met. The preliminary data analysis and plotting of individual case examples have confirmed the presence of key handedness features across numerous cases. However, if these features aggregated to form meaningful patterns indicative of similar handedness problems remains to be seen, since this would require much larger clinical samples.

Nevertheless, there were notable differences between the profiled left and right handers that appeared to be specifically related to impairment. The association between non-preferred right hand use for trained tasks in left handers, and the absence of a corresponding association in right handers supports the right-biased influence of the *environment* on handedness establishment, causing a shift to the right in many left handers. Conversely, incongruent right handers rather than left handers tended to use the non-preferred left hand for untrained tasks, and some also performed better in Ability with the left hand. Although there was some evidence of this minor Functional Hand Preference incongruence in the normative profile, it was more pronounced in the clinical sample. If untrained tasks and Ability are reflections of the *innate* handedness predisposition, Functional Hand Preference incongruence could be seen as a tentative indicator for switched handedness.

In particular, the substantially larger proportion of inconsistency amongst clinical *right handers* appears to be in contrast to the three normative studies in Chapters 2, 3 and 4 that

confirm the greater variability and inconsistency in left handers so frequently cited in the literature (e.g., Bryden, Bulman-Fleming & MacDonald, 1996; Dunaif-Harris, 1984). A possible explanation for this discrepancy is that the profiled right handers in the present study contain a number of switched left handers that are classified as right handers according to the profile score. This would confirm the earlier proposition that the handedness classification should not be based on the profile score only, but needs to be determined in the context of relevant background information and the analysis of the apparent handedness features. To this end, there appears to be a need for a conceptual framework that could enable a more in-depth interpretation, relating profile scores and profile classifications to proposed types of handedness. In other words, a conceptual framework could provide a structure for facilitating a broader understanding of an individual handedness profile, particularly if a link between specific handedness presentations and underlying causes for variable handedness is established (see Section 1.4 in Chapter 1 for a review).

6.4.2 Conclusion

The results of this study indicate that the handedness profile appears to be a sensitive and effective tool when applied to a minimally clinical sample with variable or variable handedness, yielding a range of information on incongruence, inconsistency, excessive interhand differences, subaverage unimanual/bimanual performance levels, and midline crossing avoidance. Furthermore, the handedness profile clearly conveys additional information for a more holistic milieu to the 8-group handedness classification, ranging from explicit left handedness to explicit right handedness. However, the handedness classification can only be meaningful and accurate if the profile score and handedness features are analysed in the context of relevant background information and the existing knowledge base related to handedness. A conceptual framework incorporating these aspects would assist clinical decision making for occupational therapy treatment related to handedness. The concluding chapter will address this final process of clinical decision making and subsequent treatment approaches in the context of developing a conceptual framework and identifying contextual types of variable handedness that are directly linked to possible underlying causes.

CHAPTER 7

CONCLUSION

7.1 Introduction

This concluding chapter briefly summarises the findings of the four studies presented in the previous chapters and discusses the value of the developed handedness profile for occupational therapists. In particular, a clinical decision making process is proposed to address variable handedness. This process consists of (i) assessing variable handedness by administering the Handedness Profile Test Battery; (ii) analysing and interpreting the handedness profile, using a conceptual framework; (iii) assigning a proposed variable handedness type; and (iv) deciding on an appropriate treatment approach. The literature base, empirical findings and the conceptual framework underpinning the development of this clinical decision making process, are explored and a case presentation is included for illustration. Finally, the need for further research is discussed in this context.

7.2 Resumé of Findings in the Development of a Handedness Profile

The initial literature review sketched the background to handedness as a highly complex, continuous, multidimensional, interactive and variable phenomenon. The theoretical context provided the basis for the four empirical studies of this thesis. The first two normative studies in Chapters 2 and 3 revealed that existing tests were not sufficiently sensitive to display a variety of handedness degrees, presenting with floor and ceiling effects even when younger age groups were introduced. Based on the existing tests, a set of five modified tests, the Handedness Profile Test Battery, was developed. The modified *Midline Crossing Test*, consisting of proximal and distal reaching, and the modified *Bimanual Coordination Test*, incorporating homologous and heterologous movement were initially constructed. Subsequently, a measure for hand preference was designed, based on an extension of the Edinburgh Handedness Inventory to form the *Functional Hand Preference Test* where untrained and trained tasks were treated as two separate subtests. The hand performance measure was adapted by modifying the Motor Accuracy and Hand Dominance Test measures, constructing the *Skill Test* based on tracing and dotting. Hand performance was further expanded to include a more inherent, untrained aspect of handedness consisting hammering and tapping in the *Ability Test*.

Comparative statistics of a normative sample consisting of equal numbers of left and right handers (Chapters 4 and 5) revealed that the modified Handedness Profile Test Battery achieved significantly greater variances on handedness presentation and displayed degrees of handedness across different dimensions. Based on the same normative sample, a normative handedness profile was developed using percentiles, and a distinction was made between interhand differences (i.e., the degree of difference between the hands independent of the level of motor performance) and performance levels (i.e., how well a child performed independent of interhand differences). A fourth study (Chapter 6) disclosed that children reported to have variable handedness showed significantly different handedness profiles to the norm. These differences were explored and individual case examples used to investigate the presence of key handedness features that appeared to characterise unestablished handedness.

7.3 Clinical Decision Making Process for Variable Handedness

The ability of the handedness profile to exhibit a wide range of handedness degrees and detect variability in different handedness domains makes it a unique and useful assessment. Specific handedness features that might reflect associated problems can be identified parallel to the *degrees* of handedness across a variety of related neuromotor behaviours, displaying unique individual differences, particularly when background information and present circumstances are considered. Moreover, the handedness profile developed in this thesis preserves some of the multidimensionality and variability of handedness within the context of occupational performance, and the information generated by the handedness profile provides a rich basis for clinical decision making.

Previous tests addressing handedness have either neglected the lateralised motor/performance aspect and focused only on hand preference (e.g., Oldfield, 1971), clearly dissociated the motor/performance from laterality/preference measures (e.g., Annett, 1992a), or combined motor/performance with limited laterality measures (e.g., Ayres, 1989, linking Motor Accuracy test and Space Visualisation Contralateral Use test to Preferred Hand Use in the Sensory Integration and Praxis Tests). Conversely, existing tests for motor performance have failed to provide a sufficient or specific basis for manual lateralisation (e.g., Bruininks, 1978, *Bruininks-Oseretsky Test of Motor Proficiency*; McCarthy, 1972, *McCarthy Scales*). In the context of this thesis, the

handedness profile overcame these obstacles, yielding precise information whilst preserving some of the complexity of handedness. This is apparent in the overall profile score and profile classification reflecting the direction and degree of handedness based on interhand differences. These interhand differences, available for all handedness measures, are viewed alongside performance levels, emphasising the relationship between the two whilst treating them as separate entities. In other words, an overall variable handedness profile or a low profile score does not necessarily reflect dysfunction because they measure different aspects of handedness.

The multidimensional manner in which the handedness profile assesses handedness is reflected in the proposed emergent key handedness features including incongruence, inconsistency, excessive interhand differences, subaverage unimanual performance levels (i.e., Ability and Skill), midline crossing avoidance and subaverage bimanual coordination. These handedness features appear promising in distinguishing one type of handedness from another. However, assessing problems related to handedness is only the first part of the clinical decision making process (Step 1). Before decisions on treatment approaches can be made, the individual handedness profile needs to be analysed in greater depth as an interaction phenomenon within occupational performance in order to reach a decision on the possible cause for the presenting variability. To this end, a conceptual framework analysing variable handedness is developed (Step 2), and cause-related types of variable handedness are identified (Step 3). Finally, existing treatment approaches and their suitability to handedness related problems is discussed (Step 4). Each of these steps is discussed in greater detail in the following sections.

7.3.1 Using the Handedness Profile Test Battery

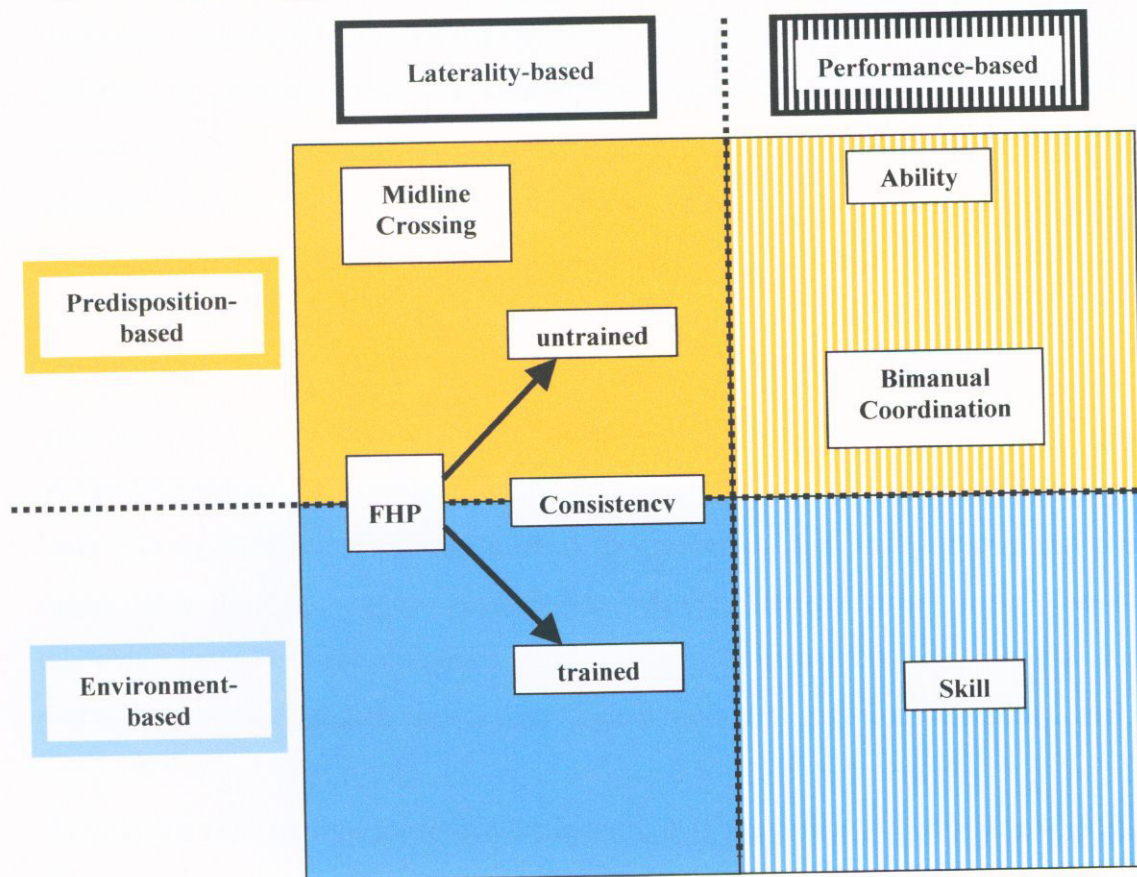
A child presenting with variable handedness is assessed using the five modified tests of the Handedness Profile Test Battery. The raw scores of the tests are categorised and a profile score forms the basis of a preliminary profile classification (see Chapters 4, 5 and 6 for more details).

7.3.2 Applying the Four-Way Analysis to the Handedness Profile

As outlined in the previous chapters, the modified tests were designed to concurrently assess two different aspects of handedness, namely interhand differences and performance levels. These two aspects can be conceptualised in the following way. Firstly, *interhand differences* provided the degree or strength of handedness, indicating to what extent one hand is employed over the other, regardless of how well the task is performed. This could be referred to as the *laterality-based* aspect of handedness. Secondly, the *performance level* demonstrated how well a child performed in relation to the normative profile's average performance, regardless of the extent of manual lateralisation apparent in the interhand differences. This second aspect of handedness could be described as *performance-based*. The results of the normative study in Chapters 4 and 5 revealed a strong relationship between the handedness measures based on interhand differences, and a moderate relationship between the performance level measures. However, there was no association between interhand differences and performance levels, supporting the laterality- versus performance-based distinction.

In addition, a clear differentiation emerged between untrained and trained Functional Hand Preference tasks in left and right handers (Chapter 4). This finding appears to verify some of the theoretical postulates discussed in Chapter 1, which parallel the untrained/trained division. Similarly, Ability and Skill performance were found to be significantly different from each other, whilst Ability showed a high correlation with untrained tasks and Skill with trained tasks. These findings support the proposition that trained aspects of handedness (e.g., trained Functional Hand Preference tasks, Skill) are influenced by the environment and subjected to training, learning and practice (i.e., *environment-based*), whilst untrained, more innate aspects of handedness (e.g., untrained Functional Hand Preference tasks, Ability) measure predominantly inherent aspects of handedness (i.e., *predisposition-based*). Together these four distinctions (i.e., laterality-based, performance-based, environment-base and predisposition-based), comprise a conceptual framework for analysing variable handedness, hereon referred to as the *Four-Way Analysis* of handedness, to differentiate between the different aspects of handedness. Figure 7.1. illustrates how the modified tests of the Handedness Profile Test Battery were allocated according the Four-Way Analysis, together covering all possible combinations of the four handedness aspects.

Figure 7.1. Diagrammatic Representation of the Four-Way Analysis of Handedness



Note. FHP = Functional Hand Preference; MC = Midline Crossing; BC = Bimanual Coordination.

The Four-Way Analysis of handedness enables a hypothetical distinction that might be useful to further understand underlying and interacting internal and external handedness factors in children presenting with variable handedness. From the present studies it was evident that normally established handers were likely to yield relatively large interhand differences in the *laterality-based measures* (trained and untrained Functional Hand Preference, Consistency and Midline Crossing). Conversely, the *performance-based measures* (Skill, Ability and possibly Bimanual Coordination) typically demonstrated small interhand differences in normal children.

The proposition that *laterality-based* aspects (interhand differences) might contribute to, or even cause motor delay (Bishop, 1990a; Kaufman, Zalma & Kaufman, 1978; Tan, 1985), is interesting, particularly since the discriminant analyses yielding predictive factors only for interhand difference and not performance level measures. The present studies demonstrated that these two aspects of handedness are relatively independent. In other words, according to the present findings, poor motor skills in the *performance-*

based aspects (performance levels) appear to exist independently of laterality problems. However, it is possible that motor delay could further impede the already retarded manual lateralisation process. Results from the study of the clinical sample (Chapter 6) indicate that variable hand use might occur more frequently in addition to general motor problems affecting both hands. For more conclusive findings, more research is needed to investigate the relationship between motor problems and handedness establishment using the normative profile.

In conjunction with general motor problems, it was found that the interhand differences of the laterality-based measures might be exceptionally large, with the non-preferred hand scoring well below average even if the preferred hand scored within the average range. This finding suggests dysfunction of the 'non-preferred' hand that might inherently have been the dominant hand. In such circumstances it is possible that the presenting variable handedness has pathological roots (i.e., pathological handedness)

As with the *laterality/performance* distinction, it is important to determine whether the observed variability is related to *environmental* learning and training, or whether it is a reflection of the innate *predisposition*. This may be detected if there is a clear distinction and incongruence between a child's performance scores on different types of tasks, such as trained and untrained Functional Hand Preference tasks, and between Skill and Ability. For example, a child might use the left hand predominantly for untrained tasks and show superior performance with the left hand in Ability, whilst conversely executing trained tasks predominantly with the right hand. Whilst the right hand might also display superior performance in Skill, it would be likely that the interhand differences would be smaller than normal, with the left hand exhibiting above average performance for a non-preferred hand. Using the hypothetical distinction between *predisposition* and *environment* for this child raises the possibility for switched handedness as an underlying cause for variable handedness. In addition, exploring the handedness profile within the Four-Way Analysis framework needs to be supplemented by relating it to possible causes or types of variable handedness as reviewed in the literature. The Four-Way Analysis could be an additional and complementary conceptual tool to contextualising and understanding handedness within occupational performance (see Section 1.3).

7.3.3 Proposing Types of Variable Handedness

Interpreting a handedness profile (based on the Handedness Profile Test Battery) in the context of literature providing evidence for different underlying causes, would assist in understanding the child's problems related to variable handedness more comprehensively. The proposed causes for variable handedness, as reviewed in Chapter 1 (see Section 1.4) were used as a basis to distinguish different *types* of variable handedness (see Table 7.1 for a summary). The first column of this table, 'Types of Variable Handedness Related to Underlying Causes' is based on the reviewed literature and defines each of the identified types of handedness variability (in italics) with the proposed underlying cause underneath, and important additional information in brackets. The second column displays the 'Handedness Measures' of the Handedness Profile Test Battery, and the third column 'Description of Presenting Handedness Features' summarises handedness features based on the findings of the present studies. The possibility of forced change of handedness due to upper limb trauma or extensive hemispheric damage, such as cerebral palsy, has been excluded for the purpose of analysing variable handedness in minimally dysfunctional children.

Table 7.1. Types of Variable Handedness and Description of Presenting Handedness

<u>Features</u>		
<i>Types of Variable Handedness Relating to Underlying Causes</i>	<i>Handedness Measures</i>	<i>Description of Presenting Handedness Features</i>
<i>Left Handed Variability</i> Normal variability of left handedness. (Parent and teacher report of left handedness, uses left hand for drawing and writing.)	Hand Preference	Uses left hand for writing and drawing, but may be variable in all other hand use.
	Hand Performance	Marginally better with left, but small IHD. Average, unless perceptual motor deficits exist.
	Midline Crossing	May cross the midline with either hand.
	Bimanual Coordination	Unimpaired unless perceptual motor deficits exist.
<i>Development-Based Variability</i> ♦ Developmental delay and SI dysfunction impact on handedness establishment. (Developmental delay in fine and gross motor, language, visual perceptual, etc.)	Hand Preference	Likely to change hands even for trained and skilled tasks. Might present in combination with switched handedness in older children.
	Hand Performance	Small IHD, both hands likely to perform poorly.
	Midline Crossing	Likely to avoid midline crossing.
	Bimanual Coordination	Likely to be poor.

(table continues)

Table 7.1. (continued)

<i>Types of Variable Handedness Relating to Underlying Causes</i>	<i>Handedness Measures</i>	<i>Description of Presenting Handedness Features</i>
<i>Motor-Based Variability</i> Deficits in motor abilities (Deficits in motor skills that are <i>not</i> clearly developmentally based.)	Hand Preference	Incongruent and inconsistent hand use.
	Hand Performance	Both hands perform poorly, and IHD values might be excessively large, indicating weakness of one side.
	Midline Crossing	Likely to be poor.
	Bimanual Coordination	Most probably poor.
<i>Switched Handedness</i> Inherent left handers change to right hand use (writing) due to environmental pressure. (Early history of left handedness, evidence of environmental pressure. Might have typical learning disability problems.)	Hand Preference	Uses left hand for untrained tasks and right hand for trained tasks, especially drawing and writing.
	Hand Performance	Left hand is in the average or above-average range for a 'non-preferred' hand unless additional motor deficits exist. Right hand might be average or below.
	Midline Crossing	Crosses midline with either hand or with the left, unless there is midline crossing avoidance.
	Bimanual Coordination	Average or above, unless motor deficits exist.
<i>Pathology-Based Variability</i> Pathological left or right handedness. (Evidence of birth related trauma and possible existing diagnosis.)	Hand Preference	More able hand is also the preferred hand for all tasks requiring some proficiency.
	Hand Performance	Large interhand differences between the more able hand and the less able hand. PL depends on the extent of neurological impairment.
	Midline Crossing	Likely to be poor because of other deficits.
	Bimanual Coordination	Likely to be impaired.
<i>Diagnostic-Based Variability</i> Diagnostic condition underlies variable handedness. (Existing diagnosis of Autism, intellectual disability, etc.)	Hand Preference	More or less ambiguous hand use.
	Hand Performance	Likely to be poor.
	Midline Crossing	Likely to avoid Midline Crossing.
	Bimanual Coordination	Likely to be poor.
<i>Ambidexterity-Based Variability</i> Variability is due to ambidextrous behaviour. (Both hands perform equally well. There might be evidence of ambitiously training both hands.)	Hand Preference	Likely to be inconsistent within and between tasks.
	Hand Performance	Both hands score in the average range or above with little or no interhand differences.
	Midline Crossing	Likely to be mixed (i.e. crosses with either hand).
	Bimanual Coordination	Probably good.

(table continues)

Table 7.1 (continued)

<i>Types of Variable Handedness Relating to Underlying Causes</i>	<i>Handedness Measures</i>	<i>Description of Presenting Handedness Features</i>
<i>Idiopathic Variability</i> Unknown cause, profile lacks specificity.	Hand Preference	Likely to be inconsistent and incongruent.
	Hand Performance	Might be subaverage, one hand or both.
(No apparent causes, none of the types of handedness apply or several types coexist.)	Midline Crossing	Might avoid Midline Crossing.
	Bimanual Coordination	Might be subaverage.

Note. IHD = interhand differences; PL = performance levels; SI = sensory integration. Hand preference consists of untrained and trained tasks, and hand performance of Ability and Skill. ♦ ‘Developmental-based variability’ is also referred to as ‘unestablished handedness’ in this thesis.

However, the link between handedness features and type of variable handedness remains speculative at this stage, and more extensive empirical investigation based on large clinical samples is required. It is also important to note that it might be difficult to find ‘pure’ cases of a stipulated handedness type, particularly since the right biased environment influences handedness establishment with a shift to the right in all individuals, including moderate to mild left handers. The right bias might also increase the variability in pathological handers, increasing the possibility that two or more causes for variable handedness coexist.

7.3.4 Implementing Occupational Therapy Treatment

Once a handedness profile with its particular handedness features has been analysed and a type of variable handedness proposed, it is useful to consider the underlying assumptions of available treatment approaches before embarking on a treatment programme. Mandich, Polatajko, Macnab and Miller (2001) identified three types of treatment strategies that were labelled ‘bottom-up’ (i.e., based on hierarchical models of mastering basic skills before complex ones); ‘task-specific’ (i.e., specific skills are trained by performing the task that requires these skills); and ‘top-down’ (i.e., based predominantly on cognitive processes such as problem solving). These three types of strategies could be used as a basis for deciding on treatment of handedness-related problems.

A *bottom-up* strategy is characteristic of a sensory integrative approach, perceptual motor training and neuro-developmental therapy. These approaches might be suitable for young children who present with a development-based or motor-based type of handedness

variability, and/or those children where handedness appears to be affected by a Bilateral Integration and Sequencing Deficit, a specific sensory integrative dysfunction. Sensory integration outlines the most comprehensive assessment and treatment approach available in paediatric occupational therapy addressing disorders that feature development-based and motor-based types of handedness variability, together with midline crossing avoidance and bilateral integration deficits. However, there is lack of empirical evidence to support the efficacy of sensory integrative treatment generally (Humphries, Wright, Snider & McDougall, 1992; Polatajko, Kaplan & Wilson, 1992; Polatajko, Law, Miller, Schaffer & Macnab, 1991; Stonefelt & Stein, 1998). More specifically, no study was found that assessed and evaluated handedness establishment in isolation using sensory integrative procedures.

The proposed laterality-based aspects and handedness features (e.g., hand preference, consistency and midline crossing, and congruence) are not proficiencies that can be developed through teaching or training. Instead, they appear more reflective of the maturational aspects of the nervous system (particularly the corpus callosum and the hemispheres). It is thus very unlikely that these handedness aspects would improve through task-specific intervention. Rather, bottom-up approaches appear suitable in these cases. In addition, the prospect of employing principles of simultaneous bimanual movement during a single task, such as bimanual isokinematic training (Mudie & Matyas, 2000) could be explored for the promotion of handedness establishment. While there are reports that bimanual practice has a greater impact on the non-preferred hand, thereby reducing interhand differences (Perelle, Ehrman & Manowitz, 1981), other studies have found this to be the case only in the initial phase, after which both hands continue to improve and the preferred hand demonstrates a superior ability to retain these improvements (Marks, 1996). Empirical studies investigating the application of bimanual isokinematic training for developing handedness are warranted.

Conversely, high level fine motor skills, and handwriting in particular, appear well suited for a *task-specific* approach. The writing hand appears to be the most crucial aspect in handedness establishment, since the possible problems relating to switched handedness have been observed in many cases where only the writing hand was switched and the individual continued to perform other tasks with the left hand (e.g., Porac, Rees & Buller, 1990; see Section 1.4.5 in Chapter 1 on switched handedness). However, it would be

important to ensure that the decision on the optimal writing hand has been finalised prior to a task-specific training programme to avoid training the 'incorrect' hand. In addition, a sound knowledge of the development of graphomotor skills would be an important prerequisite to successful task-specific training in a systematically graded fine motor programme. Ziviani (1995) defines graphomotor skills as follows:

“At the perceptual-motor level, graphomotor skills comprise the interplay between environmental conditions and individual sensory, perceptual and motor abilities in the process of executing a drawing or a piece of written work” (p.184).

Since fine motor and graphomotor deficits appear to be one of the major reasons for occupational therapy referrals, assessment and treatment of fine motor and graphomotor skills should consider handedness establishment, which could significantly impact on the child's occupational performance such as drawing or writing.

Switched handers pose the greatest challenge in clinical decision making for paediatric occupational therapists because of possible negative consequences due to writing with the non-dominant hand. Moreover, there is only limited time available for unestablished handed children at school entry before a final decision on the preferred hand for writing has to be reached. When a child presents with a handedness profile that suggests switched handedness as a cause for variability (see again Table 7.1), the therapist, the child, parents and relevant teachers need to decide whether retraining of the dominant hand is the best solution.

Whilst many of the presenting problems might be related or caused by switched handedness (Harris, 1990; Fischl, 1986; Friedman, 1987; Olsson & Rett, 1989; Richberg, 1987; Sattler, 1998; Stutte, Schilling & Weber, 1977), 'unswitching' might not be favourable in every case since there appear to be certain preconditions for successful handedness retraining. According to Sattler (1998), these preconditions include the following: (i) full support for the retraining process of parents and teachers, (ii) a relatively stress-free situation with flexible time constraints on writing, and limited writing volume, and (iii) sufficient motivation of the child. In addition, based on clinical experience of the researcher, average or above average motor performance level of the left hand, and regular occupational therapy sessions, monitoring of progress and regular follow-up, including close contact with parents and teachers, are also necessary for a successful handedness retraining outcome. Age does not appear to be a major factor for

successful retraining, as numerous case studies exist of adult switched handers who have successfully retrained their original/dominant handedness (Sattler, 1998).

In contrast to using a bottom-up approach to help establish underdeveloped or unestablished handedness, a combination of a *top-down* cognitive approach would be an appropriate basis for a handedness *retraining* programme for switched handers. This could be achieved by using problem solving and motor sequencing in task-specific intervention, particularly writing. Successful handedness retraining, employed over 5 to 12 months, can eventually result in more fluent and comfortable handwriting with the non-dominant writing hand (Sattler, 1998; researcher's own clinical experience). In addition, other changes were observed by parents and teachers, including less aggressive behaviour, greater motor coordination, improved memory, increased verbal expression and better organization (Sattler, 1998; researcher's own clinical experience). However, in some cases or under unfavourable conditions, existing problems might be exacerbated rather than relieved through a handedness retraining process (Sattler, 1998). It is thus crucial that the therapist has a thorough knowledge of the behavioural responses associated with the process of 'unswitching' handedness.

Considering the complexity of handedness, it would seem unlikely that there would be one standard, treatment approach that could effectively enhance the establishment of handedness, or that a certain combination of approaches would be effective in all cases. Whilst the appropriateness and effectiveness of these treatment approaches in addressing unestablished handedness has still to be determined; it is proposed that the therapist should be familiar with different types of intervention, applying one or more approaches as deemed most beneficial to each individual child (see Appendix 7A for a brief rationale on possible treatment approaches). The overall process of clinical decision making is summarised in Figure 7.2. In addition, Table 7.2 applies a more specific clinical decision making process, including the use of the Four-Way Analysis together with the information yielded from the handedness profile, to a case example in the form of a case presentation (i.e., Case 12, displayed in Figure 6.12 in the previous chapter, hereon referred to as 'Tim'). (See also Appendix 6E for brief notes on clinical decision making of other case examples.)

Figure 7.2. Process of Clinical Decision Making for Addressing Variable Handedness in Occupational Therapy

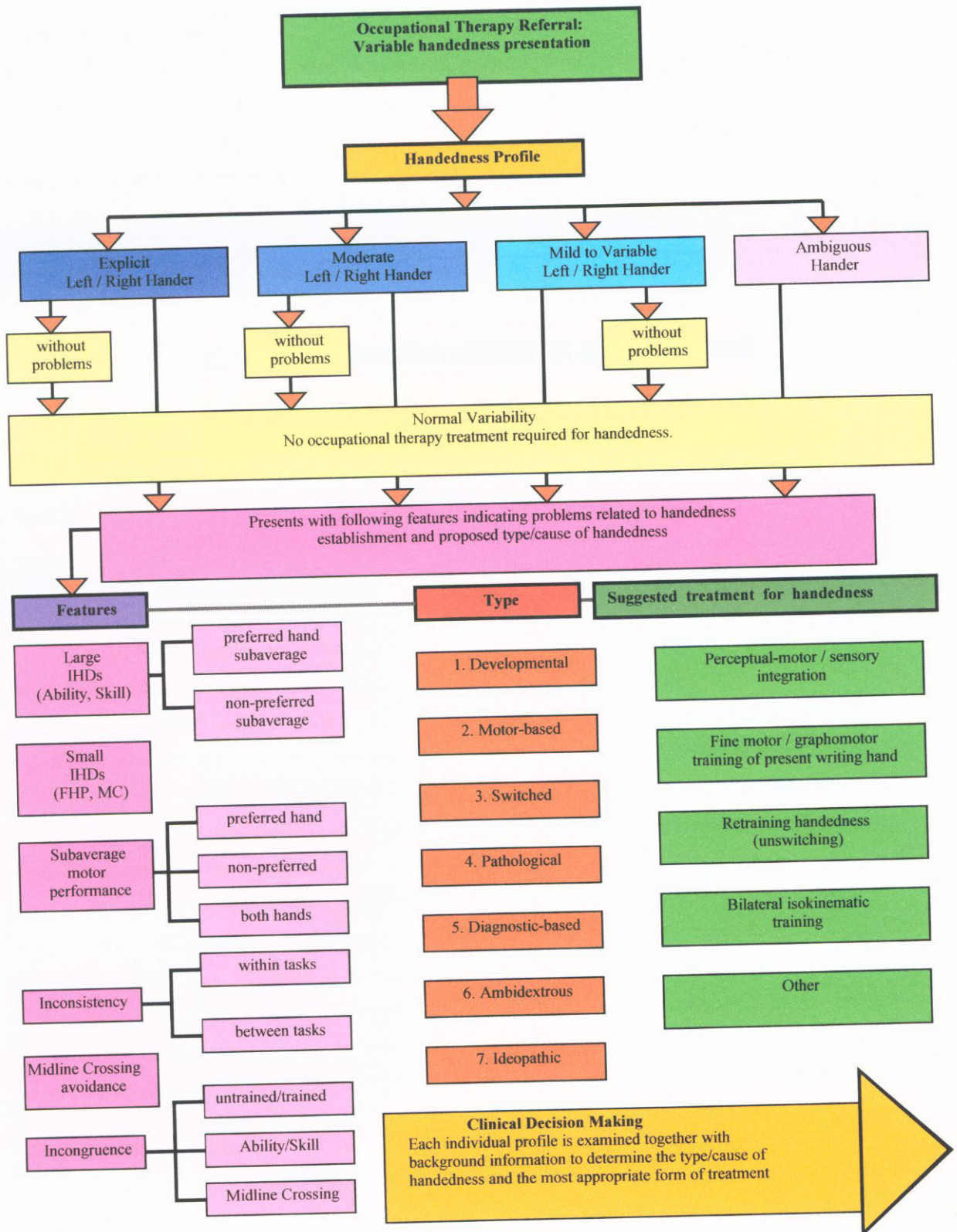


Table 7.2. Case Presentation of ‘Tim’ (Case 12) as an Example of Clinical Decision Making Based on Background Information, the Handedness Profile and the Four-Way Analysis

Background Information:

Tim presents with right handed writing. A history of early left hand use is reported, and both father and sister are self-reported switched left handers. There are indications of socio-cultural pressure for right hand use, with Tim’s father openly advocating the need to switch left handedness to right handedness. There is a history of birth-related stress and general mild developmental delay.

Handedness Profile:

Particulars	Handedness Measures	L+	L	L-	VI	Vr	R-	R	R+	Total (L = - R = +)
Case		4	3	1.5	0.5	0.5	1.5	3	4	
12	uFHP			↓						-1.5
	tFHP					↓				0.5
Age	Ability							☺		3.0
6.3	Skill							↓		3.0
Gender	MC			↓						-1.5
m	BC			☺						-1.5

☺ = average PL; ↓ = subaverage PL (10th to 24th percentile); ↓ = poor PL (0th to 9th percentile).

Profile score: -2.0

Profile Classification: VI

Discussion and Interpretation of Results:

The handedness profile indicates FHP incongruence in both within-task and across-task inconsistency, where the left hand is used more for untrained tasks (mild left) and the right slightly more for trained tasks (variable right). There was no Ability/Skill incongruence, since the right hand performed notable better than the left in both Ability and Skill. A Midline Crossing Incongruence was apparent, where the left hand was used more for contralateral reaching than the right, although Tim generally avoided crossing the midline. Ability was performed in the average range with the right hand, which is not unusual for left handers as a group. Skill, however, was performed better with the right than with the left hand but scored in the poor range. This might be due to a mild motor-based deficit, since both hands performed in the subaverage/poor PL range, despite the practice effect of the right hand. Bimanual Coordination was scored in the average range with a stronger left handed lead. This, together with average Ability performance, suggests an absence of severe coordination problems. In the context of the Four-Way Analysis, this profile shows a clear distinction between predisposition-based versus environment-based measures, and also between laterality-based and performance-based measures. In the light of socio-cultural pressure for right hand use, it can be assumed with reasonable confidence that switched handedness is responsible for Tim’s variable hand use.

Clinical Decision Making:

It would appear that Tim’s motor and perceptual problems have a developmental basis, and it is likely that these problems are exacerbated by his switched handedness. However, considering that his left hand performed in the subaverage range for the ‘non-preferred’ hand, and given the ‘pro-switching’ attitude prevalent in his family, the option of retraining handedness was rejected. Instead, a sensorimotor programme addressing his gross motor problems, and a graded fine motor and graphomotor programme appeared more appropriate.

7.4 Limitations

There are several limitations that impact on the research studies presented in this thesis, some of which have become apparent only in retrospect. Firstly, the sample size of the normative profile (Study III) was not large enough to comprehensively cover the mild and variable handedness groups. Each of the eight categories should contain at least 30 cases before conclusions about normal handedness variability can be drawn. Also, it would have been advantageous to match children for age in Study III across the left and right handed groups.

Secondly, no test-retest and inter-rater reliability studies were performed as all tests were administered by the researcher herself, and the standard error of measurement is not yet known. In addition, the validity of the modified tests needs to be ascertained. Although the three SIPT tests were compared to the modified tests in the third study, the minor changes in administration and scoring that were introduced could well jeopardised existing test validity and reliability, casting doubt on the SIPT results of the third study. Until reliability and validity are established for the modified tests by further research the results and conclusions of this thesis need to be accepted cautiously.

Thirdly, the normative profile features a certain age range, namely 5- to 6-year old children. Age norms of left and right handed boys and girls between 3 and 7 years would be needed before the Handedness Profile could be implemented as a clinically useful tool, so that children's hand preference and performance can be evaluated in relation to age norms.

Fourthly, the Handedness Profile has not been applied to different clinical populations, so the association between certain handedness presentations with specific disabilities or conditions has not been explored. The identified handedness features and the types of variable handedness related to the proposed causes of atypical handedness development remains hypothetical at this stage since there is insufficient psychometric data for understanding the data clinically. More importantly, the significance of certain handedness behaviours (e.g., crossing the midline with the non-preferred hand) is still unknown.

Fifthly, since handedness is a multidimensional interactional phenomenon, the inherent factors such as familial handedness, birth-related stress and socio-cultural influences should ideally be integrated in the final analysis. This might be achieved when a greater volume of empirical evidence pertaining to different types of variable handedness is available.

Finally, the data in this thesis do not constitute sufficient basis for effective intervention. For this purpose, further studies are needed perhaps employing a single case time-series experimental model using specific interventions with a number of variably handed children with similar types of dysfunction. Notwithstanding these limitations, the indications for treatment presented in the previous chapters may serve as examples of how variable handedness might be addressed.

7.5 Concluding Summary of the Thesis

This thesis has contributed towards furthering an understanding of children presenting with variable handedness for occupational therapy in five ways. Firstly, a conceptual framework was created, embedding handedness as an interaction phenomenon in the context of occupational performance. This was achieved by linking handedness with midline crossing and bimanual coordination, and supporting the association between the three neuromotor behaviours with neurophysiological, neurodevelopment and empirical evidence. Secondly, suitable *handedness measures* were modified and applied (Chapters 2, 3 and 4). Thirdly, based on the constructed handedness measures, a *handedness classification system* was composed by developing a normative handedness profile and a profile scoring system (Chapter 5). Fourthly, *handedness features* were identified in the clinical sample to assist the interpretation of variable handedness (Chapter 6). Finally, the handedness profile and its features were linked to the body of literature reviewed initially (Chapter 1), enabling the proposed construction of a conceptual framework for the analysis of variable handedness (i.e., the Four-Way Analysis) and the description of possible *handedness types* (Chapter 7). Knowledge of the types of handedness may, in turn, facilitate the final part of the clinical decision making process related to treatment implementation and evaluation.

7.6 Need for Further Research

The development of the normative handedness profile was based on a group of normal children and applied to a clinical sample, linking theories on variable handedness with empirical findings. The next step in the process is to establish reliability and validity of the normative profile by further research. Only then can it be applied to a normative sample of younger and older children, particularly for performance levels, with sufficiently large numbers in each age, gender and handedness group. A more expansive normative sample would enable the investigation of age-related changes in all handedness measures, gender comparisons, factor structure of handedness measures, and more detailed normative data for the variable handedness groups. Furthermore, for the purpose of further research and general clinical implementation, therapists would need to be trained to administer and score the handedness profile in a standardised manner.

The greatest need for further research using the handedness profile lies in the investigation of children presenting with variable handedness. Different cause-related types of handedness, particularly switched handedness, need to be researched to establish the presence of typical patterns and presentation associated with each type. For example, using quota sampling, minimally dysfunctional children presenting with common underlying causes such as birth-related stress, together with a notably less able non-preferred hand, could be indicative of a pathology-based type of variable handedness. The handedness profile could then be applied to investigate typical patterns of handedness features for this particular type of variable handedness.

Furthermore, as suggested above, the effectiveness of different therapeutic approaches employed with children presenting with variable handedness requires detailed investigation, including the specialised area of handedness retraining for switched hands. Scientific research of this kind is necessary to extend the multifaceted information yielded by the normative profile and related analyses, expand existing knowledge, and assist occupational therapists with clinical decision making in the assessment-treatment process addressing variable handedness in children.

Appendix 1A

Outline of Research Design of the Four Studies

Study	Sample	Main Aim	Procedure of Analysis	Type of Analysis	Rationale
Study I (Chapter 2)	Normative N = 122 Left Handers = 16, Right Handers = 106 (based on parent report) Female = 61, Male = 61 Age = 5-year olds Tests used: EHI, MAcc, SVCCU, BMC.	To examine the suitability (i.e., sufficient variability) of existing 'handedness' tests that evaluate hand preference, hand performance, midline crossing and bimanual coordination. To investigate gender differences.	1. IHD distributions in left and right handers for each test. 2. PL distribution in entire sample for each test. 3. Significant gender differences on 1 and 2. 4. Comparison of parental and EHI hand preference based on established handedness.	Comparative analysis using descriptive information and histograms. One-way ANOVA, clustered bar charts, box plots Cramer's V, crosstabs, Pearson's Chi	Since the aim of the study was to compare the extent to which existing tests could display various aspects of handedness, the distributions of left and right handers were compared rather than the differences between left and right handers. Equal numbers of females and males allowed for gender comparisons.
Study II (Chapter 3)	Normative N = 91 Left Handers = 8, Right Handers = 83 (based on parent report) Female = 40, Male = 51 Age = 30 x 3 years, 31 x 4 years, 30 x 5 years Tests used: EHI, MAcc, MCT, BCT.	To examine the suitability of the EHI and MAcc with younger children and investigate the suitability of modified MCT and BCT tests to display greater variability than the initial tests. To investigate age-related and gender differences.	1. IHD distributions (histograms) in left and right handers for each test. 2. PL distribution (histogram) in entire sample for each test. 3. Comparing initial and modified midline crossing and bimanual coordination tests in 5-year olds. 4. Significant age-related and gender differences on 1 and 2 (clustered bar charts).	Comparative analysis using descriptive information. One-way ANOVA One-way ANOVA, Tukey's b	The aim of this study, similar to Study 1, was to determine the suitability of modified tests, to demonstrate the required variability of the handedness. Thus the left and right handed distributions were compared, also in regard to age, but unequal numbers of left and right handers did not allow for a more detailed analysis between the two groups.
Study III (Chapter 4, Chapter 5)	Normative N = 62 Left Handers = 31, Right Handers = 31 (based on parent & teacher report confirmed by writing hand) Female = 26, Male = 36 Age Group = 5 and 6 years Tests used: EHI, MAcc, SVCCU, BMC, FHP, Ability, Skill, MCT and BCT.	To examine the suitability of the five modified handedness measures, and compare them with the four initial tests. To explore the modified tests and their subtests, investigating to what extent the subtests measure different aspects of handedness. To compare left and right handers by investigating significant differences in IHD and PL measures for the basis of a handedness profile. To construct a normative handedness profile for classification. To compare left and right handers on all measures, examining clustering ability and predictive factors.	1. Comparing distributions of initial and modified IHD measures in left and right handers, and initial and modified PL measures in the entire sample. 2. Reporting significant differences between initial and modified tests, and between left and right handers. 3. Identifying percentiles for an 8-group handedness classification system, applied to left and right handers. 4. Exploring clustering ability and predictive factors.	Comparative analyses descriptive statistics (histograms, box plots). One-way ANOVA Paired t-tests for normal distributions, Wilcoxon test for abnormal distributions Using percentiles on all handedness measures. K-means cluster analysis, crosstabs, sequential DFA	The use of the modified tests as a superior means to assess variability in handedness was confirmed using comparative analysis. Differences between left and right handers were explored for the first time in greater detail. This study provided the data for a normative profile, which was then constructed. To support the construction of the profile, the clustering ability and the emergence of predictive factors on each of the handedness measures was explored in the analysis.
Study IV (Chapter 6)	Impaired N = 68 Left Handers = 11, Right Handers = 57 (based on profile) Female = 13, Male = 55 Age range = 4 to 7 years Tests used: Handedness Profile Test Battery (FHP, Ability, Skill, MCT and BCT).	To explore the handedness profiles of impaired children presenting with unestablished handedness and comparing these to the normative profile. To examine the differences between impaired children and the normative profile in terms of clustering ability and predictive factors to gain a greater understanding of handedness features and possible underlying causes. To investigate support, based on the data and available literature, for a theoretical, contextual framework to analyse variable handedness.	1. Comparing distributions of impaired IHD and PL distributions to the normative profile in left and right handers. 2. Reporting significant differences between the impaired sample and the normative profile. 3. Exploring clustering ability and predictive factors. 4. Examining handedness features which appeared to be grouped together in patterns.	Comparative analyses descriptive statistics (histograms, box plots). One-way ANOVA K-means cluster analysis, crosstabs, sequential DFA Individual case examples of handedness profiles	The normative profile provides the basis for examining variable handedness in impaired children. In addition to investigation of the differences between the impaired sample and normative profile handedness features which tend to aggregate in certain cases were investigated. These features might indicate underlying possible reasons for variable handedness. This information provides a more comprehensive basis for analysing variable handedness and informing subsequent treatment approaches.

Note. Abbreviations in alphabetical order: ANOVA = Analysis of Variance; BMC = Bilateral Motor Coordination; SIPT (initial test); BCT = Bimanual Coordination Test (modified); DFA = Discriminant Function Analysis; EHI = Edinburgh Handedness Inventory (initial test); FHP = Functional Hand Preference (modified test); IHD = interhand differences; MAcc = Motor Accuracy test; SIPT (initial test); MCT = Midline Crossing Test (modified); PL = performance level; SPT = Sensory Integration and Praxis Tests; SVCCU = Space Visualisation Contralateral Use measure (initial test). Bold text under 'Sample' indicates additional aspect for investigation in that study.

Appendix 1B

Glossary

Since there is a lack of consistent terminology on handedness and related aspects, and since new terminology inadvertently emerged in the process of analysing and discussing findings, this glossary was deemed useful to provide definitions for the terminology used for the purpose of this thesis. All terms are also defined more extensively with references in the thesis.

Ability Test (Ability)	One of the two modified measures of hand performance (the other is Skill) as part of the Handedness Profile Test Battery. Ability refers to those aspects which require proficiency but are unlikely to have been influenced by training and practice, namely hammering and tapping. Written in title case if it refers to the modified test.
Ambidexterity	Both hands are <i>equally</i> skilled and equally used in trained, skilled tasks such as writing. Performance of both hands is at least average or above. Very rare condition.
Ambiguous Hand Use	Type of variable handedness. Either hand is used for the same activity (e.g., throws sometimes with the left, then with the right hand).
Ambilaterality	Either hand or side is used arbitrarily, without consistency between or within tasks
Bead Dotting Task (BDT)	One of the two modified hand performance subtests of Skill, based on a dotting task with left and right hands, involving both speed and accuracy. The other test is the Bear Tracing Task (BTT).
Bear Tracing Task (BTT)	One of the two modified hand performance subtests of Skill, based on a tracing task with left and right hands, involving both speed and accuracy. The other test is the Bead Dotting Task (BDT).
Bilateral Motor Coordination (BMC)	A Sensory Integration and Praxis test assessing the ability to use tow sides of the body in an integrated and coordinated manner. For the purpose of the first study, only the upper extremities were assessed.
Bimanual Coordination Test (BCT)	One of the five modified handedness measures assessing bimanual coordination using an adapted Etch-a-Sketch instrument. Consists of interhand difference and performance level measures.
Bimanual Coordination Test Scoring Guide	See Scoring Guide.
Binominal Distribution	Refers to a classification system based on two groups, left and right handers, regardless of the degrees of handedness.
Calculation Sheet	Refers to a separate sheet on which calculations, such as converting error scores to raw scores, are performed. Sometimes record and calculation sheets coincide (e.g., BCT).
Category Score	Each handedness category was assigned a category score for each handedness measure (i.e., explicit categories = 4, moderate categories = 3, mild categories = 1.5 and variable categories = 0.5).

(appendix continues)

Appendix 1B (*continued*)

Centre Line	Refers to the line inside the BTT path. The child is instructed to stay on the centre line as much as possibly.
Cerebral Dominance	Cerebral dominance is no longer considered to be an adequate term since it is accepted that the hemispheres are complementary rather than dominant in their relation to one another.
Cerebral Lateralisation/ Specialisation	Synonymous with cortical lateralisation. Refers to the <i>process</i> of a hemisphere becoming more specialised in certain functions. Cerebral specialisation refers to certain specialised functions of each hemisphere.
Confidence Interval (CI)	The 95% confidence interval (CI) provides a range of scores based on the probability that 95% of cases would achieve a score in that range.
Congruence	See incongruence.
Consistency	Consistent use of one hand <i>within-tasks</i> or <i>across-tasks</i> , i.e. one hand always performs a certain action for certain tasks (within) or for all tasks (between), found in well established handers. When written with initial capital letters, Consistency refers to the handedness measure, based on the modified tests, as part of the Handedness Profile Battery.
Contralateral Hemisphere	Refers to the space on the opposite side of the hand used for function.
Contralateral Reaching	Synonymous with midline crossing behaviour.
Cortical Lateralisation	Synonymous with cerebral lateralisation.
Crossing the Midline	See Midline Crossing.
Deviations (LD/RD)	Refers to the deviations from the ideal line in the Bimanual Coordination Test. These deviations may be erring to the left (referred to as LD) or to the right (RD).
Diagnostic-based Handedness	Proposed reason for variable handedness, since there is evidence that certain pathological conditions (e.g., autism), coexist with decreased manual lateralisation.
Direction of Handedness	Refers to either left or right handedness as a direction, irrespective of the degrees of handedness.
Distal Contralateral Reaching	One of the two subtests of the modified Midline Crossing Test, based on the number of times a child crosses the midline when picking up a peg distally (i.e., away from the body). The other subtest is proximal contralateral reaching.
Edinburgh Handedness Inventory (EHI)	A widely used ten item handedness inventory by Oldfield (1970). The EHI has been adapted for the present studies by using demonstration of hand use and four trials for a consistency measure. EHI left and right handers are defined by an based on EHI scores.
Established Handedness	One hand is consistently used in functional unimanual and bimanual handedness tasks, within- and across-tasks.
Established Midline Crossing Behaviour	The same preferred hand is used for all contralateral reaching, as well as all ipsilateral reaching.

(appendix continues)

Appendix 1B (continued)

Error Score (ES)	Refers to those scores based on errors and deviation from an ideal line. Need to be converted to raw scores.
Explicit Handedness Category	Constitutes two of the eight handedness categories reflecting 'strong' left or right handers demonstrating a definite preferred hand in all handedness measures, falling above the 75 th percentile of the norm. the other categories are moderate, mild and variable.
Four-Way Analysis	Refers to the conceptual framework for analysing variable handedness developed in this Thesis (Chapter 7). Modified handedness measures are analysed as either laterality- or performance-based, as well as predisposition- or environment-based.
Group Classification	Refers to a system of categorising handedness by employing, 2-group (left/right), 3-group (left/right/unestablished), 5-group (definite left, left tendency, mixed, right tendency, definite right) or 8-group (explicit left/right, moderate left/right, mild left/right and variable left/right) classification.
Hand Dominance	A term used interchangeably in the literature with handedness and hand preference. For the purpose of this thesis, hand dominance refers only to the innate, inherent predisposition of handedness.
Hand Performance	Hand performance of one hand measured both in terms of speed and accuracy. In the handedness profile, hand performance consists of Ability Test (untrained: hammering and tapping) and Skill Test (trained: tracing and dotting).
Hand Preference	Asymmetrical use and function whereby one hand is favoured over the other across a range of skilful acts. Assessed by the EHI and FHPT measures.
Handedness	Umbrella term comprising of both hand preference/hand dominance and hand performance.
Handedness Categories	Refers to the 8-group classification system employed for the normative profile, consisting of explicit left (L+), moderate left (L), mild left (L-), variable left (Vl), explicit right (R+), moderate right (R), mild right (R-) and variable right (Vr) handedness categories.
Handedness Classification	See Profile Classification.
Handedness Features	Refers to features or factors of handedness identified in the clinical sample that appear to be typical of deficits associated with some form of variable handedness. They consist of incongruence, inconsistency, excessively large motor IHD values, and excessively small motor IHD values (key handedness features); as well as subaverage performance levels avoidance of Midline Crossing, and subaverage Bimanual Coordination.
Handedness Profile	Refers to the outcome of the Handedness Profile Test Battery applied to an individual case. Not to be confused with the normative handedness profile or normative profile, which is a yard stick against which an individual handedness profile is measured.

(appendix continues)

Appendix 1B (continued)

Heterologous Movement	One of the two BCT subtests. Refers to circular movement using both hands simultaneously in one direction in a parallel fashion. The other BCT subtest is homologous movement.
Homologous Movement	One of the two BCT subtests. Refers to either inward or outward circular movement using both hands simultaneously in a mirror fashion. The other BCT subtest is heterologous movement.
Ideal Line	Refers to the 12 cm long ideal 45° line in the Bimanual Coordination Test (BCT) that is obtained when both hands turn the discs of the BCT simultaneously and at the same speed.
Incongruence	Refers to a discrepancy between the hands (i.e., the left hand in one of the four left categories and the other in one of the four right categories, with at least one category between them) in regard to IHD measures.
Inconsistency	See Consistency. Inconsistency is used as a <i>handedness feature</i> indicative of dysfunction related to variable handedness.
Interhand Differences (IHD)	Refers to difference in performance between the left and right hands, regardless of the level of performance. Left handed scores are subtracted from right handed scores (i.e., left handed scores are negative) and converted to percentages. <i>IHD measures</i> refer to those handedness measures (e.g., Skill IHD) based on interhand differences. <i>IHD values</i> refers to the actual score or numerical value.
Ipsilateral Reaching	Describes midline crossing avoidance where the child picks up objects on the right side with the right hand, and on the left side with the left hand. Opposite to contralateral reaching.
Lateralisation	See Manual and Hemispheric Lateralisation.
Laterality-Based Measures	Refers to those handedness measures which appear to investigate predominantly laterality-based aspects of handedness, such as the Functional Hand Preference Tasks, and the interhand differences on the motor tests. Part of Four-Way Analysis.
Laterality Quotient (LQ)	The number of left hand responses are subtracted from the number of right hand responses, divided by the total number of responses and multiplied by 100 to obtain a percentage.
Manual Asymmetry	Refers to the different roles that the hands assume, regardless of the leading or preferred hand. Appears to be task dependent.
Manual Lateralisation and Specialisation	The process of establishing handedness, i.e., one hand becomes more preferred and more proficient. Manual lateralisation is thought to be related to hemispheric lateralisation and specialisation. Handedness is synonymous with manual specialization.
Master Transparency	Part of the scoring guide for the Bimanual Coordination Test, together with a protractor (see Appendix 3K).
Midline Crossing Quotient (MCQ)	Midline Crossing Quotient is based on the contralateral reaching responses and calculated the same way as Laterality Quotient (i.e., $R - L$ divided by $R + L \times 100$).

(appendix continues)

Appendix 1B *(continued)*

Midline Crossing Test (MCT)	Midline Crossing Test is one of the modified handedness measures and part of the Handedness Profile Test Battery. Midline Crossing is written in title case when it refers directly to the MCT.
Midline Crossing Extent (MCE)	Computation of Midline Crossing that measures the overall ability to cross the midline, regardless of which hand is used. Comparable to a performance level measure of midline crossing.
Mixed Handedness	One hand is used consistently for certain tasks, and the other hand is employed consistently for different tasks.
Mild Handedness Category	Constitutes two of eight handedness categories (i.e., left and right) where individuals show a mild tendency for a preferred hand across most handedness measures, falling between the 25 th and 10 th percentile of the norm. The other categories are explicit, moderate and variable.
Moderate Handedness Category	Constitutes two of eight handedness categories (i.e., left and right) where individuals employ a preferred hand most of the time across all handedness measures, falling between the 25 th and 75 th percentile of the norm. The other categories are explicit, mild and variable.
Motor Accuracy (MAcc)	Revised Test of Motor Accuracy, part of the SIPT and SCSIT, used in Study I and Study III to assess hand performance.
Neuromotor Behaviour	Refers to neuromotor behaviours, including handedness and associated behaviours, referring to midline crossing and bimanual coordination.
Normative Profile	Same as normative handedness profile. Based on a normative sample of children. This is the yard stick developed in this thesis against which children with unestablished handedness are measured, based on quartiles.
Pathological Handedness	Refers to the proposition that left handedness is caused through intra-uterine, birth-related or other factors, causing a shift from the 'dominant' hemisphere to 'non-dominant' one, thereby also causing a shift in handedness.
Performance-Based Measures	Refers to those handedness measures which indicate a level of motor proficiency, such as Ability and Skill performance levels. Part of the Four-Way Analysis developed in Chapter 7.
Performance Level	Refers to the level of performance compared to the norm, irrespective of interhand differences, of both the preferred and non-preferred hands.
Preferred Hand Use (PHU)	The PHU, used in the SIPT, is based on the hand employed first for the tracing task. This 'preferred' hand is later used in calculating the preferred hand use score during contralateral reaching.
Presenting Left/Right Handers	Classification is based on left and right handers presenting their particular handedness according to parent report, in addition to teacher's report, background information and the writing hand.
Profile Classification	Based on the profile score, the mean of the categories and an analysis of presenting handedness features, the profile classification provides a overall categorization of handedness according to the 8-group handedness classification.

(appendix continues)

Appendix 1B *(continued)*

Profiled Left/Right Handers	Handedness as determined by results of the handedness profile, and not by parent report or other assessments.
Profile Score	Refers to the sum of the category scores based on all IHD measures. A negative profile score denotes left handedness.
Proximal Contralateral Reaching	One of the two subtests of the Midline Crossing Test, based on the number of times a child crosses the midline when picking up a peg proximally (i.e., close to the body). The other subtest is distal contralateral reaching.
Raw Score (RS)	Results of the handedness measures in percentages. Can be derived from an error score by using the maximum possible score as a figure from which the error score is subtracted, to obtain a raw score. Raw scores of are in percentages and classified according to handedness categories.
Reported Left/Right Handers	Handedness is reported by parents or teachers, but not assessed using the handedness profile.
Response Line	Refers to a line the child has produced in response to the tracing (BTT) task or the bimanual coordination (BCT) task.
Response Sheet	Refers to the sheet used during any of the handedness measures where the child 'responds' to the task, e.g., by tracing, dotting, hammering or tapping. Sometimes response and score sheets are combined (e.g., in the BTT/BDT tests).
Response Transparency	Blank transparency used for tracing the response lines of the BCT of all four trials (see Appendix 3K).
Reversion	This is a possible response during the Bimanual Coordination Test using the Etch-a-Sketch instrument. If a child is unable to maintain simultaneous bimanual circle drawing in the required direction, reversion might result, whereby the response line changes direction and takes on a different slope. Reversions may be complete or incomplete.
Score Sheet	Refers to the sheet used for scoring the child's response to the various handedness task, such as tracing, dotting, hammering or tapping. Sometimes score and response sheets are combined (e.g., in the BTT/BDT tests).
Scoring Guide	Consists of a master transparency attached to a protractor, used to score response lines of the Bimanual Coordination Test (see Appendix 3K).
Sensory Integration and Praxis Tests (SIPT)	A comprehensive test battery of 17 tests used to evaluate sensory integrative dysfunction, developed by Ayres (1989). The SIPT is based on an earlier version, SCSIT. Three SIPT subtests were used in this thesis: Motor Accuracy Revised, Space Visualisation Contralateral Use, and Bilateral Motor Coordination.
Skill Test	One of the two measures of hand performance (the other is Ability), based on the five modified tests (Handedness Profile Battery). In the context of this thesis, Skill refers to those aspects that require proficiency that is likely to have been influenced by training and practice, namely tracing and dotting. Written in title case when referring directly to the Skill Test.

(appendix continues)

Appendix 1B *(continued)*

Southern California Sensory Integration Tests	The original set of sensory integrative tests, which was later revised and improved to form the Sensory Integration and Praxis Tests.
Summary Calculation Sheet	Sheet included in the Handedness Profile Test Battery where all error scores can be converted to raw scores, and percentages can be calculated for all handedness measures.
Switched Handedness	Refers to usually left handed individuals who were switched to the right hand for preferred tasks, particularly writing, because of right biased physical and social environment.
Unestablished Handedness	Refers to a child who is still undergoing a maturational and developmental process affecting handedness establishment. Used as an umbrella term for those children presenting for therapy with variable handedness. May be an ambilateral or mixed hander, presents with a low laterality quotient (for the purpose of this study $\leq 60\%$).
Unestablished Midline Crossing Behaviour	The preferred hand is not used for contralateral reaching. It might operate in the ipsilateral space or in midline.
Variable Handedness	Umbrella term for all handedness behaviour that is not fully established or consistent.
Variable Handedness Category	Two handedness categories (i.e., left and right), where no clear hand preference or superior hand performance can be detected, or where performance across the handedness measures is incongruent, falling below the 10 th percentile of the norm. A slight tendency towards one side may be evident. Includes individuals with and without dysfunction at all age levels.

Appendix 1C

Minor Genetic Models

Levy & Nagylaki, 1972	Two gene model: the authors proposed one gene for the inheritance of handedness, and one gene for hemispheric specialisation. This model has been criticised for being incongruous with general handedness prevalence (VanStrien, 2000).
Klar, 1996	Klar suggested the existence of a single gene RGHT conferring right handedness in approximately 80% of people. Individuals who do not possess this gene have an equal chance of being right or left handed. Half of those lacking the RGHT gene would develop left handedness, the other half would present phenotypically as right handed while possessing the genetic make up of a left hander. Klar's theory offers an explanation to incongruous handedness in monozygotic twins. However, his model does not consider any pathological factors or socio-cultural influences that would change the prevalence of left handedness.
Laland, Kumm, Van Hoom & Feldman, 1995	The authors argued for a genetic influence on handedness as a facultative trait, with no genetic variations underlying handedness since left and right handers have the same genotype. Rather, the observed variations are considered to be due to natural selection, including a combination of parental handedness, developmental and cultural factors, and this process has increased the probability right handedness. This hybrid model is able to explain why both monozygotic and dizygotic twins may have the same or different handedness presentation. Moreover, no hypothesis is needed to justify persistence of left handedness in society. However, the hybrid model does not justify the particular incidence (i.e., approximately 12%) at which left handedness exists, nor does it convincingly explain the incidence of left handedness which has remained fairly constant across time and cultural spheres.
Gangestad & Yeo, 1994; Yeo, Gangestad, Thoma, Shaw & Repa, 1997	The authors proposed that right handedness is inherited in the form of a genetic predisposition, including a developmental design for moderate right handedness universal to humans. Another genetic predisposition to developmental instabilities interferes with the development of moderate right handedness, resulting in left handedness or extreme right handedness. This model renounces a genetic basis for handedness, since handedness variations are assigned to diversities in heterozygosity (Bryden, Bulman-Fleming & MacDonald, 1996). However, this theory does not explain why the majority of left handers do not present with any functional problems or abnormalities.

Appendix 1D

Increased Left Handedness due to Birth-Related Stress

<i>Birth related stress</i>	<i>Authors</i>	<i>Results</i>
Birth weight	O'Callaghan, Tudehope, Dugdale, Mohay, Burns & Cook, 1987	54% of subjects were left handed compared to 8% amongst normal birth weight
Prematurity	Ross, Lipper & Auld, 1987	Only 63% of premature babies showed right handedness compared to 80% of normal-term in 4-year old children
Difficult delivery, induced birth	Colbourne, Kaplan, Crawford & McLeod, 1993	The authors found an increased incidence of left handedness
Mother's age at birth of child and birth stress or complications	Coren, 1992	Mothers over 40 years were 60% more likely to have left handed children compared to 20-year old mothers
Smoking during Pregnancy	Bakan, 1991	There was an increased incidence of left handedness
Early brain injury	Saigal, Rosenbaum, Szatmari & Hoult, 1992	Increased 'non-right handedness', was found especially amongst males. However, non-right handedness did not correlate with language or cognitive deficits/school performance compared to controls

Appendix 1E

Studies Investigating Left Handedness and Pathological Conditions

Examples of studies supporting a link between left handedness and pathological conditions

- | | |
|--|--|
| Annett, 1985; Eglington & Annett, 1994; Obrzut & Atkinson, 1993; | Amongst children with reading disorders there was an elevated number of left handers compared to normal control subjects |
| Fein, Humes, Kaplan, Lucci & Waterhouse, 1984; Hauck & Dewey, 2001 | Autistic and mentally retarded children showed an increased incidence not only of left handedness, but also 'mixed' or 'ambiguous' handedness. |
| Gillberg & Rasmussen, 1982 | These authors found more left handed children with both minimal brain dysfunction and attention deficit disorder. |
| Satz, Orsini, Saslow & Henry, 1985 | The authors reported more left handers amongst children with brain injuries. |
| Geschwind & Galaburda, 1984; Porac & Coren, 1981 | Left handers were 12 times more likely to have learning disability (i.e., 12% of left handers were learning disabled compared to 1% right handers) (Geschwind et al, 1982, 1984). Similar results were found by Porac and Coren. |

Examples of studies disputing a link between left handedness and pathological conditions

- | | |
|---|---|
| Bishop, 1984, 1990b; Hugdahl, Synnevag & Satz, 1990 | These authors failed to find a higher incidence of left handedness in children with reading disorders. |
| Gillberg & Rasmussen, 1982 | These authors did not discover more left handers in a subgroup of children without attention deficit disorder. This indicates that left handedness may be more likely to coexist with attention deficit disorder than with minimal brain dysfunction. |

Note. It has not been unequivocally established whether left handedness is a causative factor in these pathological conditions or vice versa.

Appendix 1F

Studies Investigating the Relationship Between Hand Preference and Hand Performance

<i>Author(s) and Year</i>	<i>Results</i>
Rigal, 1992	Rigal investigated children aged 6 to 9 years, and found an overall correlation between preference and performance of $r = 0.54$ on a series of unimanual tasks. In particular, Pearson's r on writing and aiming was $r = 0.71^*$ and $r = 0.65^*$ respectively.
Lake & Bryden, 1976	Hand preference (questionnaire) and a visually guided repetitive manual aiming task correlated 0.78^* in overall sample, but in a separate analysis of right and left handers the correlation was 0.44^* and 0.00 respectively.
Tapley & Bryden, 1985	Authors found a 0.75^* correlation between hand preference and dot filling performance in the overall sample. However, when left and right handers were considered as separate groups, the correlations fell to 0.17 (right handers) and 0.20 (left handers). This led to the conclusion that the high correlation of the overall sample was derived from the direction of hand preference.
Bryden, Singh, Steenhuis & Clarkson, 1994	Similar to Tapley and Bryden (1985), moderate to good correlations between performance measures and individual preference items were reduced to only a few significant ones when the sample was divided into left and right handers.

Note. * = $p \leq 0.05$.

Appendix 1G

Studies Investigating 'Non-Right' Handedness and Pathological Conditions

<i>Authors</i>	<i>Findings</i>
Bryson, 1990; Fein, Humes, Kaplan, Lucci Waterhouse, 1984; Satz, Soper & Orsini, 1985; Soper & Satz, 1984; Soper, Satz, Orsini, Henry, Zvi & Schulman, 1986;	Soper and Satz (1984) found autistic and 'mentally retarded' children were up to 36% more likely to present with 'ambiguous' hand use. Left handers and variable handers were grouped together. The other author found similar results.
Kinsbourne, 1988	Kinsbourne found evidence for dysfunction in neural patterns in children with unestablished handedness. Furthermore, there was a higher incidence of 'mixed' handedness in a sample of learning disabled children.
Daniel & Yeo, 1991	The authors re-analysed Coren's (1996) data by distinguishing between left- and mixed handers, and they found that mixed handers, rather than left handers, were at greater risk to have accidents than fully right-handed individuals.
Soper, Satz, Orsini, Van Gorp & Green, 1987	The authors conducted a study on 'ambiguous' handers and found that 55% of their sample of institutionalised adults with mental retardation were 'non-right handed'. Of these individuals, 55% were right handed, 10% left handed and 45% showed 'ambiguous' hand preference.
Armitage & Larkin, 1993	Support was found in this study for an association between pathological left handedness or poorly established hand preference, and clumsiness.
Daniel & Yeo, 1992; Hicks, Pass, Freeman, Bautista & Johnson, 1993; Segalowitz & Brown, 1991	These studies demonstrated that children with unestablished handedness suffered more mild head injuries compared to established handers.
Hauck & Dewey, 2001	Autistic children with established hand preference performed higher in motor, cognitive and language tasks than children with autism who displayed unestablished handedness.
Dellatolas, Annesi, Jallon, Chavance & Lellouch, 1990	These authors found twice as many stutterers amongst mixed handers compared to established handed control groups.
Annett, 1970a	Annett reported that 'mixed' handers displayed less speed, accuracy and strength of movement compared to well established handers.
Tierney, Smith, Axworthy & Ratcliffe, 1984	These authors discovered that children with unestablished hand preference showed significantly lower cognitive abilities.
Briggs, Nebes & Kinsbourne, 1976; Miller, 1971; Swanson, Kinsbourne & Horn, 1980	These studies have demonstrated lower scores in spatial and verbal tasks in variable handers.

Note. These studies are fraught with methodological discrepancies, such as inconsistent and incongruous hand preference measures, differing criteria for defining variable handedness with the cut-off point ranging from 100% to 60% of preferred hand use, and the absence of control groups (Bryson, 1990; Hauck & Dewey, 2001). As with left handers, it is not clear whether 'non-right' handedness is a causative factor in the above pathological conditions or vice versa.

Appendix 2A

Unsuitable Hand Preference Tests for This Thesis

<i>Author(s)</i>	<i>Test Description Reasons for not using the test</i>
Kaufman, Zalma and Kaufman, 1978	McCarthy Motor Scales: drawing, bouncing a ball, catching a beanbag and aiming a beanbag at a target There were too few items, and all items except for drawing are similar, involving more ballistic-type, proximal movements that may not differentiate between inconsistent left handers (see Peters, 1990). In addition, it is generally accepted that the reliability of a hand preference test increases with the number of items as well as the number of trials (Bradshaw and Nettleton, 1983; Bryden, 1982). It is unlikely that variable handers would be identified reliably using only a few test items (Gabbard, Hart & Kanipe, 1993; O'Callaghan, Burn, Mohay, Rogers & Tudehope, 1993).
O'Callaghan, Burn, Mohay, Rogers & Tudehope, 1993a	This study was based their evaluation on a parent questionnaire stating the child's overall hand preference. This method has been found to be unreliable (Whittington & Richards, 1987).
Annett, 1970b	Annett's assessment consists of twelve skilled and unskilled tasks, whereby some tasks do not yield as high consistent hand use as others. Similar to the Edinburgh Handedness Inventory (EHI) (Oldfield, 1971), but different tasks receive different weighting. This test is not used as widely as the EHI. It is also proposed that it be used with a hand performance task (peg moving) (Annett, 1970), but no age norms have been identified nor has Annett's assessment been used as extensively with children as the EHI.
Ross, Lipper and Auld, 1992	The authors employ the 'Tell Method', an altered version of the EHI consisting of a few changed test items. Children verbally indicated whether they always or usually use the right/left hand, or whether they use both hands equally. The reliability of the Tell method has not been established convincingly (Longoni & DeGennaro, 1992; Rigal, 1992). Also, children may not be able to indicate the preferred hand reliably, nor be able to differentiate left from right verbally.

Appendix 2B
Parent Questionnaire

QUESTIONNAIRE FOR HANDEDNESS PROFILE

SURNAME: _____ NAME: _____ CODE: _____
(for the purpose of the researcher only - identity will remain confidential)

DATE OF BIRTH: _____ DATE OF TEST: _____

AGE: _____ years _____ months TELEPHONE: _____

Male Female

Please answer the following questions by circling or ticking the appropriate answer and/or writing comments where applicable.

1. Was your child premature? NO YES, _____ wks
2. Did your child have low birth weight? NO YES, _____ grams

3. Which of the following occurred during your pregnancy and post-natally:

- | | |
|---|--|
| <input type="checkbox"/> induced birth, reason: _____ | <input type="checkbox"/> caesarian |
| <input type="checkbox"/> breech <input type="checkbox"/> fetal distress <input type="checkbox"/> cord around neck | <input type="checkbox"/> blue at birth |
| <input type="checkbox"/> jaundice <input type="checkbox"/> delayed cry <input type="checkbox"/> tong delivery | <input type="checkbox"/> suction |
| <input type="checkbox"/> Other: _____ | |

4. Does or did your child have any major injuries to his/her arm or hand (e.g. broken bones, sprains, burns)? NO YES: _____
_____ at age _____, Right Left

5. Does or did your child receive any therapy or special assistance? NO YES: _____
_____ from age _____, frequency _____

6. How would you rate your child's handedness at present? Please circle.

DEFINITELY RIGHT	MORE RIGHT THAN LEFT	UNDECIDED	MORE LEFT THAN RIGHT	DEFINITELY LEFT
---------------------	-------------------------	-----------	-------------------------	--------------------

7. Has your child at any stage used either hand for activities and appeared undecided about his/her hand preference? NO YES: at age _____ until age _____

8. What factors could have contributed to your child's gaining more definite hand preference / still undecided hand preference?

Thank you for completing this questionnaire.

Appendix 2C

Example of Informed Consent Form Used Throughout the Four Studies

Form of Disclosure and Informed Consent

Project Title: An Investigation Into the Relationship Between Degrees of Hand Preference, Midline Crossing and Bimanual Coordination

Hand preference and crossing of the midline of the body play an important role in the development of hand function. There is evidence of a relationship between hand preference and crossing of the midline, and between motor co-ordination and unestablished hand preference. However, studies supporting these relationships are limited and inconclusive. The developmental process of hand function verifies that bimanual (two-handed) coordination as well as crossing of the body midline develop parallel to hand preference. What the nature of this relationship is, however, remains unclear. An investigation into this relationship with an emphasis on hand function may contribute to understanding of how to deal with children presenting with poorly established hand preference, avoidance of midline crossing and bimanual coordination problems.

Children who have difficulty with handwriting and fine motor skills (i.e., hand function) are frequently referred for occupational therapy. One of the common underlying reasons for their problems is unestablished hand preference, avoidance of crossing the body midline, and a lack of coordination between the hands (bimanual coordination). Occupational therapists working with children therefore need to understand how hand preference, crossing of the midline and bimanual co-ordination affect hand function in general, if and the nature of a relationship between them. A more comprehensive understanding may provide occupational therapists with a basis for more effective and specific treatment techniques to remediate these problems related to hand function.

This study aims to examine the extent to which the establishment of hand preference influences coordination between the two hands and crossing of the body midline in normal, English-speaking 5-year old children at local kindergartens. This research is being conducted as part of the requirements for Ms Elke Kraus' PhD in Occupational Therapy. The project is being supervised by Dr Heather Mudie, Senior Lecturer in Occupational Therapy, La Trobe University.

As guardians and representatives of your child, who is a potential participant, I invite you to allow your child to be included in this study. If you agree to do so, please sign this Form of Disclosure and Informed Consent, fill out the enclosed questionnaire, and return both to your child's teacher. Your child would then be assessed on the kindergarten premises, with permission of the relevant management committee of the kindergarten. The assessment will consist of a task involving tapping movement with both hands, short activities to identify hand preference, a tracing task and a form fitting task

(appendix continues)

Appendix 2C (continued)

that involves crossing the body midline. The assessment will not involve any discomfort. All children will be considered as part of the normative population, and you will receive brief feedback of your child's performance in terms of bimanual (both hands together) hand function and established hand preference. Should your child show any delays during this assessment or if you have any concerns, you can contact the researcher who will provide you with greater details of the assessment results, including some information on how to enhance your child's progress in this area. You are assured of absolute confidentiality. The results of the entire study may be published in a journal at a later stage, but no personal details will be disclosed at any point. The assessment of each child will take approximately 35 minutes.

The data of this project will be written on to printed forms and then transferred onto computer, as well as entered into a computer directly. Although the researchers will know who you and your child are during this study, his/her name will not be included on the written forms and computer records since they will be coded. Your child will therefore remain anonymous to everyone apart from the researchers. During the research and after the project has been completed, the written forms will be stored in a locked filing cabinet in the office of the Senior Investigator, Dr Mudie, at La Trobe University. The computer records will also be kept on a secure computer in the office of the Senior Investigator, Dr Mudie, at La Trobe University. No-one apart from Ms Kraus and Dr Mudie will have access to written forms. The findings of this project will appear in a thesis to be written by Ms Kraus, in journal publications and in presentations at conferences, but your child will not be able to be identified in any of these reports.

Your child may not directly benefit from participating in this project, but you will gain a better understanding of your child's performance in the assessed areas and will have the opportunity to discuss this further. Your child's participation will help occupational therapists to understand the impact of hand preference and midline crossing, and thus enable them to develop more effective intervention strategies to help children with problems in these areas. Your child as the participant and/or you as his/her guardian will be free to withdraw consent and discontinue their participation in the study at any time.

Any questions concerning this project may be directed to the Researcher Elke Kraus of the School of Occupational Therapy, Faculty of Health Sciences, at Tel. 9479 5667, or at Fax: 9 479 5737 (h).

If you and/or your child have any complaints or queries that the Researcher or Senior Investigator have not been able to answer, you may contact the Secretary of the Faculty Human Ethics Committee – Faculty of Health Sciences, La Trobe University, Bundoora, Victoria, 3083, Tel: 9479 3571.

(appendix continues)

Appendix 2C (continued)

I,, parent/caregiver of the participant, have read and understood the information above, and any questions I have asked have been answered to my satisfaction.

I agree for my child (first name and surname if different to parent) to participate in this activity, realizing that I may withdraw him/her any time. I agree that research data collected during the project may be included in a thesis, presented at conferences and published in journals, on condition that my name is not used.

NAME OF PARTICIPANT (in block letters):.....

PARENT: Authorised representative (in block letters):.....

SIGNATURE:.....

Date:.....

SENIOR INVESTIGATOR: (in block letters): ELKE KRAUS

SIGNATURE:.....

Date:.....

SENIOR RESEARCHER: (in block letters): DR HEATHER MUDIE

SIGNATURE:.....

Date:.....

Note. Details regarding participants, the type of assessment, and assessment time were adjusted according to the particulars of each study.

Appendix 2D

Ethics Approval for Studies I and III

La Trobe University
MEMORANDUM

Faculty Office
FACULTY OF HEALTH SCIENCES

TO: Ms Heather Mudie , School of Occupational Therapy

SUBJECT: *Reference:* FHEC95/186
Student Name: Ms Elke Kraus
Title: An Investigation Into The Relationship Between Bimanual Coordination,
 The Degree Of Hand Preference And Crossing Of The Body Midline.


DATE: 21 September, 1995

The Faculty Human Ethics Committee (FHEC) has considered and approved the above project. It is understood that approval will be obtained from School Principals and Kindergarten Management Committees prior to their inclusion in the study.

Please check that all references in correspondence are to the Faculty Human Ethics Committee, Faculty of Health Sciences. Note that Tom Matyas is in the School of Behavioural Health Sciences. Please delete the "s" from participants in third last paragraph on Informed Consent Form.

A copy of this memorandum is enclosed for you to forward to the student(s) concerned.

Please note that you are required to provide an annual report (where applicable) and/or a final report on completion of the project. A copy of the progress/final report form is enclosed. Would you please return the completed form to Ms Jane Fewings, Secretary, FHEC, Faculty Office, Faculty of Health Sciences, La Trobe University, Bundoora, Victoria, 3083.


 for Margaret Nayler
 Chairperson
 Faculty Human Ethics Committee
 Faculty of Health Sciences

Encl (1) Progress/Final Report Research Projects

Appendix 2E

Test Sheet of Motor Accuracy (MAcc) Revised

Sensory Integration
SIPT
and Praxis Tests
Motor Accuracy Test
 A. Jean Ayres, PhD

Published by
wps WESTERN PSYCHOLOGICAL SERVICES
 Publishers and Distributors
 1705 Avenue of the Stars
 Los Angeles, California 90045-1031

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 23 pages, revised.

Name _____

Hand: L _____ R _____ 1st _____ 2nd _____

Examiner: _____

Year	Month	Day
Test Date		
Birth Date		
Age		

SCORE

Line	No. broken
Black	
Short-Broken	
Mid-Broken	
Long-Broken	

BEGIN RIGHT HAND HERE BEGIN LEFT HAND HERE

Note. The original version is printed on an A3 size sheet.

Appendix 2F

Summary of Validity-Related Evidence for the Sensory Integration and Praxis Tests (SIPT)

<i>Factor Analyses</i>	<i>Sample</i>	<i>Meaningful theoretical constructs</i>
<i>Construct Related Validity</i>	Factor analytic studies with the Southern California Sensory Integration Tests and clinical observations (Ayres, 1965, 1966, 1972, 1977; Ayres, Mailloux & Wendler, 1987)	Postural ocular sores linked with bilateral integration, which consists of bilateral motor coordination, right-left discrimination and midline crossing.
	Factor analytic studies with the SIPT normative sample (Ayres, Mailloux & Wendler, 1987; Lai, Fisher, Magalhaes & Bundy, 1996)	Bilateral integration and sequencing factor, Visuopraxis factor (including form and space, visual construction and visuomotor coordination).
	Cluster analysis of the SIPT	Low average Bilateral Integration and Sequencing cluster (clinical); High average Bilateral Integration and Sequencing cluster (normal).
<i>Criterion Related Validity</i>	Learning disability (N=195, mean age = 7.3 years)	Despite normal IQ this sample tended to score below average in all SIPT tests.
	SCSIT and SIPT Other: sensory integrative dysfunction, reading disorder, language, intellectual disability, traumatic brain Injury, spina bifida, cerebral palsy	Combination of low average and below average scores, no specific mention of Preferred Hand Use, contralateral reaching, Motor Accuracy. Bilateral Motor Coordination was low in spina bifida.
	SIPT and K-ABC Bilateral Motor Integration (SIPT) & Achievement (K-ABC)	Combined sample: $r = .26, p < 0.05$.
	Motor Accuracy (SIPT) & Achievement (K-ABC)	Combined sample: $r = .29, p < 0.05$.
<i>Individual Test Validity</i>	Motor Accuracy (both preferred and non-preferred hands)	Correlated most strongly, amongst others, with Bilateral Motor Coordination.
	Bilateral Motor Coordination	Correlated most strongly, amongst others, with Motor Accuracy.
	Space Visualisation Contralateral Use score	Correlated most strongly with Bilateral Motor Coordination and Preferred Hand Use.

Note. Based on reports by Ayres and Marr (1991).

Appendix 2G

Score Sheet and Instructions for Space Visualisation Contralateral Use (SVCU) Test

Directions: If you are right-handed, seat the child to your left. For Trial I: "Which of these blocks fits this big black hole?" If the child doesn't put it in hole: "Put the block in the hole." If the child chooses wrong block: "Try the other one." For Trial II: "Here's another. Look first; then show me which one fits... Put it in the hole... That's right. Think about it first; then pick up the block that fits the hole." After 3 or 4 items: "Look at BOTH blocks. Choose carefully. The first one you move counts as your choice. You want to be right the first time."

For test items, record accuracy (R = Right, W = Wrong), hand (L = Left, B = Both, R = Right), and number of seconds (maximum = 25 seconds). Keep track of number of errors (marked "W" for accuracy) and continue after fifth error, not necessarily consecutive. Enter time as two digits (e.g., 6 seconds as 06).

Sensory Integration and Praxis Tests (SIPT)

1: SPACE VISUALIZATION (SV)

Protocol Sheet

A. Jean Ayres, Ph.D.

Directions: If you are right-handed, seat the child to your left. For Trial I: "Which of these blocks fits this big black hole?" If child doesn't put it in hole: "Put the block in the hole." If child chooses wrong block: "Try the other one." For Trial II: "Here's another. Look first; then show me which one fits... Put it in the hole... That's right. Think about it first; then pick up the block that fits the hole." After item 3 or 4: "Look at BOTH blocks. Choose carefully. The first one you move counts as your choice. You want to be right the first time." For test items, record accuracy (R = Right, W = Wrong), hand (L = Left, B = Both, R = Right), and number of seconds (maximum = 25 seconds). Keep track of number of errors (marked "W" for accuracy) and discontinue after fifth error, not necessarily consecutive. Enter time as two digits (e.g., 6 seconds as 06).

Child's Name _____

- Maximum time per item: 25 seconds
- Discontinue after 5 errors, not necessarily consecutive

Trial I L 	Trial II R 	1. L 	2. R
Do not score	Do not score	Accuracy: R W Hand: L B R Time (Seconds): _____	Accuracy: R W Hand: L B R Time (Seconds): _____
3. L 	4. R 	5. R 	6. L
Accuracy: R W Hand: L B R Time (Seconds): _____	Accuracy: R W Hand: L B R Time (Seconds): _____	Accuracy: R W Hand: L B R Time (Seconds): _____	Accuracy: R W Hand: L B R Time (Seconds): _____
7. L 	8. R 	9. L 	10. R
Accuracy: R W Hand: L B R Time (Seconds): _____	Accuracy: R W Hand: L B R Time (Seconds): _____	Accuracy: R W Hand: L B R Time (Seconds): _____	Accuracy: R W Hand: L B R Time (Seconds): _____
11. R 	12. L 	CONTINUE ON BACK	
Accuracy: R W Hand: L B R Time (Seconds): _____	Accuracy: R W Hand: L B R Time (Seconds): _____		

Number of Errors (Items 1-12): _____

Number of Errors (continued from front side): _____

- Maximum time per item: 25 seconds
- Discontinue after 5 errors, not necessarily consecutive

13. R 	14. L 	15. R 	16. R
Accuracy: R W Hand: L B R Time (Seconds): _____	Accuracy: R W Hand: L B R Time (Seconds): _____	Accuracy: R W Hand: L B R Time (Seconds): _____	Accuracy: R W Hand: L B R Time (Seconds): _____
17. L 	18. R 	19. R 	20. L
Accuracy: R W Hand: L B R Time (Seconds): _____	Accuracy: R W Hand: L B R Time (Seconds): _____	Accuracy: R W Hand: L B R Time (Seconds): _____	Accuracy: R W Hand: L B R Time (Seconds): _____
21. L 	22. L 	23. R 	24. R
Accuracy: R W Hand: L B R Time (Seconds): _____	Accuracy: R W Hand: L B R Time (Seconds): _____	Accuracy: R W Hand: L B R Time (Seconds): _____	Accuracy: R W Hand: L B R Time (Seconds): _____
25. L 	26. R 	27. L 	28. L
Accuracy: R W Hand: L B R Time (Seconds): _____	Accuracy: R W Hand: L B R Time (Seconds): _____	Accuracy: R W Hand: L B R Time (Seconds): _____	Accuracy: R W Hand: L B R Time (Seconds): _____
29. R 	30. L 		
Accuracy: R W Hand: L B R Time (Seconds): _____	Accuracy: R W Hand: L B R Time (Seconds): _____		

wps Western Psychological Services
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Appendix 2H

Score Sheet and Instructions for Bilateral Motor Coordination (BMC)

Sensory Integration and Praxis Tests (SIPT)
 6. BILATERAL MOTOR COORDINATION (BMC)

Protocol Sheet

A. Jean Ayres, Ph.D.

Directions for Arms Items: Sit facing the child. Trial item: "Watch my hands move. When they are through moving, you do the same thing. (Demonstrate.) (That's correct.) Be sure to move smoothly like this (move child's hands). When I begin with this hand (left), you begin with this hand (child's right). When I begin with this hand (right), you begin with this hand (child's left)." If insufficient number of movements: "Do it as many times as I did it." Item 1: "Watch me do another one. (Demonstrate.) Now you do it."
 Do not penalize the child for starting with the wrong hand, but remind the child on first (but only on first) wrong hand use.

Indicate the number corresponding to the child's item score (0 = incorrect, nonreciprocal, dysrhythmic, segmented, incomplete; 1 = approximately correct or slightly irregular; 2 = correct and well coordinated). Discontinue when four consecutive items are scored as 0. Then give feet items.
Directions for Feet Items: Do not give feet items to 4-year-olds. Trial item: "Now we'll do the same thing with our feet. Watch me. (Demonstrate.) You do it." Score each item as 0, 1, or 2 as for the arms items. Discontinue when two consecutive items are scored as 0.

Child's Name _____

Arms				Feet			
<ul style="list-style-type: none"> Discontinue when 4 consecutive items are scored as 0 and go on to feet items 	Incorrect	Approximately Correct	Correct	<ul style="list-style-type: none"> Do not administer to 4-year-olds Discontinue when 2 consecutive items are scored as 0 	Incorrect	Approximately Correct	Correct
Trial I: L, R, L, R (4 seconds)				Trial II: L, R, L, R (2 seconds)			
1. R, L, R, L (4 seconds)	0	1	2	11. R, L, R, L (2 seconds)	0	1	2
2. L, R, L, R (4 seconds)	0	1	2	12. LL, RR, LL, RR (3 seconds)	0	1	2
3. Both, clap clap, both, clap clap (4 seconds)	0	1	2	13. R, LL, R, LL (2 seconds)	0	1	2
4. LR, LR, LR (3 seconds)	0	1	2	14. L, RR, L, RR (2 seconds)	0	1	2
5. Both, both both, both, both both (4 seconds)	0	1	2				
6. Crossed RL, RL, RL (3 seconds)	0	1	2				
7. LL, RR, LL, RR (4 seconds)	0	1	2				
8. RR, LL, RR, LL (4 seconds)	0	1	2				
9. L, RR, L, RR (4 seconds)	0	1	2				
10. R, LL, R, LL (4 seconds)	0	1	2				

Observations:

Appendix 2I

Score Sheet for Adapted Edinburgh Handedness Inventory (EHI)

Modified Edinburgh Handedness Inventory: Score Sheet

2 = 4/4 R/L; 1 = 3/4 R/L; 0 = 2/4 R/L

Trial 1 Item	L	R	Trial 2 Item	L	R	Trial 3 Item	L	R	Trial 4 Item	L	R	L +	R	Consistent C < > I
1			1			1			1					2 1 0
2			2			2			2					2 1 0
3			3			3			3					2 1 0
4			4			4			4					2 1 0
5			5			5			5					2 1 0
6			6			6			6					2 1 0
7			7			7			7					2 1 0
8			8			8			8					2 1 0
9			9			9			9					2 1 0
10			10			10			10					2 1 0

Subtotal			Subtotal			Subtotal			Subtotal			TOTAL			Consistency
LEFT			LEFT			LEFT			LEFT			LEFT:			
RIGHT			RIGHT			RIGHT			RIGHT						

Overall Consistency:	$\frac{\quad}{20} \times 5 = \quad \%$
Laterality Quotient:	$\frac{\text{Total Right} - \text{Total Left}}{\text{Total Right} + \text{Total Left}} \times 100 = \quad \%$
Classification:	<input type="checkbox"/> Established 75% - 100% <input type="checkbox"/> Shows tendency 60% - 74% <input type="checkbox"/> Unestablished 0% - 59%

Appendix 2J**Instructions for the Adapted Edinburgh Handedness Inventory (EHI)**

- Drawing: SHOW ME HOW YOU DRAW A CIRCLE.
- Throwing: PRETEND TO THROW THIS BALL FAR AWAY, WITHOUT LETTING GO OF IT SINCE IT MIGHT GET LOST OR BREAK SOMETHING IN THE ROOM.
- Scissors: CUT A SNIP IN THE PAPER WITH THESE SCISSORS.
- Toothbrush: SHOW ME HOW YOU BRUSH YOUR TEETH WITHOUT ACTUALLY PUTTING THE TOOTHBRUSH IN YOUR MOUTH.
- Knife: SHOW ME HOW YOU USE THIS KNIFE – MAKE A MARK IN THE SPONGE BALL.
- Box: OPEN THE LID OF THIS BOX.
- Broom: SHOW ME HOW YOU SWEEP THE FLOOR WITH THIS BROOM.
- Match: SHOW ME HOW YOU STRIKE A MATCH BY RUBBING THE END OF THE STICK ON THE SIDE OF THE BOX. (A fake match was presented).
- Writing: WRITE THE FIRST THREE LETTERS OF YOUR NAME ON THIS PAPER.
- Spoon: PRETEND TO EAT SOMETHING WITH THE SPOON, BUT WITHOUT PLACING THE SPOON IN YOUR MOUTH.

Appendix 2K

Score Sheet and Instructions for the Motor Accuracy (MAcc)

Sensory Integration and Praxis Tests (SIPT)

10. MOTOR ACCURACY (MAC)

Protocol Sheet

A. Jean Ayres, Ph.D.

Directions: Sit opposite the child. Tape the test sheet flat in front of the child. Give pen to child's previously determined writing hand. Demonstration: "Watch me. I'm drawing a line on top of this black line... Now you draw a line on top of this black line." If necessary, advise the child to go slower or faster.

Test with preferred hand: "Now draw a line on top of this black line beginning here and going around to here. Draw carefully." Begin timing at horizontal short-dashed line one inch above starting point. Encourage child to take neither less than 30 nor more than 120 seconds. Discourage child's retracing line. Stop timing at horizontal short-dashed line. Child

fills in skipped portions.

Turn over test sheet to test nonpreferred hand. "Now you will draw a line with the other hand. You will draw on this black line beginning here and go around to here." Encourage child to take neither less than 30 nor more than 90 seconds.

Record number of whole seconds as three digits (e.g., 52 as 052). Measure distance to nearest half inch that child's line is off solid line or outside areas bounded by short, medium, and long broken lines (e.g., 6½ as 06.5). If child's line is not outside an area, record 00.0. Each hand's distance measurements must decrease in value, from the solid through the long broken line.

Child's Name _____ Preferred Hand (First Hand Tested) Right Left

Right Hand

Time (Seconds)	Solid Line	Short Broken Line	Medium Broken Line	Long Broken Line
_____	_____	_____	_____	_____

Left Hand

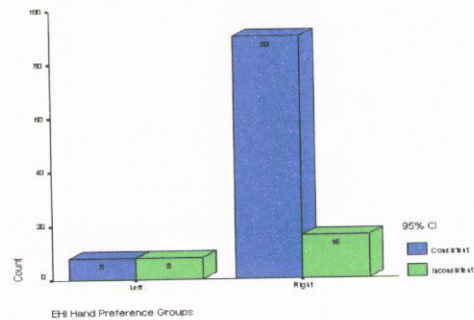
Time (Seconds)	Solid Line	Short Broken Line	Medium Broken Line	Long Broken Line
_____	_____	_____	_____	_____

Observations:

Appendix 2L

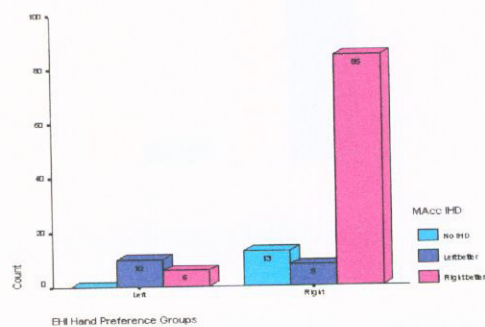
Additional Graphs Exploring Initial Tests According to EHI Hand Preference Categories for Study I

1. Extent of Consistency in Relation to EHI Left and Right Handed Responses



Only half (50%) of the EHI left handed responses were consistent, compared with 83 (78%) right handed responses.

2. Comparing Motor Accuracy (MAcc) Interhand Differences (IHD) to EHI Left and Right Hand Preference Groups

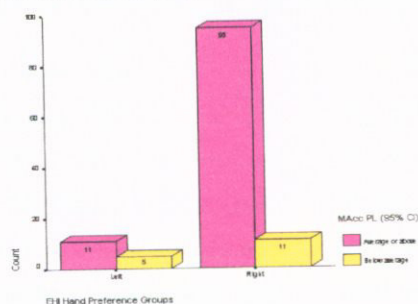


EHI hand preference groups are compared with the direction of MAcc IHD values. Six children of those categorized as established EHI left handers (37.5%) performed better with their right hand, compared to 8 children (7.5%) who performed better with their left hand in the EHI established right handed group. However, all thirteen (10.7%) children with no interhand differences were also identified as EHI right handers.

(appendix continues)

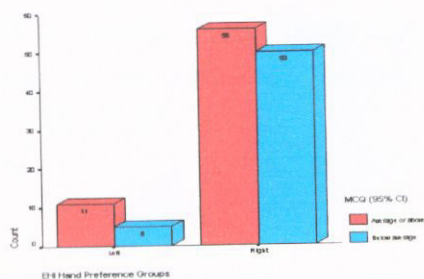
Appendix 2L (continued)

3. Motor Accuracy (MAcc) Performance Level (PL) in Relation to EHI Hand Preference Groups



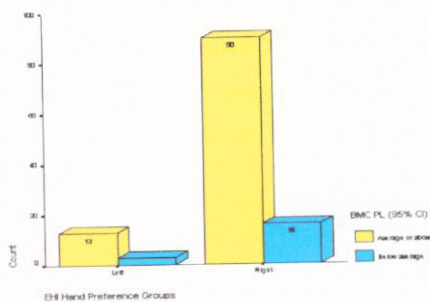
MAcc performance levels (PL) are compared to EHI left and right handed groups. In the EHI left handed group, eleven children (68.8%) performed within the average or above 95% CI range of the MAcc performance level, compared to 96 EHI right handers (90.6%).

4. Comparison Between Midline Crossing Quotient (MCQ) and Edinburgh Handedness Inventory (EHI) Hand Preference Groups



MCQ is compared to EHI left and right handed preference groups. In the EHI left handed group, 5 children (31.3%) tended to avoid midline crossing (i.e., MCQ outside the 95% CI), compared to 50 EHI right handed children (47.2%). In addition, three (19%) of the EHI left handers predominantly used the right hand, and 22 children (20%) crossed over with their left hand in the EHI right handed group.

5. Comparing Bilateral Motor Coordination (BMC) Performance with EHI Hand Preference Groups



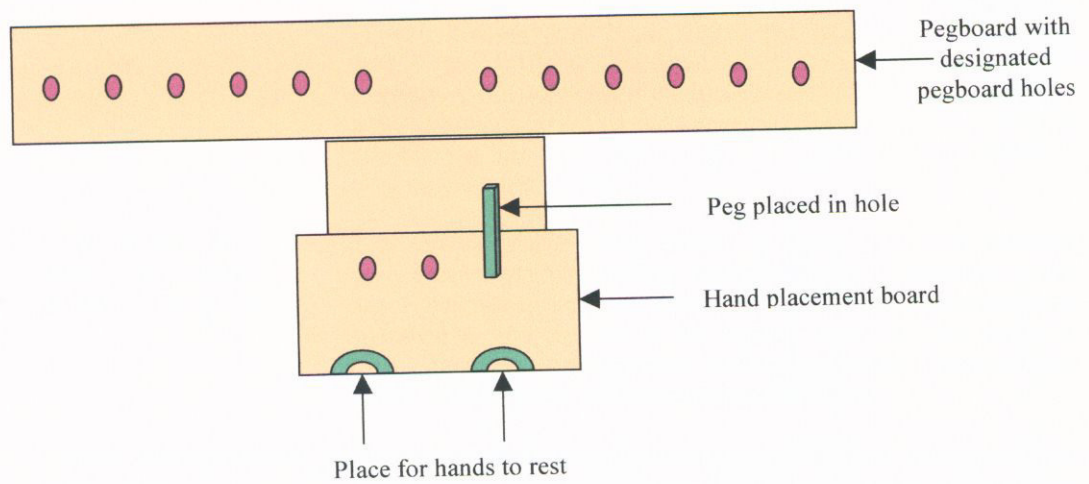
BMC performance levels are displayed in relation to the EHI hand preference groups, using the BMC 95% CI as a cut-off point for average and subaverage performances. In the EHI left handed group, thirteen children (81.3%) performed within the average or above the 95% CI range, compared to 90 children (84.9%) of EHI right handers.

Appendix 3A

Unsuitable Paediatric Tests for Midline Crossing for this Thesis

<i>Author(s) & Test</i>	<i>Description of Test</i>	<i>Reasons for not using test</i>
<i>Test of Sensory Integration (TSI)</i> Berk & DeGangi (1983)	Incorporates midline crossing as an integral part of the bilateral motor integration subtest (Berk & DeGangi, 1983). It involves a bimanually sustained grasp onto a rolling pin while using trunk rotation to push an object away.	May not be a pure test for midline crossing because of its bimanual nature. Midline crossing with trunk rotation may also be considered to be a more crude form of contralateral reach since the hand itself does not cross the imaginary body midline when operating in the contralateral hemisphere .
<i>Southern California Sensory Integration Test (SCSIT)</i> Ayres (1980)	Subtest: Crossing the Body Midline, requires pointing to ipsilateral or contralateral body parts (e.g., left eye, right ear) with the right or left hand, by imitating the test instructor. It is based on Head's test (1955).	Although Ayres adapted the test by replacing verbal instructions with imitation, the scoring criteria lacks reliability (Stilwell, 1987a).
Bradshaw, Nettleton, Pierson, Wilson & Nathan, 1987; Bradshaw, Nettleton, Wilson & Bradshaw, 1987; Bradshaw, Willmott, Umilta, Philips, Bradshaw & Mattingley, 1994	The authors explored the spatial compatibility of each hand, recognition of tactual tasks, unilateral neglect and symmetrical neglect, usually controlling the visual gaze. These responses are thought to provide information regarding the maturity of the corpus callosum and hemispheric specialisation.	While Bradshaw et al. compare the performance of each hand both in left and right handers, midline crossing is not based on a voluntary choice linked to the preferred hand. Instead, the right and left hand are each required to perform ipsilateral and contralateral tasks such as line bisection or matching textures. For the purpose of this study, crossing the midline needs to be a free choice (i.e., the option to perform either an ipsilateral or a contralateral response), while the conscious attention of the child is distracted from using either the left or the right hand.

Appendix 3B

Diagram of Stilwell's Test of Manual Midline Crossing (TMMC)

Note. The colours were not stipulated.

Appendix 3C

Unsuitable Paediatric Tests for Assessing Bilateral/Bimanual Coordination in this Thesis

<i>Test and Author(s)</i>	<i>Description of test and reasons for unsuitability</i>
<i>Bruininks-Oseretsky Test of Motor Proficiency (BOTMP):</i> Bruininks, 1978	This standardised motor test used widely in occupational therapy with children, assessing children aged 4.6 years and 14.6 years. It has been found to be reliable and valid by several authors (King-Thomas & Hacker, 1987; Wilson, Polatajko, Kaplan & Faris, 1995; Ziviani, Poulsen & O'Brien, 1982) The BOTMP has an 8-item subtest for bilateral coordination of both upper and lower extremities, but only one of the items assesses the upper extremities only, including unimanual and bimanual tasks. This means it is not a suitable test for bimanual coordination, particularly in regard to observing a leading hand.
<i>De Gangi-Berk Test of Sensory Integration:</i> Berk & DeGangi, 1983	This standardised test also contains a 4-item subtest on bilateral coordination, whereby one item assesses bilateral coordination of the lower extremities, and two items evaluate bilateral coordination in conjunction with crossing of the midline. Only one item looks at bilateral upper extremity control, and again, the score of this subtest would not be reflective of bimanual coordination.
<i>Peabody Developmental Motor Scale:</i> Folio & Fewell, 1983	This standardised test contains bimanual activities which have been grouped with fine motor items. It has the additional characteristic that the bilateral test items are not the same across the different age ranges and it would thus be difficult to compare them.
Bimanual tapping for research methods <i>Polyrhythmic finger tapping:</i> Summers & Pressing, 1994; <i>Speed finger tapping:</i> Rousselle & Wolff, 1991; Peters, 1980; <i>Hand tapping:</i> Peper, Beek & vanWieringen, 1995.	It has been found that the tendency in young children to synchronise movement during bimanual tasks is very strong because of entrainment between the hands due to lack of inhibition at that age (Kelso, 1984). Tapping would therefore not demonstrate the level of a child's bimanual coordination distinctly. Furthermore, all these bimanual movement frequency methods, including tapping, predominantly deal with temporal constraints, such as speed and rhythm.
Components of bimanual movement for research purposes: Bimanual movement frequency <i>Wrist movement:</i> Treffner & Turvey, 1995; <i>Flexion of fingers:</i> Zanone & Kelso, 1991, 1992; <i>Elbow movement:</i> Sherwood, 1994, and Swinnen, Walter, Lee & Serrien, 1993; <i>Abduction and adduction of index fingers:</i> Scholz & Kelso, 1990; <i>Sequential finger movement:</i> Baraldi, Porro, Serafini, Pagnoni, Murari, Corazzo & Nichelli, 1999.	All of these movements require differentiated, isolated and controlled muscle action of a particular part of the hand as well as the cooperation between the hands. Such movements would be unsuitable for children aged 3 to 5 years, whose ability to differentiate and coordinate different muscle groups selectively is still developing.

Appendix 3D

Ethics Approval for Study II and III

La Trobe University
MEMORANDUM

Faculty Office
FACULTY OF HEALTH SCIENCES

TO: Dr Heather Mudie, School of Occupational Therapy

SUBJECT: *Reference:* FHEC99/082

Student's Name: Elke Kraus

Title: The impact of midline crossing and hand preference on bimanual co-ordination in 3 to 5 year old unimpaired children


DATE: 13.7.99

The Faculty Human Ethics Committee (FHEC) has considered and approved the above project. You may now proceed.

Please ensure that each participant retains a copy of the Informed Consent form.

Please note that any modification to the project must be submitted in writing to FHEC for approval. You are required to provide an annual report (where applicable) and/or a final report on completion of the project. A copy of the progress/final report is enclosed. Would you please return the completed form to Mr David Williams, Secretary, FHEC, Faculty of Health Sciences Office, La Trobe University, Bundoora, 3083.

A copy of this memorandum is enclosed for you to forward to the student/s concerned.


David Williams
Secretary
Faculty Human Ethics Committee
Faculty of Health Sciences

FHEC:FHEC d/base/file

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Appendix 3E

Instructions and Story For Modified Midline Crossing Test (MCT)

Place 4 coloured pegs on the vertical centre line below the river on the child's side. Cover all the other holes using the 4 hole covers, leaving all centre holes open. Sit opposite the child with the board in the child's midline approximately 2 cm from the edge of the table. Say: WE ARE GOING TO PLAY A GAME WITH SOME TEDDY BEARS NOW. THE RED-GREEN AND THE YELLOW-BLUE TEDDY FAMILIES LIVE TOGETHER IN THEIR HOUSES IN A LOVELY FOREST WHERE THEY ARE VERY HAPPY. HOWEVER, A LION HAS COME INTO THE FOREST, AND THE BEARS ARE SCARED THAT HE MAY HARM THEM IN SOME WAY. ONE DAY THEY HAD A VERY GOOD IDEA: THEY THOUGHT OF BUILDING A FENCE AROUND THEIR HOUSES. THE ONLY PROBLEM WAS THAT THE BIG BEARS COULD NOT SWIM AND CARRY THE PEGS NEEDED FOR THE FENCE ACROSS THE RIVER, AND THE LITTLE BEARS COULD NOT SWIM AT ALL. THEY HAD TO WAIT FOR A CHILD LIKE YOU TO COME ALONG AND HELP THEM. LET'S SEE IF YOU COULD BE THEIR HELPER. PUT YOUR HANDS ON THE WAITING SPOTS.

PRACTICE TRIAL (4 items)

AS SOON AS YOU SEE A BEAR ON THE OTHER SIDE (take a bear out of the container and place it on the top centre of the board behind the holes), YOU PICK UP THE PEG WITH THE MATCHING COLOUR AS QUICKLY AS YOU CAN, CARRY IT ACROSS THE RIVER AND PLACE IT INTO THE MATCHING PEG HOLE. Demonstrate moving a peg from the child's proximal centre across the river to the distal centre line. NOW IT IS YOUR TURN. Show the child each of the large bears and encourage him/her to pick up the matching peg and place it in the matching hole on the other side of the river. Record each response on the score sheet. When finished, say: WELL DONE, YOU ARE JUST THE RIGHT PERSON TO HELP THE TEDDY BEARS!

TRIAL 1: Midline to Contra/Ipsilateral (4 items)

Turn the board around so that the vertical centre row of pegs is on the child's side. Cover the proximal arcs with the hole covers as well as the distal centre holes, leaving the holes in the distal arcs open. THE BEARS ARE NOW GOING TO START TO BUILD THE FENCE ON THE OUTSIDE. PUT YOUR HANDS ON THE WAITING SPOTS AND WAIT TO SEE WHAT COLOUR BEAR IS GOING TO COME UP. AS SOON AS YOU SEE HIM, PICK UP THE MATCHING PEG FOR THE FENCE AS QUICKLY AS YOU CAN AND PLACE IT IN THE HOLE WITH THE SAME COLOUR. Show the child which peg to pick up to ensure a maximum quick response for spontaneous hand use - it is not a colour matching exercise. Continue to show the large bears until two pegs are in each of the distal arcs and none are left in the proximal centre holes. Add the other four pegs to the distal arcs, saying: I AM GOING TO HELP THE TEDDY BEARS A LITTLE BIT ON THIS SIDE and then turn the board around.

TRIAL 2: Contra/Ipsilateral to Contral/Ipsilateral - proximal to distal (8 items)

Cover the proximal and distal centre holes with the hole cover. NOW YOU CAN HELP THE BEARS BUILD THE FENCE ON THE OTHER SIDE. THE TEDDY BEAR CHILDREN ARE ALSO GOING TO HELP NOW BECAUSE TIME IS RUNNING OUT. ARE YOU READY? Repeat the previous instructions if necessary and show large and small bears randomly. Make sure the child places his/her hands back on the resting spots after each trial and before you show another bear. At any time offer praise and encouragement, such as WELL DONE, YOU ARE A GREAT HELPER.

TRIAL 3: Contral/Ipsilateral to Contra/Ipsilateral (distal to proximal) (4 items)

Leave the board the way it is (i.e., teddy bears and pegs are distal to the child), and ensure that the child's hands are on the waiting spots. THE TEDDY BEARS HAVE FINISHED THE FENCE WITH YOUR HELP, AND THEY ARE SO HAPPY. HOWEVER, THEY ARE REALLY HUNGRY NOW. Take one of the big bears across the river to the contralateral side, saying: BLUE PAPA BEAR IS SWIMMING ACROSS THE RIVER TO LOOK FOR SOME HONEY AND BERRIES. Place the little blue bear in
(appendix continues)

Appendix 3E (continued)

front of the pegs on the distal side, saying: LITTLE BLUE BEAR WANTS TO BE WITH HIS PAPA, BUT HE CAN'T SWIM YET. COULD YOU PLEASE CARRY HIM ACROSS THE RIVER? *Repeat this with all the bears.* THANK YOU AGAIN FOR YOUR HELP. THE BEARS ARE NOW REALLY TIRED AND WILL TAKE A LITTLE NAP. WE WILL PLAY ANOTHER GAME WITH SOME OTHER BEARS ON THE PLAYGROUND IN THE MEANTIME. WE WILL COME BACK LATER, BECAUSE THE STORY IS NOT FINISHED YET. THE LION IS STILL ON THE OTHER SIDE OF THE FOREST.

BREAK - Administer the Bimanual Coordination Test now**TRIAL 4: Contra/Ipsilateral to Contra/Ipsilateral (distal to proximal) (4 items)**

Place the board at the child's midline as with the previous trials, cover both rows of central holes and place two pegs in the middle two holes of each of the distal arcs. Cover the proximal and distal centre holes. Say: PUT YOUR HANDS ON THE WAITING SPOTS. YOU ARE JUST BACK IN TIME, BECAUSE THE LITTLE BEARS HAVE JUST WOKEN UP, WHILE THEIR PARENTS ARE STILL SLEEPING. THE LITTLE BEARS WANT TO PLAY BASEBALL, BUT THEY DON'T HAVE ANY BATS. ONE OF THEM THOUGHT OF USING THE PEGS AS BATS, AND THEY ALL LOVED THIS IDEA AND THEY FORGOT ALL ABOUT THE LION. HOWEVER, THEY NEED YOUR HELP TO GET THE BATS ACROSS THE RIVER. *Take out a little bear randomly and place it behind the proximal arc holes of the matching colour, saying:* THE LITTLE BEAR SAYS "COULD YOU PLEASE BRING ME MY BAT ACROSS THE RIVER?" *Continue this with all four little bears.*

TRIAL 5: Contra/Ipsilateral to Midline (4 items)

Leave the board as it is with the pegs placed in the two centre holes of the proximal arcs. Cover the distal arcs with the hole covers. NOW THE PARENTS HAVE ALSO WOKEN UP, PROBABLY BECAUSE THEIR CHILDREN HAVE MADE SUCH A NOISE. BUT THE LITTLE BEARS WERE NOW PLAYING HIDE AND SEEK IN THE FOREST AND WERE NOWHERE TO BE SEEN. WHEN THE BIG BEARS WENT OUTSIDE, THEY SAW THAT THERE WERE HOLES IN THE FENCE. THEY SAID, "OH NO! NOW WE NEED YOUR HELP AGAIN! PLEASE COULD YOU QUICKLY HELP US TO REBUILD THE FENCE? THE LION COULD COME ANY MOMENT!" *Continue by flashing each of the four big bears consecutively. NOW THEY WANT TO HAVE A MEETING TO DISCUSS WHAT ELSE THEY SHOULD DO IF THE LION COMES.*

TRIAL 6: Midline to Contra/Ipsilateral (4 items)

Turn the board around so that the pegs are in the proximal centre. Cover the proximal arcs and the distal centre with the hole covers. THE LITTLE BEARS HAD COME BACK FROM THEIR HIDE AND SEEK GAME AND COULD NOT FIND THEIR BATS TO CONTINUE WITH THEIR BASEBALL GAME. THEY SAID, "PLEASE COULD YOU GET US OUR BATS ACROSS THE RIVER AGAIN?" *Flash up the little bears behind the subsequent coloured holes.*

TRIAL 7: Contra/Ipsilateral to Midline (4 items)

Turn the board around, leaving the hole covers where they are. The pegs should be in the two middle holes of the proximal arcs. Say: YOU CAN IMAGINE THAT THE BIG BEARS WERE REALLY UPSET WHEN THEY SAW THAT THERE WERE MORE HOLES IN THE FENCE. WHEN THEY REALISED THAT THEIR CHILDREN HAD REMOVED THE PEGS, THEY WARNED THEM, EXPLAINING ONCE AGAIN HOW DANGEROUS THE LION IS. NOW THEY NEED YOUR HELP ONCE MORE FOR THE LAST TIME. *Flash up big bears.* AND WHEN THE LION FINALLY CAME *(show a little toy lion)* HE WAS UNABLE TO GET THROUGH THE FENCE, HE TRIED TO JUMP OVER AND DIG UNDER AND BLOW IT TO PIECES, BUT NOTHING WORKED *(demonstrate)*. SO AFTER A WHILE HE GOT SO HUNGRY HE WENT TO LOOK FOR FOOD IN ANOTHER FOREST AND HE NEVER CAME BACK. THE TEDDY BEAR FAMILIES WERE VERY THRILLED ABOUT THIS AND LIVED IN PEACE HAPPILY EVER AFTER. *Should a child remark that there is lots of space for the lion to get in, say:* WE DON'T HAVE ENOUGH PEGS HERE, SO JUST IMAGINE THAT THE FENCE GOES ALL THE WAY AROUND.

Appendix 3F

Score Sheets for Modified Midline Crossing Test (MCT)

Handedness Profile: Midline Crossing Test Score Sheet 1

Subject Code: _____

PRACTICE TRIAL

Number	Right Hand	Left Hand	Swaps Hands
1			
2			
3			
4			
TOTAL			

TRIAL 1: MIDLINE to CONTRA/IPSILATERAL

Number	Right Hand	Left Hand	Mid-Contra	Mid-Ipsi	Swaps Hands
1					
2					
3					
4					
TOTAL					

TRIAL 2: CONTRA/IPSILATERAL to CONTRA/IPSILATERAL (proximal - distal)

Number	Right Hand	Left Hand	Contra-Ipsi	Ipsi-Contra	Swaps Hands
1					
2					
3					
4					
5					
6					
7					
8					
TOTAL					

TRIAL 3: CONTRA/IPSILATERAL to CONTRA/IPSILATERAL (distal - proximal)

Number	Right Hand	Left Hand	Contra-Ipsi	Ipsi-Contra	Swaps Hands
1					
2					
3					
4					
TOTAL					

Handedness Profile: Midline Crossing Test Score Sheet 2

Subject Code: _____

TRIAL 4: CONTRA/IPSILATERAL to CONTRA/IPSILATERAL (distal - proximal)

Number	Right Hand	Left Hand	Contra-Ipsi	Ipsi-Contra	Swaps Hands
1					
2					
3					
4					
TOTAL					

TRIAL 5: CONTRA/IPSILATERAL to MIDLINE

Number	Right Hand	Left Hand	Contra-Mid	Ipsi-Mid	Swaps Hands
1					
2					
3					
4					
TOTAL					

TRIAL 6: MIDLINE to CONTRA/IPSILATERAL

Number	Right Hand	Left Hand	Mid-Contra	Mid-Ipsi	Swaps Hands
1					
2					
3					
4					
TOTAL					

TRIAL 7: CONTRA/IPSILATERAL to MIDLINE

Number	Right Hand	Left Hand	Contra-Mid	Ipsi-Mid	Swaps Hands
1					
2					
3					
4					
TOTAL					

BREAK (Bimanual Coordination Test)

Appendix 3G

Instructions for Modified Bimanual Coordination Test (BCT)

This test follows immediately after the first half of the Midline Crossing Test has been administered. Place the transparency with the 12 cm markers on the screen. Moisten the back of the transparency slightly with a drop of water so that it sticks to the screen. The bottom marker should be approximately 2.5 cm from the right bottom corner. Say:

WE ARE GOING TO GO TO THE TEDDY BEARS' PLAYGROUND WHILE THE TWO BEAR FAMILIES ARE ASLEEP. THERE ARE TWO ROUND ABOUTS ON THE PLAYGROUND, AND THESE TWO BEARS (point) NEED YOUR HELP TO MAKE THEM TURN. HOLD THEIR HEADS BETWEEN YOUR THUMB AND FINGERS AND TURN LIKE THIS.

Place your hands over the child's hands and turn one complete cycle in a mirror movement outwards with both hands moving simultaneously. Make sure that only you (and not the child) return the line to the starting point by reversing the cycle movement, since this would confuse the child. Shake the BCT upside down to erase the practice line prior to each trial.

SEE HOW YOU ARE MAKING A NICE STRAIGHT SLIDE FOR THEM? *Then return the pointer to the starting point, saying:* THIS TIME YOU WILL DO IT ON YOUR OWN. TRY AND MAKE MORE STRAIGHT SLIDES FOR THE TEDDY BEARS. I WILL JUST START YOU OFF. IT IS MORE IMPORTANT THAT YOU TRY TO MOVE BOTH HANDS AT THE SAME TIME THAN TO TURN THEM FAST.

Start the movement off to ensure the correct angle of the line, and allow the child to complete the movement until the response line has reached the second marker. Place a blank response transparency over the line, ensuring that it fits exactly into the screen corner. Trace the line accurately onto the response transparency with a thin permanent pen, indicating the start with an arrow and finish with a small perpendicular line. Erase the lines after having traced them by turning the Etch-a-Sketch upside down and shaking it. Repeat this procedure for all four trials, following the following order (from the child's perspective):

- Trial 1 - start at bottom right, end at top left, using outward movement with both hands*
- Trial 2 - start at top left, end at bottom right, using inward movement with both hands*
- Trial 3 - start at top right, end at bottom left, turning to the left with both hands*
- Trial 4 - start at bottom left, end at top right, turning to the right with both hands*

Appendix 3H

Score Sheet for Modified Bimanual Coordination Test (BCT)

Handedness Profile Bimanual Coordination (BC) Test

Date: _____ Name: _____
 TRIAL 1 (Divide the total of Zone 2 and beyond by 2 before adding it to Zone 1 deviation)

Speed (sec)	Total Deviation	Zone 1 Deviation	Zone 2 Deviation	Zone 3 Deviation	Zone 4 Deviation	Zone Beyond 4 Deviation	Reversions Penalty = 6
	Total:	Total: /1	Total: /2	Total: /2	Total: /2	Total: /2	After units rev. to Trial
Ro Lo	L M R	L M R	L M R	L M R	L M R	L M R	
Maintains:	LH	RH	LH RH from to changes			P if Rev >2: 12 P if Rev =2: 6	

TRIAL 2

Speed (sec)	Total Deviation	Zone 1 Deviation	Zone 2 Deviation	Zone 3 Deviation	Zone 4 Deviation	Zone Beyond 4 Deviation	Reversions Penalty = 6
	Total:	Total: /1	Total: /2	Total: /2	Total: /2	Total: /2	After units rev. to Trial
Ro Lo	L M R	L M R	L M R	L M R	L M R	L M R	
Maintains:	LH	RH	LH RH from to changes			P if Rev >2: 12 P if Rev =2: 6	

TRIAL 3

Speed (sec)	Total Deviation	Zone 1 Deviation	Zone 2 Deviation	Zone 3 Deviation	Zone 4 Deviation	Zone Beyond 4 Deviation	Reversions Penalty = 6
	Total:	Total: /1	Total: /2	Total: /2	Total: /2	Total: /2	After units rev. to Trial
Ro Lo	L M R	L M R	L M R	L M R	L M R	L M R	
Maintains:	LH	RH	LH RH from to changes			P if Rev >2: 12 P if Rev =2: 6	

TRIAL 4

Speed (sec)	Total Deviation	Zone 1 Deviation	Zone 2 Deviation	Zone 3 Deviation	Zone 4 Deviation	Zone Beyond 4 Deviation	Reversions Penalty = 6
	Total:	Total: /1	Total: /2	Total: /2	Total: /2	Total: /2	After units rev. to Trial
Ro Lo	L M R	L M R	L M R	L M R	L M R	L M R	
Maintains:	LH	RH	LH RH from to changes			P if Rev >2: 12 P if Rev =2: 6	

Total Speed: _____ Total Ro: _____ Total Lo: _____ Total Reversals: _____ Constant hand: _____

Total Deviation: _____ Total Left Deviation: _____ Total Middle: _____ Total Right Deviation: _____

Homol Deviation: _____ Homol. Left Deviation: _____ Homol. Middle: _____ Homol. Right Dev.: _____

Heter. Deviation: _____ Heter. Left Deviation: _____ Heter. Middle: _____ Heter. Right Dev.: _____

Appendix 3I

Calculation Sheet for Modified Midline Crossing Test (MCT)

	M-I	I-M	M-C	C-M	I-C pro	C-I pro	I-C dis	C-I dis	Swap	Right	Left	TOTAL
P-T									()	()	()	
T 1 (4)	R + L		R + L									
T 2 (8)					R + L	R + L						
T 3 (4)							R + L	R + L				
T 4 (4)							R + L	R + L				
T 5 (4)		R + L		R + L								
T 6 (4)	R + L		R + L									
T 7 (4)		R + L		R + L								
TOTAL									32			
Swap												
TOTAL	R + L	R + L										
Ipsi	8	8							16			16
TOTAL single			R + L		R + L							
Cont 1			8		8							16
TOTAL multi				R + L		R + L						
Cont 2				8		8						16
TOTAL distal							R + L	R + L				
Cont 3							8	8				16
TOTAL	R + L		R + L							()	()	()
Mid St	8		8									16
TOTAL		R + L			R + L		R + L			()	()	()
Ips St		8			8		8					24
TOTAL				R + L		R + L		R + L		()	()	()
Con St				8		8		8				24
TOTAL										32	32	48
Dev/rl												

Midline Crossing Quotient (MCQ) = $\frac{R}{R + L} - \frac{L}{R + L} = \frac{\quad}{32} = \boxed{\quad} \%$

Contralateral Start %age = $\frac{\quad}{24} = \boxed{\quad} \%$ L = $\frac{\quad}{12} = \boxed{\quad} \%$ R = $\frac{\quad}{12} = \boxed{\quad} \%$

Appendix 3J

Summary Calculation Sheet for All Handedness Measures

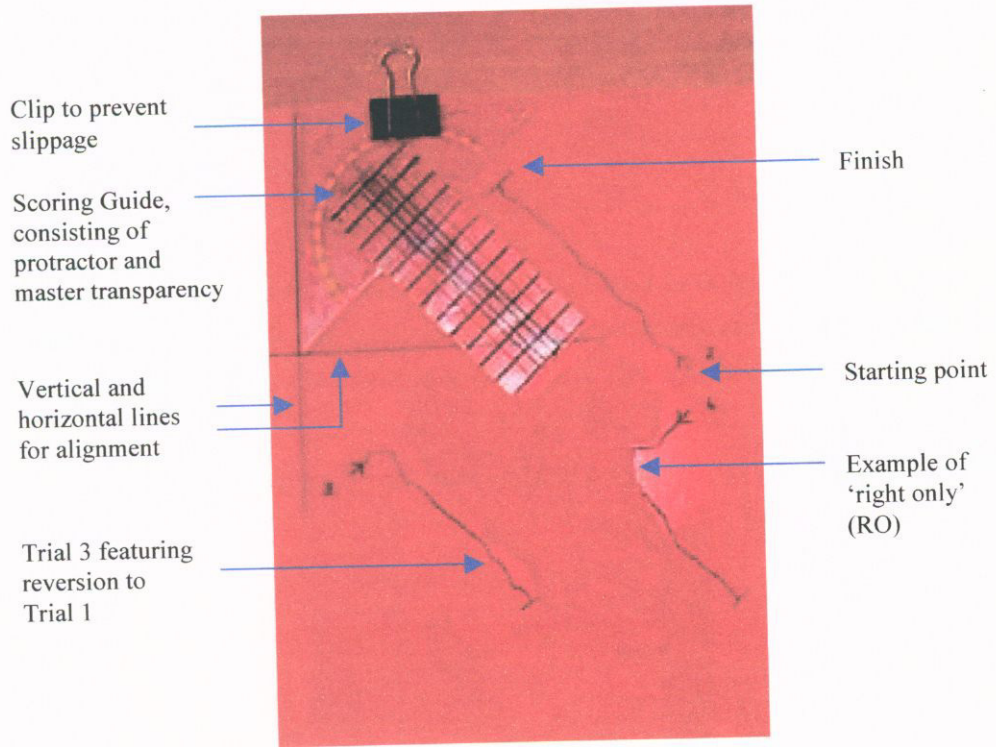
Summary Calculation Sheet for IHD and PL Percentages of all Handedness Profile Measures

Handedness Measures	LEFT HAND Calculation		RIGHT HAND Calculation		Performance Percentage	IHD/PL Calculation		IHD/PL Percentage
	Calculation	Performance Percentage	Calculation	Performance Percentage		Calculation	Performance Percentage	
Untrained FHP		%		%		R ___% - L ___%	= ___% L R	
Trained FHP		%		%		R ___% - L ___%	= ___% L R	
Total FHP		%		%		R ___% - L ___%	= ___% L R	
Consistency						24 - Ambiguity 0.24	= PL ___%	
Ability IHD <i>PL value is that of the hand with the best performance</i>	Hammering RS divide by 2.8 Tapping RS divide by 2.8	% %	Hammering RS divide by 2.8 Tapping RS divide by 2.8	% %		Ham R ___% - L ___% Tap R ___% - L ___% TOTAL IHD (sum divided by 2)	= ___% L R = ___% L R = ___% L R	
Skill IHD <i>PL value is that of the hand with the best performance</i>	250 - BTT simple ES divide by 2.5 200 - BTT advanced ES divide by 2 90 - BDT RS divide by 0.9	% % %	250 - BTT simple ES divide by 2.5 200 - BTT advanced ES divide by 2 90 - BDT RS divide by 0.9	% % %		Sim R ___% - L ___% Adv R ___% - L ___% BDT R ___% - L ___% TOTAL IHD (sum divided by 3)	= ___% L R = ___% L R = ___% L R = ___% L R	
MCQ		%		%		R ___% - L ___%	= ___% L R	
Extent of MC		%		%		R ___% + L ___%	= PL ___%	
Bimanual Coordination	42 - homol BC ES divide by 0.4 42 - heterol BC ES divide by 0.4	% %	42 - homol BC ES divide by 0.4 42 - heterol BC ES divide by 0.4	% %		R ___% - L ___% R ___% - L ___% TOTAL ES (sum divided by 2) 168 - Total ES 1.68	= ___% L R = ___% L R = ___% L R = PL ___%	

NOTE: ES = Error Score, RS = Raw Score

Appendix 3K

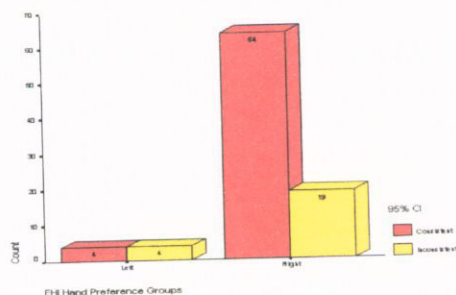
Photograph of Scoring Material and Response Transparency of the Modified Bimanual Coordination Test (BCT)



Appendix 3L

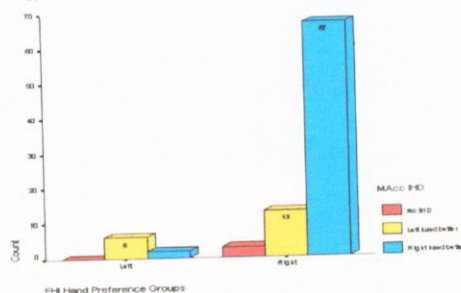
Additional Graphs Comparing EHI Left and Right Handers on Initial and Modified Tests for Study II (Chapter 3)

1. Comparing EHI Hand Preference Groups with Consistency



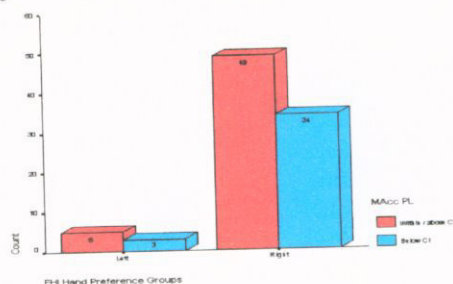
Consistent versus inconsistent hand use was differentiated by using the 95% confidence interval (CI). The frequency of consistency in relation to EHI hand preference is depicted above. Half of the EHI left group ($n = 4$) was consistent compared to 64 (77%) of EHI right handers.

2. Comparing MAcc Interhand Differences and EHI Left and Right Hand Preference Groups



EHI hand preference groups are compared with the direction of MAcc IHD values. Six (75%) of EHI left handers performed better with the left hand on the MAcc, compared to 67 (81%) EHI right handers showing superior performance with their right hand. Three (4%) EHI right handers showed no MAcc interhand differences. The proportions of EHI and MAcc groups closely resemble those of the first study (see Figure 2.7 in Chapter 2), where 3 cases with no IHD displayed EHI right hand preference.

4. Motor Accuracy (MAcc) Performance Level (PL) in Relation to EHI Hand Preference Groups

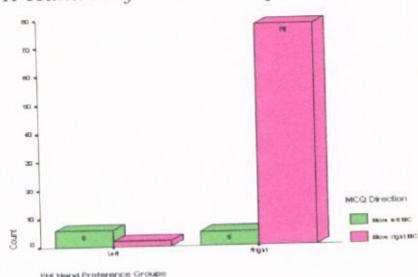


(appendix continues)

Appendix 3L (continued)

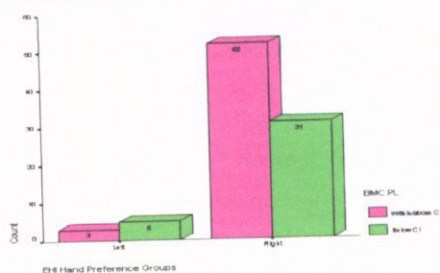
MAcc performance is compared to EHI left and right hand preference. In the EHI left handed group, 5 of 8 children (63%) scored either average or above, compared to 49 of 83 children (59%) in the EHI right handed group, indicating similar performance between the two groups.

5. Comparison Between EHI Hand Preference Groups and Direction of Midline Crossing Quotient



The midline crossing quotient is compared as an interhand difference measure (i.e., which hand crossed over the most) with EHI left and right handers. Similar to Study I, a high percentage of EHI left handers (75%) also preferred their left hand for contralateral reaching (Study I = 69%; Study II = 75%), compared to 5 EHI right handers (6%) who predominantly employed their left hand during contralateral reach.

6. Comparing Bimanual Coordination PL in EHI Left and Right Hand Preference Groups



Bimanual coordination PL is displayed in relation to the EHI hand preference groups, using the bimanual coordination 95% CI as a cut-off point for average and subaverage performance. Five of the eight EHI left handers (63%) showed average or above average performance, compared to 31 (36%) of EHI right handers.

Appendix 4A

Test-Retest Reliability on Some Functional Hand Preference (FHP) Items

<i>Items</i>	<i>Authors</i>	<i>Statistical procedure</i>	<i>Value</i>
<i>Untrained unimanual</i>			
Stacking beads	■		
Inserting pegs (pins)	Steenhuis & Bryden, 1989	Principal component analysis	Factor loading 0.73
Turning spinning top	■		
Pushing bear to shoot (marble)	Steenhuis & Bryden, 1989	Principal component analysis	Factor loading 0.71
Stacking blocks	■		
Throwing a dice	■		
<i>Trained unimanual</i>			
Writing	Steenhuis et al., 1990	Reliability	Coefficient 0.92
Brushing teeth	Steenhuis et al., 1990	Reliability	Coefficient 0.80
Throwing a ball	Longoni & DeGennaro, 1992	Item-test point biserial correlation	Correlation 0.82
Eating with a spoon	Beukelaar & Kroonenberg, 1983	Response frequency	38.0%LH, 62.0 RH
Drawing	Longoni & DeGennaro, 1992	Item-test point biserial correlation	Correlation 0.99
Cutting with a knife	Beukelaar & Kroonenberg, 1983	Response frequency	32.6%LH, 67.4 RH
<i>Untrained bimanual</i>			
Dealing cards	Ida, Mandal & Bryden, 2000	Two-factor solution	I: 0.52, II: 0.37
Sweeping with long broom	Beukelaar & Kroonenberg, 1983	Response frequency	44.3%LH, 55.7 RH
Hand broom and dust pan	Beukelaar & Kroonenberg, 1983	Response frequency	41.5%LH, 58.5 RH
Opening tube	Beukelaar & Kroonenberg, 1983	Response frequency	48.3%LH, 51.7 RH
Taking off stickers	■		
Turning a screw	Steenhuis et al., 1990	Reliability	Coefficient 0.63
Opening a small box	Beukelaar & Kroonenberg, 1983	Response frequency	44.3%LH, 55.7 RH
<i>Trained bimanual</i>			
Striking a match	Longoni & DeGennaro, 1992	Item-test point biserial correlation	Correlation 0.91
Cutting with scissors	Steenhuis & Bryden, 1989	Principal component analysis	Factor loading 0.72
Opening padlock with key	Ida, Mandal & Bryden, 2000	Two-factor solution	I: 0.36, II: 0.65
Sewing with shoe lace	Beukelaar & Kroonenberg, 1983	Response frequency	39.5%LH, 60.5 RH
Using knife and fork	■		
Using a screw driver	Ida, Mandal & Bryden, 2000	Two-factor solution	I: 0.68, II: 0.35

Note. ■ = No studies were found that analysed these tasks in terms reliability. However, they were included in the assessment since they are some of the typical activities performed by children. Most hand preference analyses target adults and related tasks. These statistics complement those of the EHI item test-retest reliability (see Table 2.1 in Chapter 2). Bryden et al. = Bryden Steenhuis, Schwartz & Lawson.

Appendix 4C

Hand Dominance Test (HDT) by Steingrüber

HDT VP-Nr.: Spurennachzeichnen Testdatum: Zeit:

Kreisepunktieren

Rechts mit linker Hand

Links

Rechts

Links

rechte Hand: linke Hand:

rechte Hand: linke Hand:

Note. These are examples of two of the HDT subtests. The third subtest, also a dotting task, consists of five rows of squares. The original size of each subtest is A4.

Appendix 4D

Response and Score Sheet for Bear Tracing Task (BTT) and Bead Dotting Task (BDT)

Handedness Profile: Bear Tracing Task (BTT) and Bead Dotting Task (BDT)

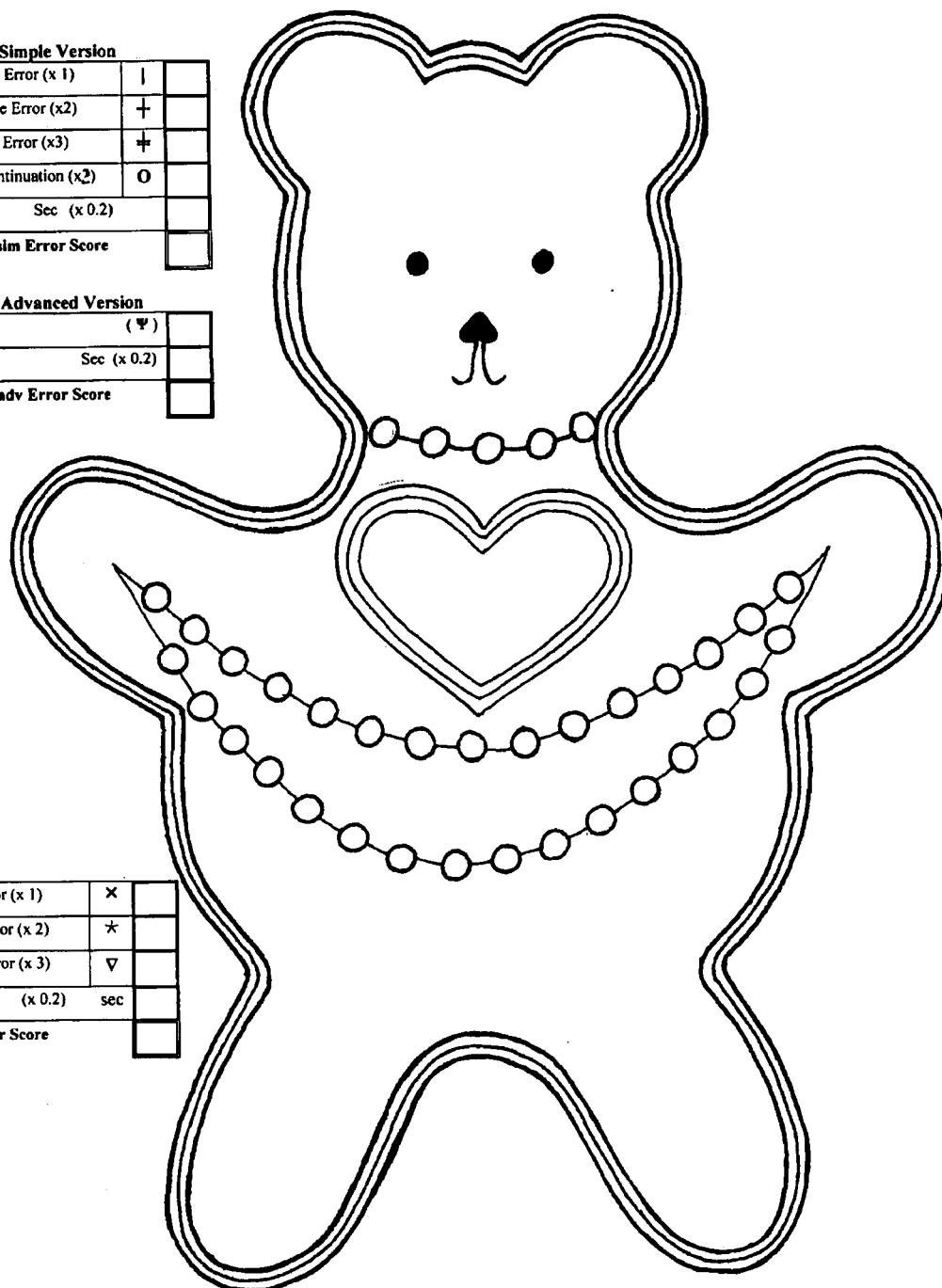
Name: _____ 1 2 L R Date: _____ Code: _____

BTT Simple Version

Single Error (x 1)		
Double Error (x2)	+	
Triple Error (x3)	⊕	
Discontinuation (x2)	○	
Sec (x 0.2)		
BTT sim Error Score		

BTT Advanced Version

180 -	(Ψ)	
Sec (x 0.2)		
BTT adv Error Score		



BDT

Single Error (x 1)	×	
Double Error (x 2)	*	
Placing Error (x 3)	∇	
(x 0.2) sec		
BDT Error Score		

Note. The original size of the BTT/BDT bear is A4.

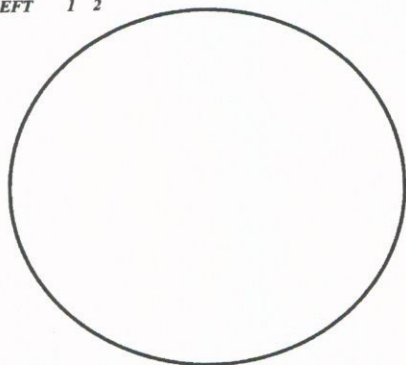
Appendix 4E

Response and Cover Sheets for Hammering and Tapping

Handedness Profile: Hammering and Tapping Response Sheet

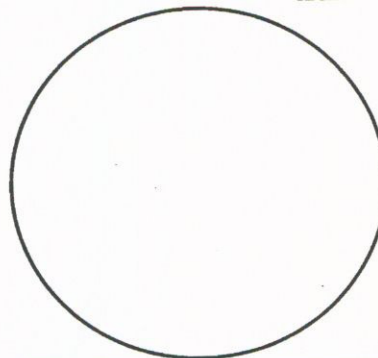
Date: _____ Hammering Tapping Name: _____

LEFT 1 2



4 x	=		x in 15 sec
3 x	=		
2 x	=		mm diameter
1 x	=		
0 x	=		
Total:			

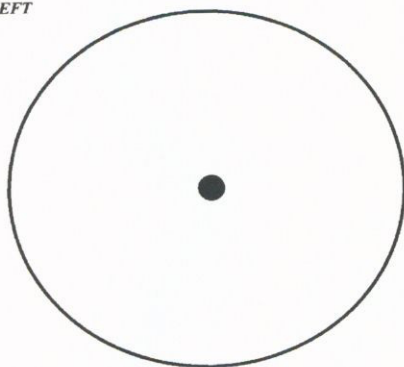
RIGHT 1 2



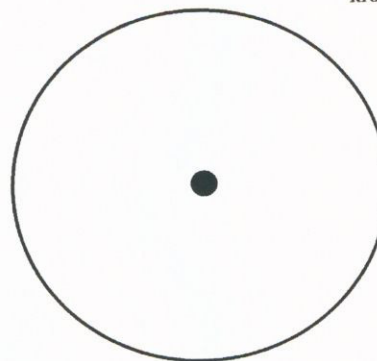
4 x	=		x in 15 sec
3 x	=		
2 x	=		mm diameter
1 x	=		
0 x	=		
Total:			

Handedness Profile: Hammering and Tapping Cover Sheet

LEFT

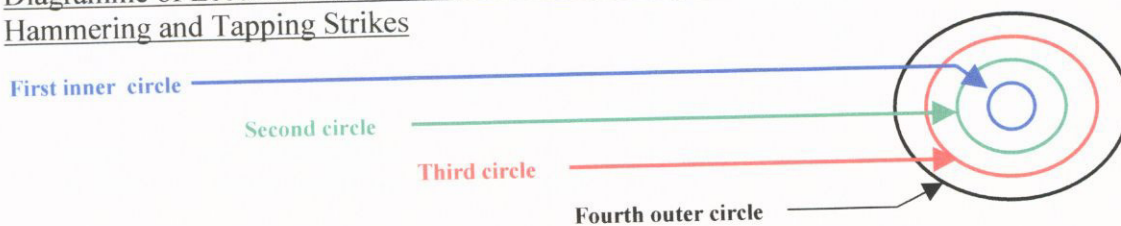


RIGHT

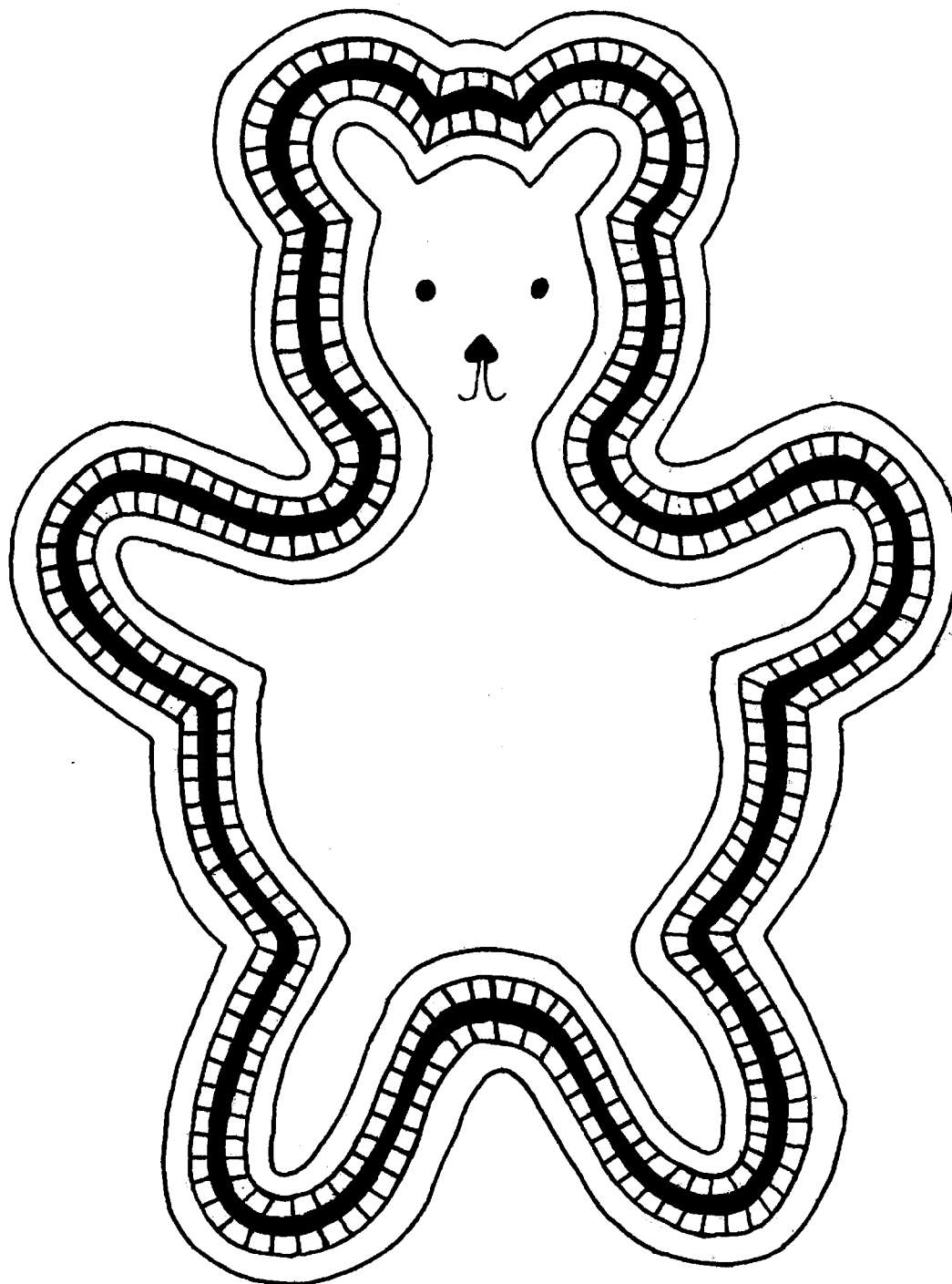


Note. The hammering and tapping cover and response sheets are circa half of their original A4 size.

Diagramme of Eccentric Circle Guide on Transparency Used for Scoring Number of Hammering and Tapping Strikes







Appendix 4F

Marking Guide for the Bear Tracing Task (BTT)

Note. There are 180 grid squares on either side of the path (i.e., solid black center). The path outline is identical to that of the BTT/BDT response sheet.

Appendix 4G

Sample Dots for Scoring the Bead Dotting Task (BDT)

Points awarded	Type of Dot Formation	Description
3 points (no mistakes)		The dot is small and round within the circle (bead). It may also be on top of the boundary but not extending beyond.
2 points (1 mistake)		The dot is within the bead and looks like a dot, but it is not completely round, OR two good dots in one bead.
1 point (2 mistakes)		Dot is in the bead but does not look like a dot, rather a line or a squiggle, OR one good dot plus one bad dot in one bead.
0 points (3 mistakes)		Dot is outside the bead, or no dot can be identified. The quality of the dot is not relevant.

If a dot is a line rather than a dot and extends fairly equally across the border of the bead, examine where the initial point of contact was made (i.e., inside or outside the bead), since this point of contact will determine its position. If the initial point of contact cannot be assessed, or if the two sides of the dot/line extend in unequal proportions across the bead border, the longer part is taken as the location for scoring. In uncertain cases, a lower score is given.

Appendix 4H

One-Way ANOVA to Examine Significant Differences in Left Handers Outside the 5- to 6-Year Age Range on All Handedness Measure

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
CONS	Between Groups	269.629	1	269.629	1.237	.270
	Within Groups	13077.742	60	217.962		
	Total	13347.371	61			
SKILPI	Between Groups	1.384	1	1.384	.043	.836
	Within Groups	1929.635	60	32.161		
	Total	1931.020	61			
PROFPI	Between Groups	346.726	1	346.726	2.412	.126
	Within Groups	8337.234	58	143.745		
	Total	8683.960	59			
crossing midline lat. quotient	Between Groups	1722.497	1	1722.497	1.736	.193
	Within Groups	59518.423	60	991.974		
	Total	61240.919	61			
BMCPPI	Between Groups	67.216	1	67.216	.730	.398
	Within Groups	3498.934	38	92.077		
	Total	3566.150	39			
TRAI.DIU	Between Groups	215.904	1	215.904	.358	.552
	Within Groups	36157.515	60	602.625		
	Total	36373.419	61			
UNTR.DIU	Between Groups	366.049	1	366.049	.301	.585
	Within Groups	72983.887	60	1216.398		
	Total	73349.935	61			
PROFDIU	Between Groups	157.534	1	157.534	2.237	.140
	Within Groups	4084.563	58	70.424		
	Total	4242.098	59			
SKILDIU	Between Groups	57.016	1	57.016	1.564	.216
	Within Groups	2187.021	60	36.450		
	Total	2244.038	61			
BMCDIU	Between Groups	59.202	1	59.202	.075	.785
	Within Groups	29827.321	38	784.930		
	Total	29886.523	39			

Appendix 4I

Complete Case Example (Case 65) Employing the Handedness Profile Test Battery

Appendix 4I [Part i] Handedness Profile Cover Sheet

Case: 65 **Age: 6.3 years** **Gender: Male**
Background Information Draws / writes with Left Right Either

Main reasons for referral *Visual perception, concentration*

Familial left handedness Don't know No Yes:

Birth-related stress Maybe No Yes: *One week overdue, induced*

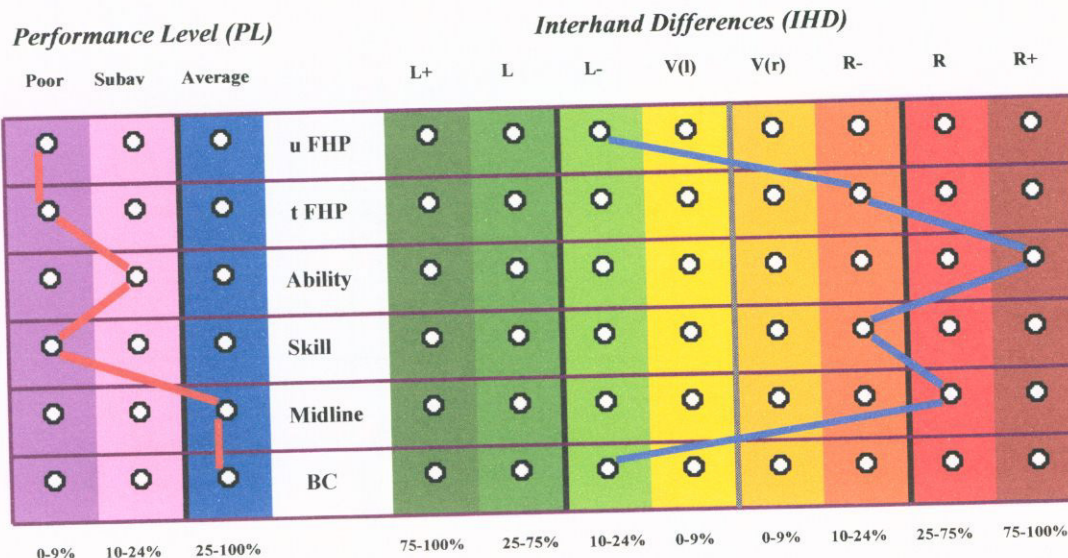
Developmental delay Don't know No Yes: *but needed glasses*

Injury to upper limb / hemispheres Don't know No Yes: L R

Evidence of socio-cultural pressure Don't know No Yes: *Mother encouraged RH use*

Early hand use Left Right Mixed Changed at age:

Parental estimation of handedness Very left More left Mixed More right Very right



Handedness Features *Profile Score: 7* *Profile Classification: Vr to R-*

Incongruence No Yes: FHP Ability/Skill Motor MC

Inconsistency No Yes: within-tasks across-tasks

Excessive IHDs No Yes: above average (*Ability*) below average (*Skill*)

Poor motor performance No Yes: preferred non-preferred both

Midline Crossing avoidance No Yes: avoids preferred hand non-preferred either

Poor Bimanual Coord. No Yes: reversions steps more *left* deviations

Appendix 4I [Part ii]
Functional Hand Preference (FHP) Response Sheet

Name: _____

Age: _____

Date: _____

Code: **65**

Handedness Profile: Functional Hand Preference (FHP)

1. Hand preference in untrained, unimanual activities	R		L		W		B		Ambig		First	
	III	○	III	○	2	2	2	2	✓		R	L
Stacking beads	III	○	III	○	2	2	2	2	✓			
Inserting pegs	III	○	III	○	2	2	2	2	✓			
Spinning top	II	○	II	○	2	2	2	2	✓			
Bear and ball	II	○	III	○	2	2	2	2	✓			
Building a tower	III	○	III	○	2	2	2	2	✓			
Rolling a dice	III	○	+++		2	2	2	2	✓			
Total R: 13 / 25					12				6		5	5
Total L: 12 / 25											1	1
Use percentage: L 52 %											1st Use: (R) L	

2. Hand preference in trained, bimanual activities	R		L		W		B		Ambig		First	
	III	○	III	○	4	0	4	0	✓		R	L
Writing	III	○	III	○	4	0	4	0	✓			
Toothbrush	III	○	III	○	4	0	4	0	✓			
Ball	III	○	III	○	4	0	4	0	✓			
Spoon	III	○	III	○	4	0	4	0	✓			
Drawing	III	○	III	○	4	0	4	0	✓			
Cutting with a knife	III	○	III	○	4	0	4	0	✓			
Total R: 25 / 25					24				0		0	6
Total L: 0 / 25											0	0
Use percentage: L 0 %											1st Use: (R) L	

3. Hand preference in untrained, bimanual activities	R		L		W		B		Ambig		First	
	III	○	III	○	0	4	0	4	✓		R	L
Dealing cards, mixing	III	○	III	○	0	4	0	4	✓			
Hand broom and skoppe	II	○	III	○	2	2	2	2	✓			
Closing & opening tube	III	○	III	○	2	2	2	2	✓			
Taking off stickers	+++		III	○	2	2	2	2	✓			
Screwing	I	○	III	○	1	3	1	3	✓			
Opening small box	I	○	III	○	0	4	0	4	✓			
Total R: 5 / 25					5				3		0	0
Total L: 20 / 25						19					6	1
Use percentage: L 80 %											1st Use: (R) L	

4. Hand preference in trained, bimanual activities	R		L		W		B		Ambig		First	
	I	○	III	○	1	3	4	0	✓		R	L
Striking a match	I	○ <td>III</td> <td>○ <td>1</td> <td>3</td> <td>4</td> <td>0</td> <td>✓</td> <td></td> <td></td> <td></td> </td>	III	○ <td>1</td> <td>3</td> <td>4</td> <td>0</td> <td>✓</td> <td></td> <td></td> <td></td>	1	3	4	0	✓			
Cutting with scissors	III	○ <td>III</td> <td>○ <td>2</td> <td>2</td> <td>2</td> <td>2</td> <td>✓</td> <td></td> <td></td> <td></td> </td>	III	○ <td>2</td> <td>2</td> <td>2</td> <td>2</td> <td>✓</td> <td></td> <td></td> <td></td>	2	2	2	2	✓			
Key and lock	II	○ <td>III</td> <td>○ <td>2</td> <td>2</td> <td>2</td> <td>2</td> <td>✓</td> <td></td> <td></td> <td></td> </td>	III	○ <td>2</td> <td>2</td> <td>2</td> <td>2</td> <td>✓</td> <td></td> <td></td> <td></td>	2	2	2	2	✓			
Sewing	III	○ <td>III</td> <td>○ <td>2</td> <td>2</td> <td>2</td> <td>2</td> <td>✓</td> <td></td> <td></td> <td></td> </td>	III	○ <td>2</td> <td>2</td> <td>2</td> <td>2</td> <td>✓</td> <td></td> <td></td> <td></td>	2	2	2	2	✓			
Knife and fork	III	○ <td>III</td> <td>○ <td>4</td> <td>0</td> <td>4</td> <td>0</td> <td>✓</td> <td></td> <td></td> <td></td> </td>	III	○ <td>4</td> <td>0</td> <td>4</td> <td>0</td> <td>✓</td> <td></td> <td></td> <td></td>	4	0	4	0	✓			
Screwdriver	III	○ <td>III</td> <td>○ <td>4</td> <td>0</td> <td>4</td> <td>0</td> <td>✓</td> <td></td> <td></td> <td></td> </td>	III	○ <td>4</td> <td>0</td> <td>4</td> <td>0</td> <td>✓</td> <td></td> <td></td> <td></td>	4	0	4	0	✓			
Total R: 18 / 25					17				3		5	5
Total L: 7 / 25						7					1	1
Use percentage: L 28 %											1st Use: (R) L	

Total Use Percentage L:	39 %
Unimanual Use Percentage L:	24 %
Bimanual Use Percentage L:	54 %
Untrained Use Percentage L:	64 %
Trained Use Percentage L:	14 %

Total Use Percentage R:	61 %
Unimanual Use Percentage R:	76 %
Bimanual Use Percentage R:	46 %
Untrained Use Percentage R:	36 %
Trained Use Percentage R:	86 %

Laterality Quotient	22 %
Ambiguity	50 %
First Hand Use L:	33 %
First Hand Use R:	17 %

R.
Ambiguity: $\frac{12}{24} = 50\%$
Consistent: 50%

Appendix 4I [Part iii]
Bear Tracing Task (BTT) and Bead Dotting Task (BDT) Response and Score Sheet

Right Hand

Handedness Profile: Bear Tracing Task (BTT) and Bead Dotting Task (BDT)

Name: _____

① 2 L **② R**

Date: _____

Code: **65**

BTT Simple Version

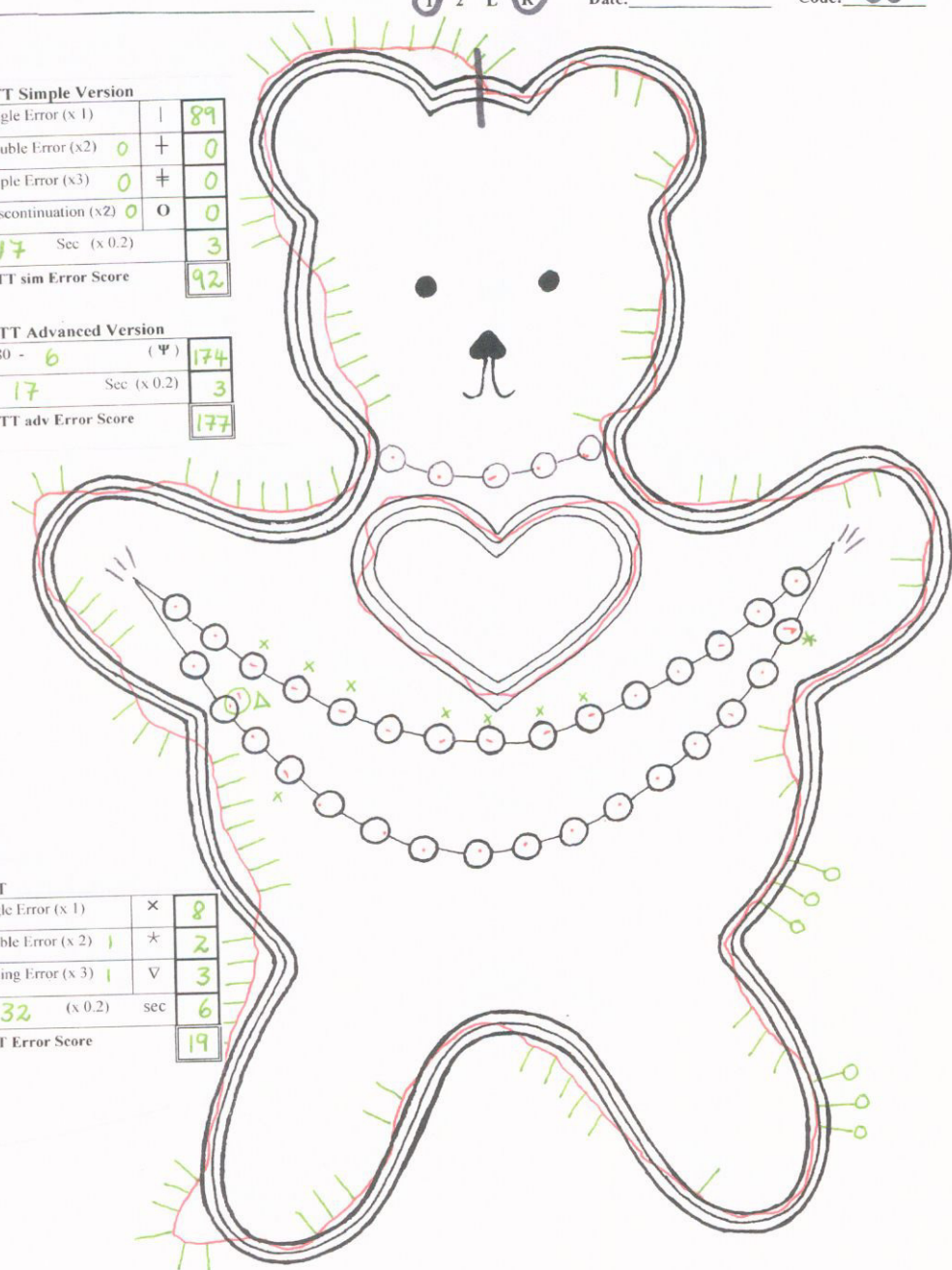
Single Error (x 1)		89
Double Error (x2)	+	0
Triple Error (x3)	≠	0
Discontinuation (x2)	○	0
17 Sec (x 0.2)		3
BTT sim Error Score		92

BTT Advanced Version

180 - 6 (Ψ)	174
17 Sec (x 0.2)	3
BTT adv Error Score	177

BDT

Single Error (x 1)	×	8
Double Error (x 2)	*	2
Placing Error (x 3)	∇	3
32 (x 0.2) sec		6
BDT Error Score		19



(appendix continued)

Appendix [4I Part iii] (continued)

Left Hand

Handedness Profile: Bear Tracing Task (BTT) and Bead Dotting Task (BDT)

Name: _____ 1 **2** L R Date: _____ Code: **65**

BTT Simple Version

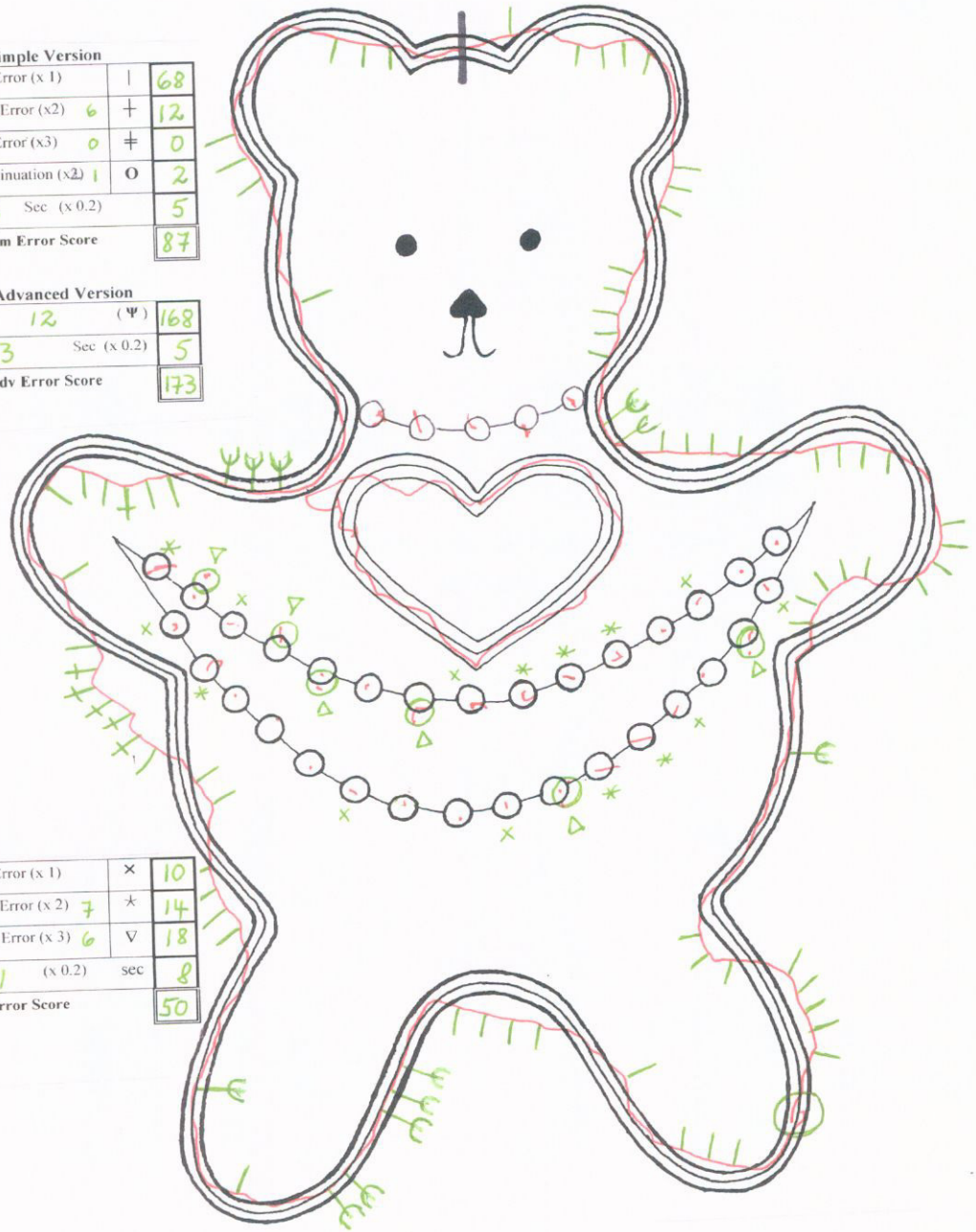
Single Error (x 1)		68
Double Error (x2)	6 +	12
Triple Error (x3)	0 ≠	0
Discontinuation (x2)	1 O	2
23 Sec (x 0.2)		5
BTT sim Error Score		87

BTT Advanced Version

180 -	12 (Ψ)	168
23 Sec (x 0.2)		5
BTT adv Error Score		173

BDT

Single Error (x 1)	×	10
Double Error (x 2)	*	14
Placing Error (x 3)	∇	18
41 (x 0.2) sec		8
BDT Error Score		50



Appendix 4I [Part iv] Hammering and Tapping Response Sheets

Handedness Profile: Hammering and Tapping Response Sheet

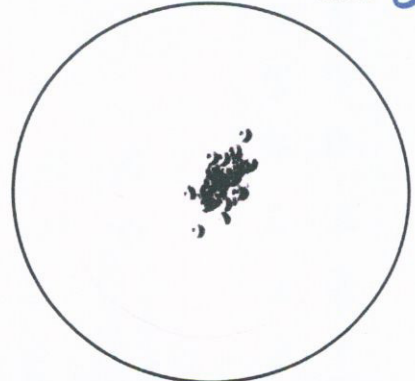
Date: _____ Hammering Tapping Name: Case 65

LEFT 1 (2)



4 x	1	=	52	39	x in 15 sec
3 x	1	=	39		
2 x	1	=	18	40	mm diameter
1 x	0	=	0		
0 x	0	=	0		
Total:			112		

RIGHT (1) 2



4 x	2	=	112	51	x in 15 sec
3 x	2	=	60		
2 x	3	=	6	30	mm diameter
1 x	0	=	0		
0 x	0	=	0		
Total:			178		

Handedness Profile: Hammering and Tapping Response Sheet

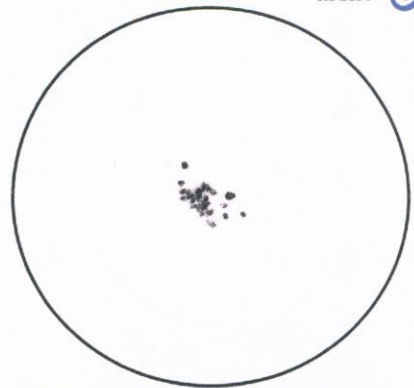
Date: _____ Hammering Tapping Name: Case 65

LEFT 1 (2)



4 x	1	=	44	33	x in 15 sec
3 x	2	=	23		
2 x	2	=	16	40	mm diameter
1 x	4	=	4		
0 x	1	=	0		
Total:			91		

RIGHT (1) 2



4 x	2	=	112	39	x in 15 sec
3 x	2	=	23		
2 x	1	=	4	20	mm diameter
1 x	0	=	0		
0 x	0	=	0		
Total:			143		

Appendix 4I [Part vi]
Midline Crossing Calculation Sheet

65

	M-I	I-M	M-C	C-M	I-C pro	C-I pro	I-C dis	C-I dis	Swap	Right	Left	TOTAL
P-T									()	(4)	(0)	
T 1 (4)	$\begin{matrix} R + L \\ 2 \quad 0 \end{matrix}$ 2		$\begin{matrix} R + L \\ 2 \quad 0 \end{matrix}$ 2							4	0	
T 2 (8)					$\begin{matrix} R + L & R + L \\ 4 & 3 & 1 & 0 \end{matrix}$ 7	1				5	3	
T 3 (4)							$\begin{matrix} R + L & R + L \\ 2 & 0 & 2 & 0 \end{matrix}$ 2	2		4	0	
T 4 (4)							$\begin{matrix} R + L & R + L \\ 2 & 0 & 2 & 0 \end{matrix}$ 4	0		2	2	
T 5 (4)		$\begin{matrix} R + L \\ 2 & 2 \end{matrix}$ 4		$\begin{matrix} R + L \\ 0 & 0 \end{matrix}$ 0						2	2	
T 6 (4)	$\begin{matrix} R + L \\ 2 & 1 \end{matrix}$ 3		$\begin{matrix} R + L \\ 1 & 0 \end{matrix}$ 1							3	1	
T 7 (4)		$\begin{matrix} R + L \\ 2 & 0 \end{matrix}$ 2		$\begin{matrix} R + L \\ 2 & 0 \end{matrix}$ 2						4	0	
TOTAL Swap									0 32	24	8	
TOTAL Ipsi	$\begin{matrix} R + L \\ 4 & 1 \end{matrix}$ 5 8	$\begin{matrix} R + L \\ 4 & 2 \end{matrix}$ 6 8							16	8	3	11 16
TOTAL single Cont 1			$\begin{matrix} R + L \\ 3 & 0 \end{matrix}$ 3 8		$\begin{matrix} R + L \\ 4 & 3 \end{matrix}$ 7 8					7	3	10 16
TOTAL multi Cont 2				$\begin{matrix} R + L \\ 2 & 0 \end{matrix}$ 2 8		$\begin{matrix} R + L \\ 1 & 0 \end{matrix}$ 1 8				3	0	3 16
TOTAL distal Cont 3							$\begin{matrix} R + L & R + L \\ 4 & 2 & 2 & 0 \end{matrix}$ 6 8	2		6	2	8 16
TOTAL Mid St	$\begin{matrix} R + L \\ 4 & 1 \end{matrix}$ 5 8		$\begin{matrix} R + L \\ 3 & 0 \end{matrix}$ 3 8							(7)	(1)	(8) 16
TOTAL Ips St		$\begin{matrix} R + L \\ 4 & 2 \end{matrix}$ 6 8			$\begin{matrix} R + L \\ 4 & 3 \end{matrix}$ 7 8		$\begin{matrix} R + L \\ 4 & 2 \end{matrix}$ 6 8			(12)	(7)	(19) 24
TOTAL Con St				$\begin{matrix} R + L \\ 2 & 0 \end{matrix}$ 2 8		$\begin{matrix} R + L \\ 1 & 0 \end{matrix}$ 1 8		$\begin{matrix} R + L \\ 2 & 0 \end{matrix}$ 2 8		(5)	(0)	(5) 24
TOTAL Dev/rl				/	/	/	/	/		24 32	8 32	/ 48

$$\text{Midline Crossing Quotient (MCQ)} = \frac{R \ 24 - L \ 8}{R + L} = \frac{16}{32} = 50\% \ R$$

$$\text{Contralateral Start \%age} = \frac{5}{24} = 21\% \quad L = \frac{0}{12} = 0\% \quad R = \frac{5}{12} = 42\%$$

Appendix 4I [Part vii]
Bimanual Coordination Response Transparency and Score Sheet

Date: _____ Name: _____ **65**

(Divide the total of Zone 2 and beyond by 2 before adding it to Zone 1 deviation)

Zone 1		Zone 2		Zone 3		Zone 4		Zone Beyond 4		Reversions	
Speed (sec)	Deviation	Speed (sec)	Deviation	Speed (sec)	Deviation	Speed (sec)	Deviation	Speed (sec)	Deviation	Penalty = 6	Alter units
Total: 10	1	Total: 0	0	Total: 0	0	Total: 0	0	Total: 0	0		0
Ro: 0	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R		0
Lo: 0	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R		0
Mount ans: LH both	RH	LH RH changes	from to					P if Rev > 2: 12	P if Rev > 2: 12		6

TRIAL 2

Zone 1		Zone 2		Zone 3		Zone 4		Zone Beyond 4		Reversions	
Speed (sec)	Deviation	Speed (sec)	Deviation	Speed (sec)	Deviation	Speed (sec)	Deviation	Speed (sec)	Deviation	Penalty = 6	Alter units
Total: 16	12	Total: 8	0	Total: 0	0	Total: 0	0	Total: 0	0		0
Ro: 0	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R		0
Lo: 0	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R		0
Mount ans: LH both	RH	LH RH changes	from to					P if Rev > 2: 12	P if Rev > 2: 6		6

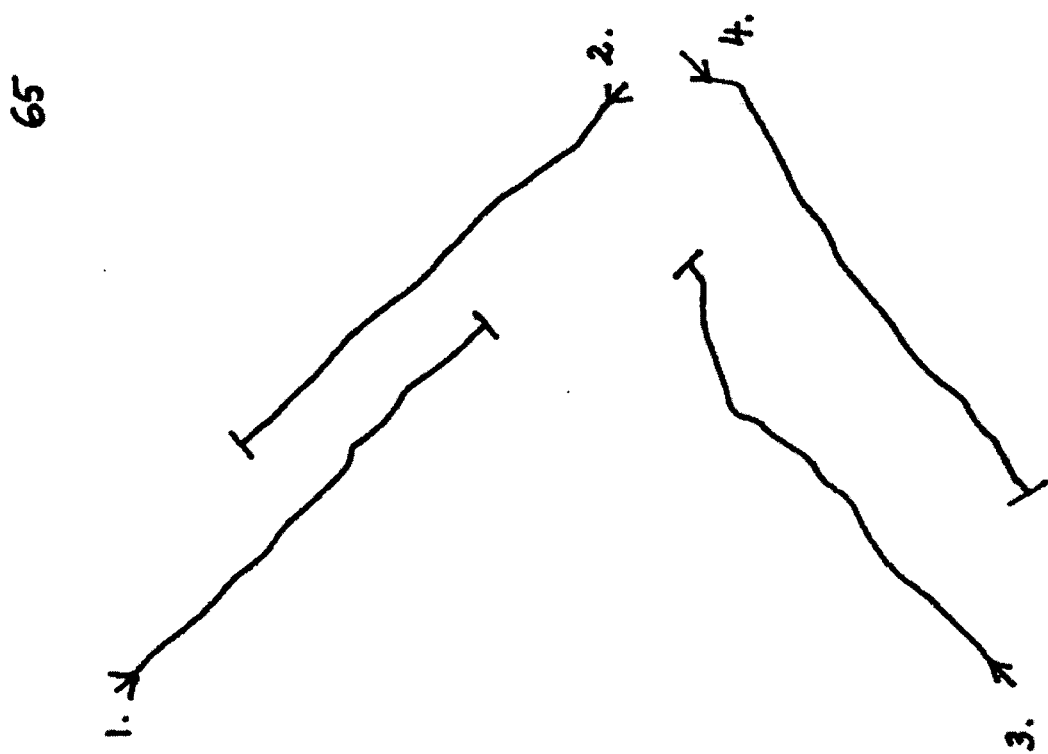
TRIAL 3

Zone 1		Zone 2		Zone 3		Zone 4		Zone Beyond 4		Reversions	
Speed (sec)	Deviation	Speed (sec)	Deviation	Speed (sec)	Deviation	Speed (sec)	Deviation	Speed (sec)	Deviation	Penalty = 6	Alter units
Total: 15	11	Total: 6	2	Total: 2	0	Total: 0	0	Total: 0	0		0
Ro: 0	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R		0
Lo: 1	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R		0
Mount ans: LH both	RH	LH RH changes	from to					P if Rev > 2: 12	P if Rev > 2: 6		6

TRIAL 4

Zone 1		Zone 2		Zone 3		Zone 4		Zone Beyond 4		Reversions	
Speed (sec)	Deviation	Speed (sec)	Deviation	Speed (sec)	Deviation	Speed (sec)	Deviation	Speed (sec)	Deviation	Penalty = 6	Alter units
Total: 23	12	Total: 9	8	Total: 8	5	Total: 5	0	Total: 0	0		0
Ro: 0.5	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R		0
Lo: 0	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R	L M R L M R		0
Mount ans: LH both	RH	LH RH changes	from to					P if Rev > 2: 12	P if Rev > 2: 6		6

Total Speed: _____ Total Rev: 0.5 Total Ls: 12 Total Reversals: 0 Constant hand: _____
 Total Deviation: 64 Total Left Deviation: 13.5 Total Middle: 44.5 Total Right Deviation: 6
 Homod. Deviation: 26 Homod. Left Deviation: 1 Homod. Middle: 31.5 Homod. Right Dev.: 3.5
 Heter. Deviation: 38 Heter. Left Deviation: 12.5 Heter. Middle: 23 Heter. Right Dev.: 2.5



Appendix 4I [Part viii]
Summary Calculation Sheet for All Handedness Measures

65

Summary Calculation Sheet for IHD and PL Percentages of all Handedness Profile Measures

Handedness Measures	LEFT HAND Calculation		Performance Percentage	RIGHT HAND Calculation		Performance Percentage	IHD/PL Calculation	IHD/PL Percentage
Untrained FHP			<u>64</u> %			<u>36</u> %	R <u>36</u> % - L <u>64</u> %	= <u>28</u> % L R
Trained FHP			<u>14</u> %			<u>84</u> %	R <u>86</u> % - L <u>14</u> %	= <u>72</u> % L R
Total FHP			<u>39</u> %			<u>61</u> %	R <u>61</u> % - L <u>39</u> %	= <u>22</u> % L R
Consistency							24 - Ambiguity <u>12</u> 0.24	= PL <u>50</u> %
Ability IHD <i>PL value is that of the hand with the best performance</i>	Hammering RS divide by 2.8 <u>112</u> Tapping RS divide by 2.8 <u>92</u>		<u>40</u> % = <u>33</u> %	Hammering RS divide by 2.8 <u>178</u> Tapping RS divide by 2.8 <u>143</u>		<u>64</u> % = <u>51</u> %	Ham R <u>64</u> % - L <u>40</u> % Tap R <u>51</u> % - L <u>33</u> % TOTAL IHD (sum divided by 2) <u>(42)</u>	= <u>24</u> % L R = <u>18</u> % L R = <u>21</u> % L R
Skill IHD <i>PL value is that of the hand with the best performance</i>	250 - BTT simple ES divide by 2.5 <u>87</u> 200 - BTT advanced ES divide by 2 <u>173</u> 90 - BDT RS divide by 0.9 <u>50</u>		<u>65</u> % = <u>14</u> % = <u>44</u> %	250 - BTT simple ES divide by 2.5 <u>92</u> 200 - BTT advanced ES divide by 2 <u>177</u> 90 - BDT RS divide by 0.9 <u>19</u>		<u>63</u> % = <u>12</u> % = <u>79</u> %	Sim R <u>63</u> % - L <u>65</u> % Adv R <u>12</u> % - L <u>14</u> % BDT R <u>51</u> % - L <u>41</u> % TOTAL IHD (sum divided by 3) <u>(31)</u>	= <u>2</u> % L R = <u>2</u> % L R = <u>35</u> % L R = <u>10</u> % L R
MCQ			<u>0</u> %			<u>50</u> %	R <u>50</u> % - L <u>0</u> %	= <u>50</u> % L R
Extent of MC			<u>0</u> %			<u>50</u> %	R <u>50</u> % + L <u>0</u> %	= PL <u>50</u> %
Bimanual Coordination IHD PL	42 - homol BC ES divide by 0.4 <u>1.0</u> 42 - heterol BC ES divide by 0.4 <u>12.5</u>		<u>3</u> % = <u>31</u> %	42 - homol BC ES divide by 0.4 <u>3.5</u> 42 - heterol BC ES divide by 0.4 <u>2.5</u>		<u>9</u> % = <u>6</u> %	R <u>9</u> % - L <u>3</u> % R <u>6</u> % - L <u>31</u> % TOTAL ES (sum divided by 2) <u>(31)</u> 168 - Total ES <u>64</u> 1.68	= <u>6</u> % L R = <u>25</u> % L R = <u>16</u> % L R = PL <u>62</u> %

NOTE: ES = Error Score, RS = Raw Score

Appendix 4I [Part ix] Handedness Profile Classification Sheet

Handedness Categorisation Sheet

65

Interhand Differences								
	Explicit Left L+	Moderate Left L	Mild Left L-	Variable Left V(l)	Variable Right V(r)	Mild Right R-	Moderate Right R	Explicit Right R+
Untrained FHP	<input type="checkbox"/> 76% - 100%	<input type="checkbox"/> 40% - 75%	<input checked="" type="checkbox"/> 3% - 39%	<input type="checkbox"/> 0% - 2%	<input type="checkbox"/> 0% - 26%	<input type="checkbox"/> 27% - 47%	<input type="checkbox"/> 48% - 75%	<input type="checkbox"/> 76% - 100%
Trained FHP	<input type="checkbox"/> 80% - 100%	<input type="checkbox"/> 42% - 79%	<input type="checkbox"/> 18% - 41%	<input type="checkbox"/> 0% - 17%	<input type="checkbox"/> 0% - 69%	<input checked="" type="checkbox"/> 70% - 77%	<input type="checkbox"/> 78% - 93%	<input type="checkbox"/> 94% - 100%
Ability	<input type="checkbox"/> 13% - 100%	<input type="checkbox"/> 6% - 12%	<input type="checkbox"/> 2% - 5%	<input type="checkbox"/> 0% - 1%	<input type="checkbox"/> 0% - 3%	<input checked="" type="checkbox"/> 4% - 9%	<input type="checkbox"/> 10% - 18%	<input checked="" type="checkbox"/> 19% - 100%
Skill	<input type="checkbox"/> 17% - 100%	<input type="checkbox"/> 10% - 16%	<input type="checkbox"/> 4% - 9%	<input type="checkbox"/> 0% - 3%	<input type="checkbox"/> 0% - 4%	<input checked="" type="checkbox"/> 5% - 13%	<input type="checkbox"/> 14% - 21%	<input type="checkbox"/> 22% - 100%
Midline Crossing Quotient	<input type="checkbox"/> 81% - 100%	<input type="checkbox"/> 19% - 80%	<input type="checkbox"/> 3% - 18%	<input type="checkbox"/> 0% - 2%	<input type="checkbox"/> 0% - 23%	<input type="checkbox"/> 24% - 46%	<input checked="" type="checkbox"/> 47% - 93%	<input type="checkbox"/> 94% - 100%
Bimanual Coordination	<input type="checkbox"/> 48% - 100%	<input type="checkbox"/> 23% - 47%	<input checked="" type="checkbox"/> 4% - 22%	<input type="checkbox"/> 0% - 3%	<input type="checkbox"/> 0% - 3%	<input type="checkbox"/> 4% - 7%	<input type="checkbox"/> 8% - 35%	<input type="checkbox"/> 36% - 100%

7	Subtotal L+	Subtotal L	Subtotal L-	Subtotal V(l)	Subtotal V(r)	Subtotal R-	Subtotal R	Subtotal R+
			-3			+3	+3	+4

Record number of ▲ = excessively large IHDs: **1** ★ = subaverage small IHDs: **3** ● = excessively small IHDs: **0** Incongruencies: **1**

Performance Level								
	Explicit Left L+ Above average	Moderate Left L Average	Mild Left L- Subaverage	Variable Left V(l) Poor	Variable Right V(r) Poor	Mild Right R- Subaverage	Moderate Right R Average	Explicit Right R+ Above average
Consistency	<input type="checkbox"/> 75% - 100%	<input type="checkbox"/> 58% - 74%	<input type="checkbox"/> 47% - 57%	<input type="checkbox"/> 0% - 46%	<input checked="" type="checkbox"/> 0% - 57%	<input type="checkbox"/> 58% - 61%	<input type="checkbox"/> 62% - 82%	<input type="checkbox"/> 83% - 100%
Ability (preferred)	<input type="checkbox"/> 71% - 100%	<input type="checkbox"/> 58% - 70%	<input type="checkbox"/> 48% - 57%	<input type="checkbox"/> 0% - 47%	<input type="checkbox"/> 0% - 56%	<input checked="" type="checkbox"/> 57% - 59%	<input type="checkbox"/> 60% - 74%	<input type="checkbox"/> 75% - 100%
Ability (non-preferred)	<input type="checkbox"/> 57% - 100%	<input type="checkbox"/> 49% - 56%	<input type="checkbox"/> 39% - 48%	<input checked="" type="checkbox"/> 0% - 38%	<input type="checkbox"/> 0% - 35%	<input type="checkbox"/> 36% - 45%	<input type="checkbox"/> 46% - 54%	<input type="checkbox"/> 55% - 100%
Skill (preferred)	<input type="checkbox"/> 67% - 100%	<input type="checkbox"/> 61% - 66%	<input type="checkbox"/> 57% - 60%	<input type="checkbox"/> 0% - 56%	<input checked="" type="checkbox"/> 0% - 54%	<input type="checkbox"/> 55% - 58%	<input type="checkbox"/> 59% - 66%	<input type="checkbox"/> 67% - 100%
Skill (non-preferred)	<input type="checkbox"/> 60% - 100%	<input type="checkbox"/> 51% - 59%	<input type="checkbox"/> 46% - 50%	<input checked="" type="checkbox"/> 0% - 45%	<input type="checkbox"/> 0% - 29%	<input type="checkbox"/> 30% - 46%	<input type="checkbox"/> 47% - 55%	<input type="checkbox"/> 56% - 100%
Midline Crossing Extent	<input type="checkbox"/> 94% - 100%	<input checked="" type="checkbox"/> 31% - 93%	<input type="checkbox"/> 3% - 30%	<input type="checkbox"/> 0% - 2%	<input type="checkbox"/> 0% - 18%	<input type="checkbox"/> 19% - 24%	<input checked="" type="checkbox"/> 25% - 87%	<input type="checkbox"/> 88% - 100%
Bimanual Coordination	<input type="checkbox"/> 66% - 100%	<input checked="" type="checkbox"/> 59% - 65%	<input type="checkbox"/> 49% - 58%	<input type="checkbox"/> 1% - 48%	<input type="checkbox"/> 1% - 33%	<input type="checkbox"/> 34% - 45%	<input checked="" type="checkbox"/> 46% - 62%	<input type="checkbox"/> 63% - 100%

Profile Score 17 - 24
Profile Score 10 - 16
Profile Score 5 - 9
Profile Score 1 - 4
Profile Score 0

- Explicit Left Hander
- Moderate Left Hander
- Mild Left Hander
- Variable Left Hander
- Variable Hander
- Explicit Right Hander
- Moderate Right Hander
- Mild Right Hander
- Variable Right Hander

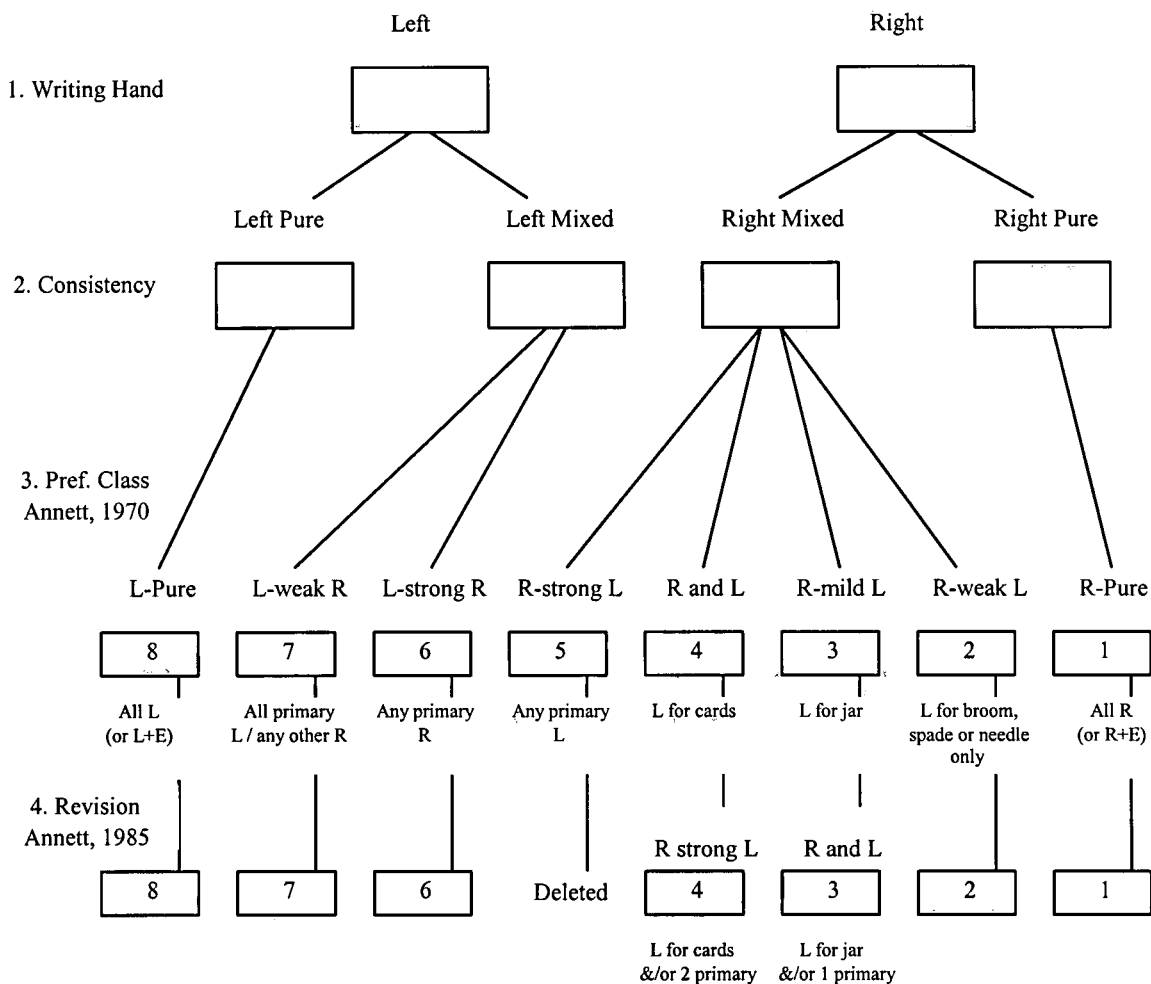
- with motor deficits (preferred / non-preferred / both hands)
- without motor deficits
- bimanual motor deficits
- midline crossing avoidance
- incongruence
- inconsistency
- excessively large IHDs
- excessively small IHDs

This profile indicates mild to variable right handedness. There are severe motor problems, both with the preferred and non-preferred hands, although MC and BC are scored in the average range. There is an excessive right hand advantage in Ability and in the BDT (Skill), while tracing (BT) was performed equally poor with both hands. Therapy: writing with R hand in a graded grapho-motor training programme. Investigate visual-perceptual domain (MC performed with L hand).

Appendix 5A

Decision Tree for Handedness Classification by Annett (1994)

Handedness as a Continuous Variable with Dextral Shift



A decision tree for hand preference: the criteria of classification into subgroups of left and right handers) based on Annett, 1970a, 1985, Table 11.4). 'Primary actions are writing, throwing, racket, match, hammer and toothbrush. Nonprimary actions are scissors, needle, broom, spade, dealing cards, and unscrewing a jar.

Diagram taken from article by Marian Annett (1994), "Handedness as a Continuous Variable with Dextral Shift: Sex, Generation, and Family Handedness in Subgroups of Left- and Right Handers", Behavioral Genetics, 24(1), p.53.

Appendix 5B

Correspondence Between Clusters and Handedness Categories Based on Profile Scores for the 5-Group Classification in the Normative Sample

	<i>Cluster 3: Definite Left n=16 CC: -23.0</i>	<i>Cluster 5: Left n=5 CC: -13.0</i>	<i>Cluster 1: Variable n=6 CC: 0.0</i>	<i>Cluster 4: Right n=9 CC: 8.5</i>	<i>Cluster 2: Definite Right n=14 CC: 22.0</i>
<i>Category -2 Definite Left</i>	12 75%				
<i>Category -1 Left</i>	4 / 16 25%	3 60%			
<i>Category 0 Variable</i>		2 40%	4 67%		
<i>Category 1 Right</i>			2 33%	7 78%	
<i>Category 2 Definite Right</i>				2 22%	14 100%

Note. The top figure denotes the number of cases showing correspondence between cluster and category, and the figure underneath illustrates the percentage of corresponding cases. CC = cluster centre. The overall agreement for the 5-Group classification was 83%. Figures in bold donate the majority of cases, and the orange squares indicate 100% correspondence between clusters and categories.

Appendix 6A

Ethics Approval for Study IV

La Trobe University
MEMORANDUM

Faculty Office
FACULTY OF HEALTH SCIENCES

TO: Dr. Heather Mudie Occupational Therapy

SUBJECT: Reference: **FHEC00/122**

Student Name Elke Kraus


Title: **Manual Asymmetries in Young Children:
Investigating the Therapeutic Influence of Bimanual
Actions and Contralateral Reaching on Developing**

DATE: 20 October 2000

The Faculty Human Ethics Committee (FHEC) has considered and approved the above project. You may proceed as soon as you have provided the FHEC with a copy of the consent form on letterhead. Please also remove the word "do" on line 5 of paragraph 3 of the consent form.

Please ensure that each participant retains a copy of the Informed Consent Form. Researchers are also required to retain a copy of all Informed Consent Forms separately from the data for a period of 5 years.

Please note that any modification to the project must be submitted in writing to FHEC for approval. You are required to provide an annual report (where applicable) and/or a final report on completion of the project. A copy of the progress/final report is enclosed. Would you please return the completed form to Ms Natalie Humphries, Secretary, FHEC, Faculty of Health Sciences Office, La Trobe University, Bundoora, 3083.


by **Natalie Humphries**
Secretary
Faculty Human Ethics Committee
Faculty of Health Sciences

Appendix 6B

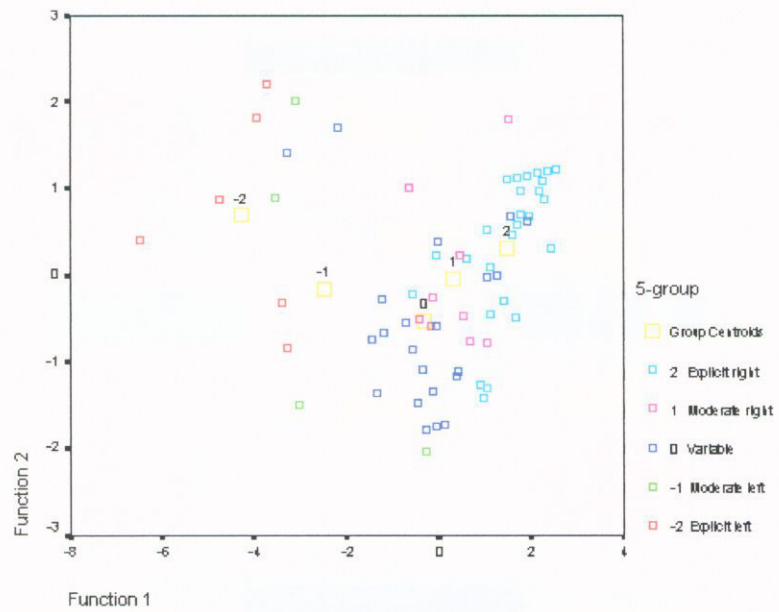
Correspondence Between Clusters and Handedness Categories Based on Profile Scores for the 5-Group Classification in the Clinical Sample

	<i>Cluster 2: Definite Left n=4 CC: -16.3</i>	<i>Cluster 5: Left n=10 CC: -11.0</i>	<i>Cluster 1: Variable n=21 CC: 8.8</i>	<i>Cluster 4: Right n=27 CC: 13.9</i>	<i>Cluster 3: Definite Right n=6 CC: 18.6</i>
<i>Category -2 Definite Left</i>	2 50%	1 10%		1 4%	
<i>Category -1 Left</i>	1 25%	3 30%			
<i>Category 0 Variable</i>	1 25%	6 60%	4 19%	4 15%	1 17%
<i>Category 1 Right</i>			17 81%	15 55%	
<i>Category 2 Definite Right</i>				7 26%	5 83%

Note. The top figure denotes the number of cases showing correspondence between cluster and category, and the figure underneath illustrates the percentage of corresponding cases. CC = cluster centre. The overall agreement for the 5-Group classification was 83%. Figures in bold donate the majority of cases, and the orange squares indicate 100% correspondence between clusters and categories.

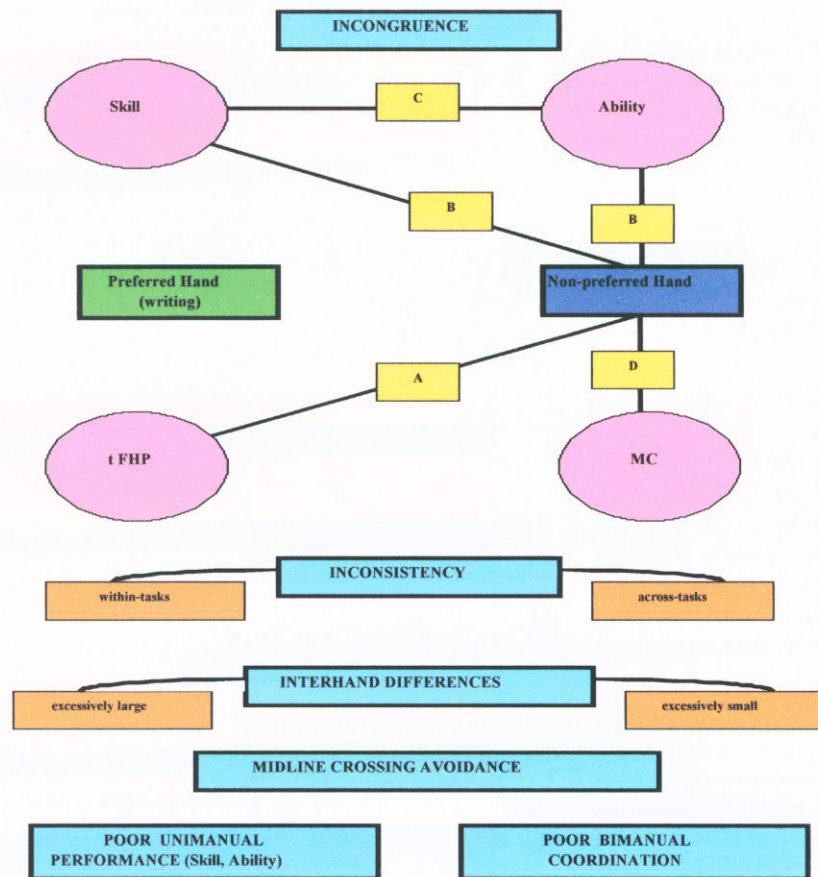
Appendix 6C

Canonical Discriminant Function Graph of the 5-Group Handedness Classifications Based on Interhand Difference (IHD) Measures



Note. Functions refer to predictive factors. Function 1 = Midline Crossing; Function 2 = trained Functional Hand Preference.

Appendix 6D
Summary of Handedness Features Indicative of Dysfunction Related to
Variable Handedness



Note. Preferred hand refers to presenting writing/drawing hand; FHP = trained Functional Hand Preference; MC = midline crossing. A = FHP Incongruence; B = Ability/Skill Incongruence; C = Motor Incongruence; and D = Midline Crossing Incongruence.

Appendix 6E

Case Examples with Comments on Clinical Decision Making

Particulars	Handed-ness Measures	L + 4	L 3	L - 1.5	V l 0.5	V r 0.5	R - 1.5	R 3	R + 4	Total (L=- R=+)	Comments based on Clinical Decision Making
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Case 29	uFHP					↓				0.5	<i>Incongruence between FHP and motor measures, with innate tasks tending toward the right. Since trained/skilled tasks are performed with the L despite the right biased environment, keep writing with left hand. Incongruence and inconsistency are thought to be normal variability for left handers, but performance (in Skill) is low in both hands, and a fine motor programme in OT would be appropriate.</i>
	tFHP		↓							-3.0	
Age 7.10	Ability						☺			1.5	
	Skill		↓							-3.0	
Gender f	MC		☺							-3.0	
	BC						☺			1.5	
Writes left									▷	(i)	
Profile Score		=	=	=	=	=	=	=	▷	-5.5	
Profile Class.		=	=	=	=	=	=	=	▷	VI	

Case 60	uHP			↓						-1.5	<i>Inconsistent but congruent in FHP, and incongruent in motor measures, crosses midline adequately but with right hand. Skill is greater in right, but both are below the 10th percentile. Could be a pathological left hander. Keep writing with left hand but needs fine motor skills programme (more skills training/hand writing, since Ability is OK).</i>
	tFHP			↓						-1.5	
Age 5.4	Ability		☺							-3.0	
	Skill						↓			1.5	
Gender m	MC						☺			1.5	
	BC						☺			1.5	
Writes left									▷	(i)	
Profile Score		=	=	=	=	=	=	=	▷	-1.5	
Profile Class.		=	=	=	=	=	=	=	▷	VI	

Case 34	uHP		↓							-3.0	<i>Performs most FHP tasks with left hand especially untrained. Ability and Skill are both below average with slight right advantage but crosses adequately with left hand. BC is low. Indications that this is a mild left hander who is in the process of being switched. Therapy should encourage left hand for writing in addition to a specific FM/graphomotor programme.</i>
	tFHP				↓					-0.5	
Age 4.8	Ability						↓			1.5	
	Skill						↓			0.5	
Gender m	MC		☺							-3.0	
	BC			↓						-1.5	
Writes either									▷	(i)	
Profile Score		=	=	=	=	=	=	=	▷	-3.0	
Profile Class.		=	=	=	=	=	=	=	▷	VI	

Case 4	uHP			↓						-1.5	<i>Incongruence in both FHP and motor measures, with trained/skill being more right and untrained/inherent more left. Avoids midline crossing but when she crosses, it is with the left. BC is OK. Parents report early left hand use (her mother is left handed), but she wants to be like her right handed brother – she resists using the left. Seems to be a switched hander. Without her motivation, focus more on general coordination skills and bimanual tasks where both hands are involved. If she resists at school going age, start writing with the right hand.</i>
	tFHP					↓				0.5	
Age 5.2	Ability					↓				-0.5	
	Skill						↓			1.5	
Gender f	MC					↓				-0.5	
	BC			☺						-3.0	
Writes right									▷	(i)	
Profile Score		=	=	=	=	=	=	=	▷	-2.0	
Profile Class.		=	=	=	=	=	=	=	▷	VI	

(appendix continues)

Appendix 6E (continued)

Particulars	Handedness Measures	L + 4	L 3	L - 1.5	V l 0.5	V r 0.5	R - 1.5	R 3	R + 4	Total (L=- R=+)	Comments based on Clinical Decision Making
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Case 5	uFHP			↓						-1.5	<i>Birth related stress and mixed hand preference reported. Highly incongruent and inconsistent. Only trained FHP & Skill are right handed, whereby the right performs clearly better than the left, even though still in the subaverage range.</i>
	tFHP						↓			1.5	
Age 7.4	Ability			↓						-1.5	
	Skill							↓		3.0	
Gender m	MC		↓							-3.0	
	BC			☺						-1.5	
Writes:	right									(i)	<i>Seems to be a switched left hander or possibly a pathological right hander. Handedness retraining does not seem to be viable since the non-preferred hand scored in the subaverage range in both Skill and Ability. Therapy should focus on improving fine motor skills, with emphasis on left hand use. Keep writing with right hand.</i>
Profile	Score	=	=	=	=	=	=	=	▷	-3.0	
Profile	Classification	=	=	=	=	=	=	=	▷	VI	

Case 61	uFHP			↓						-1.5	<i>Shows some incongruence typical of a switched hander. Avoids midline crossing and if he does cross, it is with the left hand. Motor based measures are average, however, he is on the upper age limit, and other motor tests for older children need to con-firm these results. Keep writing with the right hand, since there already is a marked advantage but engage the left hand in fine motor tasks.</i>
	tFHP					↓				0.5	
Age 7.11	Ability								☺	4.0	
	Skill							☺		1.5	
Gender m	MC			↓						-1.5	
	BC			☺						-1.5	
Writes:	right									(i)	<i>Shows more untrained tasks with left but There is no incongruence between Ability and Skill, but both are subaverage, especially Skill. Midline crossing is OK as is BC. Appears to be a variable right hander with motor delays. Keep writing with right hand. Both preferred hand and non-preferred are subaverage. Assess other areas of function and incorporate a fine motor programme for therapy.</i>
Profile	Score	=	=	=	=	=	=	=	▷	-1.5	
Profile	Classification	=	=	=	=	=	=	=	▷	Vr	

Case 32	uHP			↓						-1.5	<i>Shows the profile of a variable right hander (increased use of left hand in tasks) with motor delays in Ability and untrained Skill (both hands). Crosses midline adequately, but shows some bimanual coordination problems (reversions, strong left lead). Broke left arm at the age of 2yrs. Therapy should include a general fine motor and graphomotor programme in conjunction with addressing other problem areas.</i>
	tFHP					↓				0.5	
Age 6.3	Ability								↓	4.0	
	Skill						↓			1.5	
Gender m	MC							☺		-1.5	
	BC			☺						-1.5	
Writes:	right									(i)	<i>Shows the profile of a variable right hander (increased use of left hand in tasks) with motor delays in Ability and untrained Skill (both hands). Crosses midline adequately, but shows some bimanual coordination problems (reversions, strong left lead). Broke left arm at the age of 2yrs. Therapy should include a general fine motor and graphomotor programme in conjunction with addressing other problem areas.</i>
Profile	Score	=	=	=	=	=	=	=	▷	-1.5	
Profile	Classification	=	=	=	=	=	=	=	▷	Vr	

Case 36	uHP			↓						-1.5	<i>Shows the profile of a variable right hander (increased use of left hand in tasks) with motor delays in Ability and untrained Skill (both hands). Crosses midline adequately, but shows some bimanual coordination problems (reversions, strong left lead). Broke left arm at the age of 2yrs. Therapy should include a general fine motor and graphomotor programme in conjunction with addressing other problem areas.</i>
	tFHP					↓				0.5	
Age 5.0	Ability						↓			3.0	
	Skill						↓			3.0	
Gender m	MC							☺		3.0	
	BC			↓						-1.5	
Writes:	right									(i)	<i>Shows the profile of a variable right hander (increased use of left hand in tasks) with motor delays in Ability and untrained Skill (both hands). Crosses midline adequately, but shows some bimanual coordination problems (reversions, strong left lead). Broke left arm at the age of 2yrs. Therapy should include a general fine motor and graphomotor programme in conjunction with addressing other problem areas.</i>
Profile	Score	=	=	=	=	=	=	=	▷	5.5	
Profile	Classification	=	=	=	=	=	=	=	▷	Vr	

(appendix continues)

Appendix 6E (continued)

Particulars	Handedness Measures	L + 4	L 3	L - 1.5	V l 0.5	V r 0.5	R - 1.5	R 3	R + 4	Total (L=- R=+)	Comments based on Clinical Decision Making
Case 7	uFHP			↓						-1.5	<i>Left hander with normal variability and mild motor delays. Shows midline crossing avoidance but average bimanual coordination. Was referred for hand writing – embark on a graded graphomotor programme for writing with the left hand. Shows within and across inconsistency but no incongruence.</i>
	tFHP			↓						-1.5	
Age 6.3	Ability		☺							-3.0	
	Skill		↓							-3.0	
Gender m	MC			↓						-1.5	
	BC			☺						-1.5	
Writes left	Profile Score	=	=	=	=	=	=	=	▷	-12.0	
Profile Class.		=	=	=	=	=	=	=	▷	L/L-	
Case 58	uFHP								↓	3.0	<i>Shows two types of incongruence (Ability, MC) and is inconsistent within tasks rather than across tasks. Contralateral reaching was average with left. Uni-manual motor delays may also be due to age-related immaturity. Poor motor performance in both hands. Also shows SI problems in addition to motor delays. A sensory integrative approach appears to be applicable.</i>
	tFHP								↓	3.0	
Age 4.10	Ability				↓					-0.5	
	Skill							↓		3.0	
Gender m	MC		☺							-3.0	
	BC				☺					-0.5	
Writes right	Profile Score	=	=	=	=	=	=	=	▷	(i) 5	
Profile Class.		=	=	=	=	=	=	=	▷	R/R-	
Case 68	uFHP			↓						-1.5	<i>Demonstrates FHP and MC incongruence, and within task inconsistency. Shows poor motor skills and excessively large IHD for Skill favouring the right, where both hands perform poorly. Avoids midline crossing but tends to use left hand. Should write with the right hand during a fine motor programme.</i>
	tFHP								↓	3.0	
Age 5.2	Ability						↓			1.5	
	Skill							↓		4.0	
Gender f	MC			↓						-1.5	
	BC							☺		3.0	
Writes right	Profile Score	=	=	=	=	=	=	=	▷	(i) 8.5	
Profile Class.		=	=	=	=	=	=	=	▷	Vr/R-	
Case 9	uFHP								↓	1.5	<i>Although highly inconsistent, showed no incongruence, with a constant tendency for right hand use. Both hands were poor in the motor tasks, and midline crossing was avoided. Also evidence of general developmental delay and immaturity due to age. Handedness variability appears to be diagnostically related. A sensory integrative/sensory motor programme appears to be suitable.</i>
	tFHP								↓	0.5	
Age 4.5	Ability								↓	1.5	
	Skill								↓	1.5	
Gender f	MC								↓	-0.5	
	BC							☺		1.5	
Writes either	Profile Score	=	=	=	=	=	=	=	▷	7	
Profile Class.		=	=	=	=	=	=	=	▷	Vr/R-	

Note. Negative signs denote left handedness, and (i) indicates that incongruence is present.

☺ = average or above average performance ↓ = subaverage performance (between 10th and 25th percentile)
 ↓ = below the 10th percentile

uFHP = untrained Functional Hand Preference; tFHP = trained Functional Hand Preference; MC = Midline Crossing; BC = Bimanual Coordination, m = male; f = female; Vl = Variable Left Hander; Vr = Variable Right Hander; FM = Fine motor.

Appendix 7A

Summary of Treatment Approaches Related to Types of Variable Handedness

<i>Types of Variable Handedness</i>	<i>Rationale</i>	<i>Treatment Approaches</i>
Left Handed Variability (e.g., Case 7)	The observed variability is normal for many mild to variable left handers, provided there is no excessive incongruence and within task inconsistency.	No treatment required for handedness.
Development-Based Variability (Unestablished Handedness) (e.g., Case 9)	Overall developmental delay (including SI deficits) in younger children might also included delays in handedness establishment.	Sensorimotor, perceptual motor, neuro-developmental, sensory integrative procedures, or bilateral isokinematic training
Motor-Based Variability (e.g., Case 4)	Lack of proficiency in either or both hands influences handedness establishment. Might overlap with developmental delay.	Sensorimotor, perceptual motor, neuro-developmental or sensory integrative procedures. Specific motor training program based on motor learning principles.
Switched Left Handedness (e.g., Case 12)	Needs to be determined if retraining is an option by assessing existing circumstances.	Either fine motor training present writing hand, or handedness retraining. Frequent use of simultaneous bilateral and contralateral movement.
Pathology-Based Variability (e.g., Case 60)	Uses non-dominant hand for writing because dominant hand has inferior motor abilities.	Graded fine motor training program, possibly combined with sensory-motor, perceptual motor, neuro-developmental therapy, sensory integrative procedures or bilateral isokinematic training.
Diagnostic-Based Variability	Handedness is one of several symptoms related to the diagnosis (e.g. autism).	Diagnostic-specific treatment. Training of the emerging preferred hand.
Ambidexterity-Based Variability	Very rare, but when present usually combined with extensive practice of both hands in a conscious quest for ambidexterity (Porac, Rees & Buller, 1990).	No treatment for handedness. Raise awareness that ambidexterity is not desirable (see Section 1.4.8, Chapter 1).
Idiopathic Variability	Handedness profile is obscured from any specific cause / type of variable handedness.	Any of the above combinations or other treatment as need arises.

Note. SI = sensory integration.

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