HANDEDNESS IN CHILDREN

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SUMMARY

Handedness can be defined as the consistent and more proficient use of the preferred hand, compared with the nonpreferred hand, in functional and skilled tasks (Annett, 1985). Established handedness generally is considered to be an important indicator of hemispheric specialization and callosal myelination necessary for development of motoric skills, language, and cognitive processes (Annett, 1998; Bishop, 1990a,b). Conversely, unestablished handedness, associated with developmental delay or even pathologic conditions, sometimes reflects inadequate hemispheric specialization (Corin, 1992; Gazzaniga, 1970). From a functional perspective, the establishment of handedness is critical for successful occupational performance and development of high manual skill levels (Hurlock, 1975; Mandell, Nelson, & Cermak, 1984; 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 because the preferred hand will fail to specialize to the necessary proficiency (Hurlock, 1975). Furthermore, evidence exists that motor and learning problems frequently occur in children who learn to write with the nonpreferred hand as a result of incorrect handedness classification (Ardila et al., 1988; Bishop, 1990a; Peters, 1990; Sattler, 1998, 2001, 2002). Occupational therapists should understand and meet the special needs of left-handed children, particularly in relation to handwriting. In this context, the correct identification of a child’s handedness, its promotion, and the development of manual skill in children with unestablished or left-handedness are necessary and important aspects.
in pediatric occupational therapy (Mandell et al., 1984; Sattler, 2001).

Children with unestablished handedness are frequently referred to pediatric 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 in Germany it was reported that overall 73% of referred children between 4 and 7 years presented with ambiguous hand use (Riedel, Künnemann, & König, 2002).

However, handedness, particularly unestablished handedness, has received little attention within occupational therapy literature to date. Although the 1970s and 1980s resulted in an abundance of handedness literature in the field of neuropsychology, this knowledge was not comprehensively applied to, or incorporated into, the occupational therapy frame of reference. Since this time, research studies of handedness have been much fewer, and particularly unestablished or mixed handedness has received little attention in neuropsychology. 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. Unestablished handedness in the developmental context is considered to be an indicator of neuromaturational delay (Bishop, 1990a), and the degree to which handedness is established may be an indicator of dysfunction or pathology (see Factors Determining and Influencing Handedness). Unestablished handedness may also coexist with other behaviors such as avoidance of midline crossing and poor bimanual motor coordination, which together affect functional hand use (Ayres, 1972; Cermak, Quintero, & Cohen, 1980; Dahl Reeves & Cermak, 2002). In addition, it is possible that one hand might be prevented from gaining sufficient practice to become adequately skilled in drawing and writing tasks. Consequently, unestablished handedness is likely to retard the development of highly integrated manual skill and fine motor coordination that refine occupational performance.

This chapter presents an empirical, theoretical, and developmental knowledge base for the establishment and nature of handedness to provide therapists with a more comprehensive basis for assessing and treating children’s handedness. This knowledge base draws from different approaches and is divided into six sections. First, the definition of handedness is presented, differentiating between hand preference and hand performance, and considerations for evaluating these are reviewed. In addition, the process of classifying handedness and the description of two particular types of handedness conclude the first section. The prevalence of handedness, followed by the assessment of handedness, comprise the second and third sections. Fourth, various factors that determine and influence handedness are presented as critical background information, and fifth, the development of handedness is outlined. In the final part of the chapter, handedness is discussed in relation to pediatric occupational therapy assessment and treatment.

DEFINITION AND CLASSIFICATION
OF HANDEDNESS

The definition of handedness in the literature is inconsistent and ambiguous. For the purpose of this chapter, handedness is first defined in terms of dimensions of handedness, followed by discussion on the classification of handedness into categories, with particular emphasis on consistency as an important classification factor. In this context, left and switched handedness are described in more detail. Figure 9-1 summarizes the aspects discussed in relation to the handedness definition.

DEFINING HANDEDNESS IN TERMS OF
HANDEDNESS DIMENSIONS

In the context of the many handedness definitions in the literature, the term “handedness” refers to a combination of hand preference and hand performance (Annett, 1998) as two dimensions of handedness. Hand preference has been defined as the tendency to perform the majority of tasks with one hand rather than the other (Naçaçi et al., 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; Sattlle, 1998; Steenhuis & Bryden, 1989; Steenhuis et al., 1990). Conversely, 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 inherently more skillful hand also becomes the preferred one, whereas McManus and Bryden (1992) conclude that preference precedes performance. Note that dif-
Handedness in Children

Figure 9-1  Summary of aspects related to the definition of handedness. Handedness can be defined both in terms of dimensions and classification. An important distinction is made between hand preference and hand performance as two dimensions of handedness, each with a trained and untrained aspect. Classifying handedness can be subject to observing the consistency of hand preference during task execution (across and within tasks), but in essence handedness is viewed across a continuous spectrum, ranging from explicitly left handed, to various extents of handedness variability, to explicitly right handed. However, to draw comparisons for differences and similarities between different strengths of handedness, it is useful to divide the continuum into categories: explicit left, mixed, and explicit right. The mixed category can be divided further into variable left and right handers, and unestablished (switched and pathological) handers.
different assessments were used in studies supporting the preceding conclusions, which may be responsible for the contradictory findings. A cause-and-effect relationship between preference and performance is far from clear, as Peters (1996) suggested when he asked

"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 and proficiency distributions displays a variety of results in which some performance and preference tasks yield large differences between the hands (bimodal) and others do not (unimodal) (Annett, 1992; Borod, Caron, & Koff, 1984; Steenhuis, 1996). For example, there is greater discrepancy between the hands in handwriting proficiency than grip strength (Provis & Magliaro, 1989). In addition, factors such as practice or task nature may influence the magnitude of the interhand performance differences (Annett, 1992).

It might be assumed that hand preference and hand performance and 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. Porac and Coren (1981) suggested that preference and performance have a common underlying factor, because their correlation, although 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 et al., 1994; Lake & Bryden, 1976; Tapley & Bryden, 1985), indicating different patterns of preference and performance in the two groups. Furthermore, Peters (1996) found that hand preference correlated more strongly with performance in consistent handers than inconsistent handers (see Classifying Handedness). The discrepancy between preference and performance is also likely to be compounded by incompatible assessments in which hand preference often is assessed subjectively, based on self-report or inventories, whereas 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 multifaceted and multidimensional (Steenhuis, 1996). Numerous authors have attempted to identify the factors determining hand preference and hand performance, but so far no consensus on these factors has been reached.

Hand Preference
Several authors have defined hand preference in terms of types or components. 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 (in which one is inclined to change hands because of fatigue), and bimanual actions in which 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).

Healey, 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 physiologic 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 & Kuppers, 1973; Glickstein & Buchbinder, 1998; Haaxma & Kuppers, 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 lateralized than gross motor tasks involving mainly proximal musculature (Bryden, Bulman-Fleming, & MacDonald, 1996; Peters & Pang, 1992). Other studies only partially supported these findings, suggesting that the musculature used seems to be task dependent (Case-Smith, Fischer, & 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 and Bryden (1989) proposed that the position of an object in space (i.e., ipsilateral or contralateral) influences preferred hand use, an observation already made by Ayres (1972) years earlier. In addition, Steenhuis and Bryden argued that hand preference consists of two dimensions relating to skilled and unskilled tasks. Similarly, Bishop (1990a) postulated that when the two hands are equally skilled for a task, either hand may be selected. As skill level differences increase, so does the extent of preferred hand use.

Hand Performance
As with hand preference, various dimensions of hand performance have been proposed. Some researchers proposed that hand performance consists of two main factors: strength, and a combination of speed and accuracy or dexterity (Borod et al., 1984; Porac &
Coren, 1981). However, several authors found that hand strength correlated only weakly with hand preference (Johnstone, Galin, & Herron, 1979; Provins & Cunliffe, 1972; Satz, Achenbach, & Fennell, 1967). Different hand performance factors identified by other researchers through component analysis (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).

**Considerations for Evaluating Hand Preference and Hand Performance**

The divergent definitions in the literature demonstrate the complex nature of handedness as a multidimensional variable. Furthermore, although 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 interstudy comparability, hand preference frequently has been treated as a unidimensional variable (Porac & Coren, 1981), in which all assessment items are equally weighted and, in combination, reflect a single dimension of preferred hand use.

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). Provins (1997) and McManus (1984) believed that the direction of hand preference has a genetic basis, whereas 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).

Occupational therapists should analyze handedness both in terms of hand preference and hand performance as two of its dimensions, because both are subjected to different levels of training. To provide a comprehensive context for a handedness assessment, the genetic predisposition and environmental factors determining and influencing the direction and degree of handedness also should be considered (see Fig. 9.2 for an illustration of these handedness dimensions).

**CLASSIFYING HANDEDNESS INTO CATEGORIES**

**The Process of Classification**

In general, classification of handedness in the literature appears to entail a nonspecific process that frequently involves the creation of multiple categories, ranging from three to five or more handedness groups, in which “strong” or explicit handers are distinguished from “weak” or moderate handers (Annett, 1985; Peters, 1996; Schachter, 2000). Clearly, the classification method influences the incidence of left, right, and mixed handers (Gudmundsson, 1993; see Bishop, 1990a, for a review). 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 because no natural limits exist for the “mixed” category, and the range for mixed subjects

![Figure 9-2](image-url)
often is 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 were classified as mixed (Annett, 1970b). Another method to classify handedness is by means of a continuum. More specifically, strength or the degree of preferred hand use frequently has been measured as a percentage or continuous variable.

Annett (1998) summarized 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).

In this light, Annett (1970b) derived a subgroup classification to determine whether 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.

**Handedness Classification**

Annett’s work has demonstrated the usefulness of using categories of hand preference based on frequency of use. However, in line with the present definition of handedness consisting of both hand preference and hand performance, handedness categories also can be formulated in a broader sense, based on different types or presentations. Several of these presentations have been selected from various authors to provide a basis for distinction (Box 9-1).

When a child presents with an unambiguous preference for either the right or left hand, and when this hand also demonstrates superior performance over the other hand, he or she has established handedness and is said to be right or left handed (Annett, 1998). Conversely, when a child swaps hands during and across tasks and thus presents with mixed handedness, this is called unestablished handedness (Whittington & Richards, 1987), because children are still in the process of developing. Adults and older children showing a similar presentation are called mixed handers (Bishop, 1990).

When children are inherently left handed but learn to draw and write with the right hand, they are called switched handers (Coren, 1992). The most obvious difference between unestablished and switched handedness is the clear transition from predominantly left-handed use to right hand use because of sociocultural influences, mainly through pressure from parents, grandparents, and teachers.

As discussed in the following, it is thought that hand preference can be altered by neural insult, depending on the locus and extent of lesion as well as timing (Harris & Carlson, 1988; Liederman, 1983; Satz, 1972). If there is evidence of prenatal, perinatal, or postnatal trauma, and one hand is significantly weaker and inferior compared with the other hand but still shows some preference patterns. Ambidextrous individuals show no performance difference between the hands and can draw or write equally well with the left and right hands, although performing in the average or above-average normative range.
because performance is influenced and developed through practice, and to be truly ambidextrous, both hands have to be trained equally.

**Consistency**

The left/right/mixed classification, whether categorical or continuous, has not been the only criterion for grouping a sample population. *Consistency* in hand use is another important means of categorization. Although several studies have investigated handedness consistency in relation to performance domains (e.g., consistency and intelligence; Kee, 1991), the definition of consistency differs among 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 also can be measured across tasks, whereby high consistency reflects exclusive left or right hand performance (Peters, 1990, 1996; 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 show consistency within-tasks by always using the same hand for the same tasks. The across-task inconsistency and within-task consistency correspond with Bishop’s (1990a) mixed handedness described earlier. Figure 9-3 summarizes both types of 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, although inconsistent left handers demonstrated a stronger right hand. Peters proposed that the increased variability in left handers compared with 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” (Peters, p. 118).

Figure 9-3  Summary of definitions for consistency. Within-tasks consistency displays consistent hand use within a single task (e.g., constant use of one hand when executing a task repeatedly, such as throwing a ball). If the same hand is not used during several executions of the same task, within-tasks inconsistency is demonstrated. Across-tasks consistency reflects the same hand use across a range of different tasks, such as writing, throwing, and cutting. Across-tasks inconsistency is displayed by using the left hand for some tasks and the right hand for others, irrespective of within-tasks consistency.
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 unestablished handedness, and therapists assessing handedness should take this into account. Furthermore, therapists particularly should have an understanding of how left and switched handers differ from right handers.

**Description of Left and Switched Handedness**

**Left Handedness**

Left handers have obscured the postulate of handedness as a predictor of cerebral specialization (Bradshaw & Nettleton, 1983; Bryden et al., 1996). Although consistent left handers tend to perform much like right handers (Amazeen et al., 1997; Peters, 1996), 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 heterogeneous behavior as a group (Bryden et al., 1996; Dunaif-Harris, 1984).

Evidence suggests that left handers in general are less strongly lateralized 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 nonpreferred 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 nonpreferred hand tapped the more complex patterns. This lateralization 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 nonpreferred hand (Satz et al., 1967).

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

**Switched Handedness**

The concept of switched left handedness has received attention from several theorists (Collins, 1975, 1985; Olsson & Rett, 1989; Peters, 1990; Porac, Rees, & Buller, 1990; Sakano, 1982; Sattler, 1998, 2001; Steenhuis, 1996). Payne (1987) investigated older individuals and reported the incidence of switched left handers to be 46%, although another study found that 89% of innate left handers in the age group between 65 and 74 years had been switched, compared with 26.6% aged 35 to 44 years (Galobardes, Bernstein, & Morabia, 1999). The authors assigned the elevated percentage of switched handedness to increased sociocultural 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 and co-workers (1986).

Individuals with an innate predisposition for 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; Stute, 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 et al., 1990; Sattler, 1998). Olsson and Rett (1989) suggest that some less strongly lateralized 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 nondominant hand can become the preferred hand for these untrained tasks (Fischl, 1986; Harris, 1990; Richberg, 1987; Sakano, 1982; Sattler, 1998; Stute et al., 1977). However, switched handers are likely to
BOX 9-2 Some Problems Associated with Switched Handedness

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<th>Problems</th>
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<tr>
<td>Decreased academic performance</td>
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<td>Inferior bimanual coordination performance</td>
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<td>Psychological abnormalities: Switching to the non-dominant hand</td>
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<td>might have an unfavorable effect on cortical functioning, and</td>
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<td>functional specialization of the hemispheres may be altered through</td>
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<td>switching handedness, which in turn might interfere with</td>
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<td>interhemispheric communication processes</td>
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<td>Primary problems: Memory deficit (i.e., recalling learned material),</td>
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<td>concentration difficulty (i.e., tiring quickly, poor endurance),</td>
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<td>learning difficulties (i.e., reading, spelling), position in space</td>
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<td>problems (including poor left-right concept), speech deficit</td>
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<tr>
<td>(especially stammering), and fine motor problems (e.g., handwriting)</td>
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<tr>
<td>Secondary problems: Poor self-esteem, insecurity, social withdrawal,</td>
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<td>overcompensation with increased effort, oppositional and provocative</td>
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<tr>
<td>behavior (e.g., playing the clown, temper tantrums), bed wetting and</td>
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<td>nail biting generally coexist with socioemotional difficulties</td>
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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 a few studies have addressed the consequences of switched handedness (Box 9-2). They have found decreased academic performance (Ardila et al., 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 (1998, 2001, 2002) identified primary and secondary problems after switched handedness. Primary problems included memory deficit (i.e., recalling learned 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., handwriting). 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, 2001, 2002). Secondary problems associated with switching were poor self-esteem, insecurity, social withdrawal, overcompensation with increased effort, oppositional and provocative behavior (e.g., playing the clown, temper tantrums), bed wetting and nail biting, or general socioemotional difficulties (Sattler, 1998, 2001, 2002).

Other authors have reported similar psychological problems as Sattler (Friedmann, 1987; Richberg, 1987; Young & Knapp, 1966). These findings appear to indicate that switching to the nondominant hand might have an unfavorable effect on cortical functioning (Sattler, 1998, 2001, 2002). Furthermore, it has been speculated that functional specialization of the hemispheres may be altered through switching handedness, which in turn might interfere with interhemispheric communication processes (Olsson & Rett, 1989; Sattler, 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, 1998, 2001, 2002; Stutte et al., 1977). The nature and extent of switching effects also seem to vary greatly among individuals, whereby some appear to adapt more easily to right handedness with minimal problems, compared with others who experience great difficulties (Friedmann, 1987; Harris, 1990; Sakano, 1982; Sattler, 1998, 2001, 2002). 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 behavior 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 favor pathologic 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 limit the conclusions that can be drawn on this group with variable handedness.

PREVALENCE OF HANDEDNESS

The lack of coherent definitions, standard assessments, and universal classification procedures for handedness (Annett, 1998; Bishop, 1990a) makes accurate estimation of the incidence of left, right, and unestablished
handedness difficult. As has been discussed, findings of demographic studies have considered handedness as a trinomial phenomenon in terms of left, right, and “mixed” (unestablished) handers, whereby the cut-off point for the latter group is quite arbitrary. 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 mixed handedness (Coren & Porac, 1977). Other studies have provided more specific distinctions between different handedness groups. Coren (1992) differentiated between “strong” and “weak” left or 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, in which ambidextrous handers by definition have the same level of skill in either hand, whereas “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 and co-workers (2000).

Furthermore, the prevalence of left handedness has been estimated to be 25% higher in males than females (Heim & Watts, 1976; Seddon & McManus, 1993). This gender difference may result from 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 (Beaton & Mosley, 1984; Bishop, 1989; Bryden, 1977; Salmaso & Longoni, 1985). All in all, there is a general consensus that among more liberal societies, including most westernized and Caucasian-based populations, 10% to 12% of individuals are left handed (Ardila et al., 1989; Connolly & Bishop, 1992; Ellis, Ellis, & Marshall, 1988; Harris, 1990; Nicholls, 1998).

### ASSESSMENT OF HANDEDNESS

This section provides a brief overview of general assessments, as found in the handedness literature, that appear to be useful and relevant to occupational therapists. (Specific occupational therapy assessments related to handedness are discussed further on under Pediatric Occupational Therapy and Handedness, Assessment.)

### Tests for Hand Preference

Hand preference assessments in the neuropsychology domain typically consist of observing preferred hand use across a variety of everyday tasks, some of which are more skilled (e.g., writing and throwing) and some less skilled (e.g., picking up items, opening containers) (Ida et al., 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), whereas 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 et al., 1977). In general, there appears to be no consensus on superior test items for assessing hand preference, but a mixture of both trained and untrained items appears to be the best option.

One of the most frequently used tests is the standardized Edinburgh Handedness Inventory (EHI) (Oldfield, 1971). The EHI consists of 10 items (Table 9-1), which include highly skilled and trained activities such as writing and drawing, as well as less trained or skilled ones, such as opening the lid of a box.

The EHI is a good choice for assessing hand preference for several reasons: It has been used extensively (Annett, 1998; Schachter 2000), including with children (Brito et al., 1992; Ross, Lipper, & Auld, 1996).
1992); has been standardized on several populations (McMeekan & Lishman, 1975; Williams, 1986); and has a high general reliability. These factors make it a superior test to other nonstandardized and less used hand preference tests, such as the Harris Test (1958) and Annett’s hand preference test (1976). However, there is evidence that the EHI is not sensitive to the degree of hand preference; children between 3 and 5 years of age scored high on this test, at an age in which the degree of handedness is still developing (Kraus, 2003). It is possible that most of the EHI items are lateralized early in life, thus displaying very similar distributions for the different age groups. Furthermore, the EHI also failed to detect significant differences between the age groups (Brito et al., 1992; Kraus, 2003).

All considered, it can be concluded that the EHI is a useful tool for assessing hand preference until more sensitive measures have been developed (see Kraus, 2003, Functional Hand Preference Tasks as an example of a more sensitive measure). In the interim, the EHI can be used with some caution in addition to hand performance measures. In particular, it is useful to distinguish between trained and untrained hand preference tasks, and to draw comparisons between the two preference groups.

Tests for Hand Performance

When assessing hand performance, note that superior control of one hand may not necessarily indicate that it is also the preferred hand. For example, if an innately left-handed child learns and practices to use the right hand for drawing and writing, it is possible that a higher performance level in these tasks will be achieved with the right hand, as case studies of such “switched handers” have shown (Coren, 1992; Peters & Murphy, 1992; Sattler, 1998; Stutte et al., 1977). Thus although activities such as tracing and dotting appear to be suitable for assessing forms of trained performance (i.e., hereafter called skill), hand performance should also reflect the more inherent and innate proficiency (hereafter called 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 multifactorial context (Annett, 1985; Barnsley & Rabanovitch, 1970). More specifically, speed and accuracy should be combined to achieve an accurate measure of performance (Fitts, 1954). Thus, to conduct a comprehensive hand performance test, the speed-accuracy combination should be applied in hand performance Skill (i.e., trained) and Ability (i.e., untrained) tasks (Box 9-3).

| BOX 9-3 | Tests for Hand Performance in Skill (i.e., Trained) and Ability (i.e., Untrained) Tasks |
| | **Skill:**
| | Tracing and dotting: Can be performed in the context of the Motor Accuracy Test (MAc; Ayres, 1989) and the Hand Dominance Test (HDT; Steingrüber & Lienert, 1971)
| | **Ability:**
| | Hammering (as a form of hand tapping) and tapping (as a form of finger tapping): See Knickerbocker (1980) for a timed hammering sample and Kraus (2003) for a tapping adaptation.

Skill

Tracing, a proficiency task subject to training, performed with the preferred and nonpreferred hands can demonstrate the extent to which one hand has acquired superior control as reflected in assessment tasks (e.g., Ayres, 1989; Steingruber & Lienert, 1971). Similarly, several studies have employed timed dotting as a skilled task to assess superior hand performance (e.g., Annett, 1992a; Carlier et al., 1993; Steingruber, 1975; Tapley & Bryden, 1985). Although 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 learned task of drawing and writing (Annett, 1992a; Steingruber, 1975; Tapley & Bryden, 1985), and they can thus be considered to be trained and skilled tasks.

Tracing and dotting are two suitable skilled hand performance tasks, and they can be performed in the context of the Motor Accuracy Test (MAc; Ayres, 1989) test and the Hand Dominance Test (HDT; Steingruber & Lienert, 1971). The MAc

"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 MAc requires timed tracing of a butterfly-shaped line on an A3 paper, first with the preferred hand and then with the nonpreferred hand. The standardized version of the HDT for children consists of three parts: (a) a mazelike angled path for tracing; (b) a path of irregularly spaced circles, 0.5 cm in diameter for dotting; and (c) rows of equally spaced adjacent squares, also for dotting. All three tasks have to be attempted at maximum speed and precision for 30 seconds. The distance of the traced path is
measured, and the number of successfully dotted circles and squares is counted.

Both these standardized tests are suitable to assess hand performance skill, but they have their limitations. Kraus (2003) found that although the MAc performance level increased significantly across all age groups, the interhand differences on the test were not found to be significantly different between 3- and 5-year-old normal children. This might partly be a consequence of revisions to the MAc, including adjustments to decrease the difference between the hands (Smith, 1983). Although the MAc appears to be a valid tool for assessing performance levels, the interhand differences lack variability (Kraus, 2003), and thus sensitivity to detect more subtle differences between the hands. This needs to be considered when using the MAc as a hand performance measure. The HDT, on the other hand, has some structural drawbacks: It has angled paths for tracing, which encourages stop-start movements, and the scoring of both the tracing and the dotting task do not take the quality of the child’s response into account (i.e., a dot can also be a line as long as it is placed inside the circle). Once again, these limitations have to be considered until a more comprehensive assessment is available (see, e.g., Kraus, 2003, for the Bear Tracing Task and the Bead Dotting Task).

Ability
Tapping as a motor performance task to assess innate motor ability is used most frequently in research to distinguish manual asymmetry in rapid repetitive upper extremity movements (McManus, Kemp, & Grant, 1986) as an innate and untrained task. Numerous studies have shown that the preferred hand taps faster than the nonpreferred hand (Peters, 1978, 1990; Peters & Durdling, 1979; Watter & Burns, 1995). However, stipulations for tapping differ across studies, with some employing hand tapping controlled from the shoulder girdle (Peters, 1990) and others using finger tapping with stabilization of the wrist (Watter & Burns, 1995). No studies were found that investigated the difference or similarities between these two forms of tapping (i.e., whether and to what extent distally controlled tapping is indeed similar to proximally controlled tapping/hammering). For this reason, it is useful to include both hammering (as a form of hand tapping) and tapping (as a form of finger tapping) as tests to assess Ability hand performance. Knickerbocker (1980) 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). The same principles can be used for tapping, although some adaptation should be made so that the wrist-generated tapping also results in “blows” on carbon paper (see Kraus, 2003, for a tapping adaptation as part of the Ability Test).

FACTORS DETERMINING AND INFLUENCING HANDEDNESS

For a comprehensive understanding of handedness, one should have a knowledge base of factors that may determine, or at least influence, the establishment of handedness. Although empirical evidence concerning the determining factors of handedness remains inconclusive, there is an abundance of information relating to four different contexts: (a) neuroanatomical and neurophysiological foundations, (b) genetic theories, (c) pathological influences, and (d) sociocultural influences. Therapists should draw on this knowledge base when assessing and treating handedness in children.

NEUROANATOMICAL 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, and social competence, as well as handedness establishment (Chiarello, 1980; Ettinger et al., 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; Luria, 1973; Sperry, 1974), whereas the right (“lesser, inferior”) hemisphere provided a general context to function in nonverbal,
emotionally, and visuospatial domains (Hécaen & Sauguet, 1971; Luria, 1973; see Beaton, 1985, for a review).

Currently however, hemispheric “dominance” is viewed as relative rather than absolute, whereby one hemisphere is specialized 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, although 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 cortical lateralization literature for specialized hemispheric function and fundamental differences in information processing (Galin, 1974; Pally, 1998; Tucker, 1981).

Based on this type of neurophysiological and neuroanatomical research investigating hemispheric lateralization and specialization, it has been suggested that the two hands display asymmetric behavior 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 as to whether these asymmetries are present in embryogenesis, and develop into corresponding functional asymmetries in later life, or whether anatomical asymmetries develop later as a result of learned 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, & Byrne, 1986; Cowell et al., 1992). In addition, there is neuroanatomical evidence that the corpus callosum differs with handedness, being approximately 11% larger in left-handed and “ambidextrous” individuals than in well-established right-handed individuals (Aboitiz et al., 1992; Bleier et al., 1986; Witelson, 1985).

Gazzaniga (1970) stressed the importance of interhemispheric communication for the establishment of handedness. It has been proposed that the corpus callosum, one of the last neurologic structures to complete myelination (Farber & Knyazeva, 1991), is instrumental in manual lateralization and specialization. Myelination of the corpus callosum is thought to signal the emergence of hand preference, reflecting hemispheric specialization 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).

Although it may not yet 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 (Weissman & Banich, 2000). These findings suggest that, to an unknown extent, neurophysiologic 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 et al., 1980), handedness could be viewed as one aspect of the neuromotor system interacting with the environment. Therefore it is important to review other possible origins and genetic, circumstantial, and environmental influences of handedness in relation to its establishment.

**Genetic Theories 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 1 in 10 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 et al., 1996; McManus & Bryden, 1992; Porac & Coren, 1981). Other studies have found an even higher ratio between left-handers and their 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 pathologic left handers. 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, toward the right (i.e., right shift). One allele causes right handedness and another allele results in the
independent and random lateralization of manual praxis. Those individuals homozygous for the random factor have a 50% chance of being left or right handed. Two factors influence the handedness outcome and hemispheric specialization for speech: a genetic right shift (RS+) factor, and a random congenital but nongenetic factor that 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, whereas 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 specialization (i.e., right and bilateral cerebral speech representation) 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, because 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 criticized for lack of empiric support for the 50% frequency of both dominant and recessive alleles, and the assumption that hand performance and hand preference covary (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 are right handed, whereas persons with a Chance-Chance (CC) genotype 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 specialization 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.

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 because 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, because monozygotic twins sharing identical genetic make-up do not necessarily present with the same handedness (Oberleke, 1996), and the incidence of handedness discordance is as high as 25% (Carter-Saltzman et al., 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 sociocultural 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 et al., 1996). Furthermore, it has been proposed that the “strength” of handedness is inherited, with some individuals presenting with strong left and right handedness, whereas others show greater variation in their preferred hand use (Bryden, 1982; Coren, 1992; Coren & Porac, 1980).

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 incomplete. 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 that may increase the incidence of left handedness.

**Pathologic Influences on Handedness**

Models linking intrauterine influences and birth stress with handedness appear to be based on the assumption of 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 pathologic (see Harris & Carlson, 1988, for a review on existing theories relating to pathologic left handedness). The Geschwind-Galaburda theory is the most prevalent and controversial intrauterine 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 because of its slower rate of
interpreted the results as evidence against the notion of hemiplegia and familial left handedness. Goodman found a highly significant correlation between hemiplegia in relation to familial handedness. Unexpectedly, dominance by investigating 463 children with hemiplegia (Best, 1988). Goodman (1994) tested the hypothesis that the "dominant" hemisphere, which may not necessarily be 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, as has been noted, significant gender differences were found in some prevalence studies but not others.

More recently, an increased incidence in left handedness was revealed in male individuals who were exposed to ultrasound in utero, which has been considered another factor responsible for shifting inherent right handedness to left handedness (Kieler et al., 1998). However, intrauterine conditions do not appear to be the only early influence on handedness development. Just as abnormal prenatal intrauterine conditions may affect the development of hemispheric specialization, unfavorable perinatal and postnatal circumstances, including birth-related stress, seem to have a similar or 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 (Uvebrandt, 1988). Several reasons for the increased vulnerability of the left hemisphere have been proposed. First, the blood supply to the left hemisphere has less volume (Raichle, 1987). Second, 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 hemorrhage (Schuhmacher et al., 1988). Third, the left hemisphere requires more blood flow for metabolism and burns oxygen more quickly (Bakan, 1977). Fourth, 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 pathologic left handedness (Orsini & Satz, 1986; Rasmussen & Milner, 1977; Soper & Satz, 1984).

Several prenatal, perinatal, and postnatal factors related to the birth process have been associated with an increased incidence of pathologic left handedness. These factors include birth weight (O’Callaghan et al., 1987), prematurity (Ross et al., 1987), difficult delivery and induced birth (Colbourne et al., 1993), the mother’s age (Coren, 1992), and smoking during pregnancy (Bakan, 1991). It has been suggested that these factors might later result in associated disorders such as dyslexia (Eglington & Annett, 1994), attention deficit disorder (ADD) (Gillberg & Rasmussen, 1982), learning disability (Geschwind & Galaburda, 1984), and intellectual disability (Fein et al., 1984). However, some studies have failed to find support for an association between left handedness and pathologic conditions (Bishop, 1990). It has been argued that the proposed elevated incidence of “pathologic” left handedness is based almost exclusively on clinical groups that consist of twice as many left handers as the normal population (Perelle & Ehrman, 1982; Satz, 1972), and there is little evidence of an association between left handedness and pathology in the general population (Annett, 1992; Hardyck & PetrinoVich, 1977; Satz, Soper, & Orsini, 1988).

Considering the evidence for a genetic versus intrauterine or birth-related stress basis for handedness, it is generally accepted that left handedness consists of two subgroups: familial (genetically based) and pathologic (caused by brain damage). Distinguishing between these two subgroups may produce different research outcomes about comparisons between left and right handers (Annett, 1985; Hécaen & Sauguet, 1971;
McKeever, 1981; Orsini & Satz, 1986). To date, there is no agreement on the definition of pathologic left handedness. There are those researchers who suggest that pathologic left handedness appears to develop only with substantial damage to the left hemisphere (Annett, 1985; McManus & Bryden, 1992; Satz et al., 1985), in which case the incidence of pathologic left handedness is relatively low. Conversely, other researchers propose that pathologic left handedness is a result of relatively minor neurologic trauma. In the latter case, at least half of all left handers or even all left handers are thought to demonstrate left handed behavior with a pathologic origin (Coren, 1992). Taking an even more extreme approach in the absence of strong genetic evidence for left handedness, Bakan (1990) considered all left handedness to stem from some form of pathology.

Hopkins and Rönqvist (1998) emphasized that strongly lateralized 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 nonpreferred hand might be suggestive of early brain damage (Bishop, 1984; Gillberg, Waldenström, & Rasmussen, 1984). This may affect the left or right hand. There is indeed evidence for the existence of “pathological right handers” (Kim et al., 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 pathologic right handers has been estimated to be low because of 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 also has been linked to a greater incidence of unestablished handedness (Satz & Fletcher, 1987), appears to be related to poor hemispheric lateralization (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, b). Also, magnetic resonance imaging (MRI) of the corpus callosum did not reveal differences in callosal size between dyslexic and normal children (Larsen, Höien, & Ødegaard, 1992).

In summary, the proposition that unusual prenatal, perinatal, and postnatal conditions influence the cerebral lateralization process of the immature brain is supported by empiric evidence. Although many of the findings remain inconclusive, the impact of early unfavorable conditions on hemispheric specialization 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 sociocultural influences that are likely to cause an increased occurrence of right handedness.

Sociocultural and Environmental Influences

Genetic, intrauterine, and birth-related stress theories have concentrated on predispositions and 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). Although the direction of handedness already may be apparent in infancy and is considered to be stable by 5 years (McManus et al., 1988), the degree and consistency of handedness are 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 et al., 1984). Environmental and cultural influences are likely to have a significant effect on handedness, although there is little empiric 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 sociocultural 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, in which the incidence of left-handed writing is only 0.7% (Teng et al., 1976). However, no evidence was found that forced right-handed writing also resulted in increased right hand use in other activities.

There is empiric 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; Hugdahl et al., 1993; Porac & Coren, 1981; Porac et al., 1986). Stricter sociocultural 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 sociocultural and physical environments coerces left handers to “switch” handedness to the right (Coren, 1992; Sakano, 1982). However, the modification theory has only addressed switching of well-established left handers. It is plausible that individuals with a mild
left-handed predisposition are most vulnerable to right-biased sociocultural pressures. Therefore it is possible that inherently mildly established left handers constitute a proportion of unidentified switched handers within the right-handed population.

CONCLUDING REMARKS

In summary, hand preference can be perceived as a multicausal behavior that is influenced by a variety of mechanisms, including genetic and nongenetic 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 lateralization are 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 that are not yet well understood. In contrast, the development of handedness has been well documented since the 1940s, as reviewed in the following section.

THE DEVELOPMENT OF HANDEDNESS

Occupational therapists should have good understanding of handedness development because this forms an important basis for the intervention phase. Defining a developmental process of a particular behavior in the holistic context of occupational performance most often requires the inclusion of related behaviors. This is also the case with the development of handedness, in which the hands tend to be used initially in the ipsilateral hemispace before contralateral reaching with the preferred hand is observed (Provine & Westerman, 1979; Pryde, Bryden, & Roy, 1999). Furthermore, handedness is expressed both unimanually and bimanually (Hopkins & Rönqvist, 1998). In particular, Fagard (1998) argued that stabilization

“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 it seems appropriate to follow the emergence of handedness in relation to midline crossing and bimanual coordination. The different developmental stages are discussed in the following, first in relation to handedness with reference to the developmental stage of the corpus callosum, then to midline crossing, and finally to bimanual coordination.

BIRTH

At birth, the corpus callosum is underdeveloped and nonfunctional (Gazzaniga, 1970; Hewitt, 1962), developing over the next 10 years at an unprecedented rate compared with its later development. Movement of the upper limbs 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 stabilized 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 & Woollacott, 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 MONTHS

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 (e.g., controlling contralateral motor performance). Hand preference coincides with unilateral swiping of either hand (Gesell & Ames, 1947) and a decrease in the grasp reflex that 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 or mirrorlike and simultaneous, resulting soon in bilateral body and object exploration, and hand interplay in midline (Fagard, 1990, 1998; Fagard & Pezé, 1997).
6 MONTHS
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 the right hand, use becomes apparent (Gesell & Ames, 1947). As the infant’s 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 toward bilaterality (Gesell & Ames, 1947) from simultaneous to successive movement (Castner, 1932). For example, the infant holds an object in 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 MONTHS
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 et al., 1990), but no active contralateral reaching has been recorded at this stage. There is a definite shift toward bilaterality (Gesell & Ames, 1947) from simultaneous to successive movement (Castner, 1932). For example, the infant holds an object in 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).

12 MONTHS
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 without 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) suggested a diminished “midline barrier” at this stage. The hands begin to work together in an increasingly complementary fashion and coordinated asymmetric roles (Goldfield & Michel, 1986), in which one hand is more active, the other more passive. Bimanual hand preference emerges after 9 to 10 months of age, involving temporal and spatial coordination and complementary action. Sequential rather than simultaneous bimanual activity is performed (Fagard, 1998; Fagard & Pezé, 1997).

18 MONTHS
Around this age, the left hemisphere develops more rapidly than the right (Jacobson, 1978). The clear shift toward 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 (Michel, Ovrut, & Harkins, 1985; Ramsey, Campos, & Fenson, 1979), concluding that unimanual hand preference precedes bimanual hand preference. 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. At this stage, the first active contralateral reaching across the body is observed (White et al., 1964), without one hand being occupied or used for support. Children are now able to combine stabilizing the object with one hand and manipulating it with the other in an alternating manner (Gilfoyle et al., 1990), which leads to more mature bimanual coordination (Corbetta & Thelen, 1996; White et al., 1964).

24 MONTHS
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 in which the preferred hand is more active and the nonpreferred hand has a stabilizing and assistive role (Fagard & Marks, 2000). At this stage, most young children show a more definite preference for the right hand (Gesell & Ames, 1947) because the fingers and arms are increasingly dissociated for a large variety of functional skills (Case-Smith, 1995). Stilwell (1987) 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 et al., 1990). Two-year-old children can also perform a sequence of bimanual movements whereby the arm and hand stabilization and movement are controlled simultaneously (Knobloch & Pasamanick, 1974), such as holding a crayon and drawing, or threading beads.
MRI studies have supported age-related increases in cerebral white matter and myelination of the corpus callosum in children and adolescents (DeBellis et al., 2001; Giedd et al., 1999; Thompson et al., 2000). There is evidence that callosal transfer is not optimal until approximately 10 to 12 years (Yakovlev & Lecours, 1967), and that subsequent sensorimotor and cognitive development further increase the callosal interconnections between the hemispheres up to adulthood (Pujol et al., 1993).

By the third and fourth year, the direction of hand preference is evident (McManus et al., 1988) and there is a tendency toward unilateral activity (Gesell & Ames, 1947). This stage appears to be followed by another period of well-differentiated bilaterality between 5 and 7 years of age. Hand preference becomes fully established between 6 and 9 years of age (Gesell & Ames, 1947; Tan, 1985). At the age of 6 years children use the preferred hand consistently to cross the body midline (Stilwell, 1987). However, more complex tactile tasks requiring crossed localization 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). Children are increasingly able to execute complex activities requiring differentiated hand performance, in which 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), but inconsistent coordination patterns are still observed in children between the ages of 6 and 10 years (Haken, Kelso, & Bunz, 1985).

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 infants to use both hands in succession until they 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

“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 among hand preference, midline crossing, and bimanual coordination and appears to be closely linked to the development of the corpus callosum.”

PEDiATriC OCCUPATIONAL tHERAPY AND hANDEDNESS

Assessment

Tests Used in Occupational Therapy

There is a lack of specific test procedures in occupational therapy to assess handedness. 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 the United Kingdom and involves simultaneous drawing with both hands. However, findings from an evaluative study indicate that hand preference could not be confirmed definitely using the Mesker test (Warren & McKinlay, 1993).

Two assessments that include aspects of handedness in children are frequently used in occupational therapy; the Southern California Sensory Integration Tests (SCSIT) (Ayres, 1980) and the Sensory Integration and Praxis Tests (SIPT) battery (Ayres, 1989). Because 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),

there is an advantage of using the SCSIT or SIPT to obtain a more holistic picture of handedness. The two tests combine the assessment of preferred hand use, hand performance, midline crossing, and bilateral motor coordination, in addition to other behaviors related to sensory integrative dysfunction. In the SCSIT and SIPT, midline crossing is closely related to preferred hand use: The therapist observes to what extent the preferred hand is used for contralateral reaching. In addition, hand performance is assessed in both hands by means of a tracing task, with scores

“hand movements that approach and/or cross the centre longitudinal axis of the body (the body midline)” (Stilwell, 1994).
Incorporating both time and accuracy. However, note that although the inclusion of handedness-related information was initially aimed at detecting the extent of hemispheric specialization (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). Although the SCStT and SIPT test batteries still contain and use measures of preferred hand use, motor accuracy for both left and right hands, and a midline crossing measure, the purpose of these measures is to obtain information on laterality establishment in general rather than handedness, because it is considered to be an important component for detecting bilateral integration and sequencing (BIS) deficits.

In both the SCStT and SIPT, preferred hand use (i.e., the measure of hand preference) is obtained by first recording the hand that initially uses the pen to draw. However, it is essential not to assume that a highly trained task such as drawing and writing provides an accurate reflection of hand preference, because these tasks are subject to sociocultural influences (Ida, Mandal, & Bryden, 2000). The inclusion of an additional test with more opportunity to demonstrate hand preference across a range of functional tasks is thus necessary.

It seems evident that the multidimensional nature of handedness requires a careful multifaceted assessment in which hand preference, hand performance, consistency, and interhand differences are recorded. In addition, an assessment of bimanual coordination and midline crossing contribute to a more functional analysis of handedness, although background information on early hand use, familial handedness, and possible prenatal, perinatal, or postnatal trauma could provide some context to the influences of handedness establishment. A test battery addressing all of these facets, the Handedness Profile, has been proposed by Kraus (2003). The test battery includes a Handedness Profile Chart, that summarizes both the extent of interhand differences (ranging from explicit left L+, moderate left L-, variable V, moderate right R-, to explicit right R+ handedness), and performance levels for six handedness aspects (Fig. 9-4). In addition, the Handedness Profile features a Diagnostic Summary that incorporates background information and qualitative information on each of the handedness aspects to assist the final diagnostic classification of the type of presenting handedness.

**INTERVENTION THEORY**

**Unestablished Handedness**

Occupational therapy intervention for unestablished handedness has its roots in perceptual motor theory (Keogh & Sugden, 1985; Kephart, 1971; Lerch, Becker, & Nelson, 1974), 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" (Kephart, 1971, p. 88).

<table>
<thead>
<tr>
<th>Performance Level</th>
<th>Inter-Hand Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below Border Average</td>
<td>L+</td>
</tr>
<tr>
<td>Untrained FHP</td>
<td>•</td>
</tr>
<tr>
<td>Trained FHP</td>
<td>•</td>
</tr>
<tr>
<td>Skill</td>
<td>•</td>
</tr>
<tr>
<td>Ability</td>
<td>•</td>
</tr>
<tr>
<td>Midline Crossing</td>
<td>•</td>
</tr>
<tr>
<td>Bimanual Coordination</td>
<td>•</td>
</tr>
</tbody>
</table>

**Figure 9-4** Example of a handedness profile chart combining performance levels and interhand differences. Note: FHP = Functional Hand Preference, L+ = explicit left handedness, L- = moderate left handedness, V = variable handedness, R- = moderate right handedness, R+ explicit right handedness. This handedness profile is based on an 8-year-old boy with PDD who had left-handed tendencies but was encouraged at home and in therapy to use his right hand. (Kraus, 2004)
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 (Kephart, 1971). Although 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. Indeed, handedness should not be considered synonymous with laterality, because the correlation between handedness and other modalities (foot, eye, and ear) is variable.

Footedness (as assessed through kicking) appears to be most strongly related to handedness, with about 85% of right handers and 80% of left handers using their right and left feet, respectively (McManus, 2002). However, clinical experience has indicated that one-leg standing balance, another task used to assess the preferred leg, does not appear to correlate strongly with kicking, possibly because the nonkicking leg needs to acquire good balance to support the kicking leg (Kraus, 2002, personal observation). Eyedness has been assessed and it was found that about 70% of people demonstrate right eye preference and 30% left eye preference: Although there is a correlation between eyedness and handedness, it is rather weak (McManus, 2002). Finally, earedness correlates even less with handedness, because only about 60% of people listen with the right ear and 40% show left ear preference (McManus, 2002).

The importance of the lateralization of these modalities remains controversial, particularly because there is a lack of empirical evidence that they reflect brain and language specialization more accurately than handedness (Bryden et al., 1996). The concept of “cross-dominance” (i.e., hand-, foot-, eye-, and ear-dominance are not congruent) was introduced by Orton (1925, 1937), who proposed that “cross-dominance,” particularly between hand and eye preference, is associated with dysfunction such as dyslexia, a theory supported by other early perceptual motor theorists (Delacato, 1963; Harris, 1957; Rengsdorf, 1967). However, more recent research has challenged these early theories, because no relationship was found between them and a mixed or “crossed” dominance profile and intelligence or achievements (Sulzbacher et al., 1994). Other existing asymmetries or lateralities in humans, such as arm folding, hand clapping, and leg crossing, have been researched because they are not subject to any learning. Luria (1973) and Sakono (1982) suggested that these lateralities can denote “latent left handedness,” which could explain why some individuals were more likely to recover from aphasia after unilateral left hemisphere brain damage. However, the supplied evidence is rather weak (Bryden et al., 1996), and it has been suggested that these types of lateralities are inherited genetically and not related to brain lateralization (McManus, 2002).

Traditionally, clinicians have considered laterality to be a sensorimotor-based phenomenon that becomes established independently of the child’s knowledge of left and right, and it is thought to be stabilized when the child has acquired the left-right concept (Williams, 1983). This concept of laterality assumes hierarchical functioning of the central nervous system, in which 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 and the establishment of a preferred hand in contralateral space. Since then, sensory integration theory has refined these concepts or expanded on Ayres’ propositions by linking theoretical postulates to clinical practice and sensory integrative therapy using case examples (Dahl Reeves & Cermak, 2002; Kimball, 1999; Koomar & Bundy, 1991, 2002; Murray, 1991; Windsor et al., 2001). More specifically, some authors suggested that the inclusion of trunk rotation is important in developing bilateral integration and crossing of the midline (Kimball, 1999; Koomar & Bundy, 1991, 2002). These authors proposed that employing these behaviors together in therapy might assist in promoting the cerebral specialization 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 pediatric 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 presupposes 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.

A sensorimotor and sensory integrative approach to treatment of a 3- to 4-year-old child with unestablished
handedness seems appropriate, because an overall development of laterality may well assist in establishing handedness. However, older children presenting with unestablished handedness pose the greatest challenge, particularly so if a decision on handedness is eminent because of school entry. Based on the current handedness knowledge discussed so far, assessment results should be analyzed carefully before embarking on clinical decision making. How do we know if a child is inherently left or right handed? Are there other factors to consider before making a final decision? What is the most beneficial treatment for that child? In her doctoral thesis, Kraus (2003) methodically evaluated existing handedness measures, proposed several different reasons why children could present with unestablished handedness (or types of variable handedness), devised a novel assessment battery and suggest treatment guidelines in the context of her Handedness Profile. This process could be one way to deal with these questions, but it extends beyond the scope of this chapter. In the absence of evidence-based practice to substantiate certain treatment approaches, differential handedness assessment methods are crucial.

Switched Handedness
When addressing switched handedness flag a note of caution. Although many of a child’s presenting problems might be related to, or caused by, switched handedness (Fischl, 1986; Friedman, 1987; Harris, 1990; Olson & Rett, 1989; Richberg, 1987; Sattler, 1998; Stutte et al., 1977), “unswitching” might not be favorable in every case because there appear to be certain preconditions for successful handedness retraining. According to Sattler (1998), these preconditions include the following: (a) full support for the retraining process of parents and teachers; (b) a relatively stress-free situation with flexible time constraints on writing, and limited writing volume; (c) sufficient motivation of the child; and (d) a skilled therapist experienced with handedness issues. In addition, based on my own clinical experience as an occupational therapist, average or above-average motor performance level of the left hand, regular occupational therapy sessions, monitoring of progress, and regular follow-up (including close contact with parents and teachers), also are necessary for a successful handedness retraining outcome. Age does not appear to be a major factor for successful retraining because numerous case studies exist of adult switched handers who have successfully retrained their original or dominant handedness (Sattler, 1998). A case study, based on the Handedness Profile (Kraus, 2003), illustrates the clinical decision making process for a child with switched handedness (Box 9-4).

However, a note of caution: Until therapists are more familiar with the dynamics and associated problems of unestablished or variable handedness, they should refrain from retraining handedness, unless they receive professional supervision or have completed special courses in this field.

Left Handedness
In most aspects, there are no differences between treating left and right handed children in therapy, because motor problems are common in both groups and should be treated according to the same principles. However, two intervention areas require specific attention for left handers: writing and those ADL activities that involve utensils designed for right handers.

Writing
The act of writing from the left to the right is conducive to right handers, who engage in a pulling motion across the page whereby the written work is clearly visible. Left handers have to adhere to the same left-to-right direction in writing and thus should apply a pushing motion that is more difficult to control. Furthermore, if left handers employ the mirror image hand position of right handers during writing, the left hand obscures the written work, and if a fountain pen is used, smudges it. The pushing action and visual limitations seem to be the main reasons why many left handers develop compensatory positions that often result in an unfavorable, cramped writing grasp with wrist flexion. Although the pushing action may be more laborious when learning to write, this is no reason to switch a left-handed child to right-handed writing, because there is evidence that left handers are able to develop the same writing speed as right handers (Sattler, 2001). However, if a child learns to use a hooked or clawed writing position through compensation, this is more likely to impede on the speed, legibility, and ergonomics of writing.

In therapy it is thus crucial to establish the correct writing pattern for left handers. The basic principles are the same as in right handers:
- 90°-90°-90° position at hips, knees, and feet, with table height two fingers above the adducted elbow; good upright posture
- The upper arm only abducts slightly when the forearm moves outward to the side, and the elbow does not protrude sideways
- Lateral support of the ulnar side of the hand and wrist extension
- Refined and relaxed tripod grip enabling intrinsic finger movement

The following principles are specific to left-handed writing:
- Paper or exercise book placed slightly toward the left of the body midline with the left top corner slanted between 20° and 40° up to the left
In general, wrist extension can be greater than in right handers; that is, closer to maximum extension (and not closer to neutral, as in right handers). This allows the writing hand to be placed below the written work and thereby ensures good visibility as well as a functional and refined pencil grasp. In practice, wrist extension might be closer to neutral when starting to write from the left side, and may increase as the hand moves toward midline.

Mirror writing or reversals is another interesting aspect often observed with left-handed writing. There seem to be two reasons for this. First, there appears to be a natural tendency for a pulling motion during drawing and writing, which, for left handers, extends from right to left. Second, there is evidence that right handers tend to process visual information in a left-to-right direction, whereas left handers process in the opposite right-to-left direction (Sattler, 1998). These tendencies may result in reversals but do not necessarily presuppose problems, unless the child also has visual perceptual processing problems. It is a matter of practice and habit to adopt the left-to-right visuomotor processing direction, but left-handed children might thus undergo a more extensive phase of reversals and mirror writing.

Activities of Daily Living

Although many activities of daily living (ADL) tasks can be performed by left handers in a mirrorlike fashion to right handers (e.g., brushing teeth, getting dressed, doing buttons, tying laces), there are several ADL tasks that involve utensils with a right-handed bias, or that are performed in a right-hand-biased environment. These include cutting with scissors and one-sided bladed knives, pencil sharpeners, computer mice with clicks for the right index finger, playing the piano (with the more difficult part usually on the right), reading and using measuring jugs, tightening of screws with a screwdriver, and opening lids and taps with external wrist rotation that usually require greater strength. Clearly, there are differences in proficiency levels involved in these tasks, and many left handers quite easily learn to perform low-level skill tasks with their right hand. For higher skill levels, such as cutting with scissors, it is
advisable to provide left-handed scissors. (Incidentally, the so-called two-bladed scissors that are advertised for both left and right handers may have a good cutting action, but vision is obscured for left handers because the scissor blades are assembled for right handers.) However, if a left-handed child has already taught herself or himself to cut with good results with the right hand, and if he or she resists changing to the left, this is usually in order. If a left-handed child experiences difficulties in other ADL tasks, there are several shops for left handers advertised on the internet, in which information on left handers is available and equipment and utensils can be ordered (e.g., info@leftherder-consulting.org, info@sinErgo.com).

**Concluding Remarks**

Considering the complexity of handedness, it seems unlikely that there is one standard treatment approach that could effectively enhance the establishment of handedness, or that a certain combination of approaches is effective in all cases. Although 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. Furthermore, the development of handedness, in relation to the development of midline crossing and bimanual coordination, provides valuable guidelines for therapy.

**Summary**

This chapter has demonstrated that handedness is a variable, complex, interactive, and multidimensional phenomenon subject to hereditary, environmental, and social influences. To understand and assess handedness not only in this context but also in terms of function within occupational performance, those behaviors closely linked to handedness, function, and environment (i.e., bimanual coordination and midline crossing) should be assessed. The development, publication, and standardization of a comprehensive handedness assessment tool that satisfies these criteria is still pending, as is the analysis of the results for clinical decision making. A comprehensive assessment procedure is a crucial research tool for investigating the nature of unestablished, left and right handedness as well as the effectiveness of different treatment approaches. It can be concluded that handedness is a pediatric specialist area in occupational therapy that is in need of much empirical evidence and support.

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