processes language, it may be able to compensate for the left hemisphere damage in this population.

After reviewing selected anatomical data, McGlone (1980) concluded that the right hemisphere is larger in males than females. However, in at least one study, the size of the corpus callosum was larger in females (Holloway & de Lacoste, 1986). This tract is considered to be of major importance in interhemispheric communication. If it is true that the corpus callosum is larger in females (and if one assumes that size is related to efficiency), then bilateral representation of language functions in females may reflect greater interhemispheric communication in females.

In another line of research, right-handed females were shown to be more likely than males to have visuospatial functions lateralized to the left hemisphere and language functions lateralized to the right (Bryden, Hecaen, & DeAgostini, 1983). Therefore, although the left hemisphere is generally viewed as specialized for language-related processes and the right for visuospatial functions, this may be representative of the male brain only, with more variability in lateralization for females.

Handedness and Brain Organization

In addition to gender, differences in hemispheric lateralization are also related to handedness. While the incidence of right-handedness in the population is estimated

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**PRACTICE EFFECTS AND LATERAL
TRANSFER OF TRAINING**

by

Tracey L. Semeniuk, B.Sc.

**A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfillment of
the requirements for the degree of**

**Master of Arts
Department of Psychology**

**Carleton University
Ottawa, Ontario
May 1, 1992**

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TRANSFER OF TRAINING

submitted by Tracey L. Semeniuk, B.Sc.
in partial fulfillment of the requirements for
the degree of Master of Arts

Thesis Supervisor

Chair, Department of Psychology

Carleton University
May 1, 1992

Abstract

Interhemispheric communication was investigated in 120 subjects using the Lateral Transfer of Training method. Subjects performed an inverted-reversed printing task, with either the right or the left hand for 2, 12 or 22 practice trials. Following a short unfilled interval, two test trials were then completed, using either the opposite or the same hand. Opposite hand training favored the right hand when the task was relatively novel (12 practice trials) and the left hand once the task had become well-learned (22 practice trials). No directional effects were observed following 2 practice trials, although some transfer was evident at this level. These findings support the model of hemispheric specialization proposed by Goldberg and Costa (1981), whereby the right hemisphere plays a greater role when a task is novel, while the left hemisphere assumes superiority once a task has become well-learned. This is also compatible with the cross-activation model of interhemispheric communication proposed by Parlow and Kinsbourne (1989). The proficiency model (Parlow and Kinsbourne, 1989) which predicted transfer to favor the left hand at all levels of training was not strongly supported by these findings.

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INTRODUCTION

The phenomenon of transfer for a novel task following opposite hand practice is known as "lateral transfer of training". Parlow and Kinsbourne (1989) investigated the amount of skill transferred from one hand to the other for an inverted-reversed printing task. These researchers proposed that it can be used to investigate interhemispheric communication in the brain and argued that information flow is not symmetrical in the brain. They observed that the left hand benefitted more from opposite hand training in an inverted-reversed printing task than the right hand did. Parlow and Kinsbourne (1989) suggested that the directional effect may be linked to the greater proficiency of the left hemisphere/right hand for a language-based task. They speculated that there is greater transfer from the more proficient to less proficient hemisphere for a skill such as this.

The idea that the amount of practice may be an influential factor in asymmetrical transfer is a provocative one. In Parlow and Kinsbourne's experimental procedure, the amount of practice provided prior to opposite hand performance was held constant for all subjects. However, it is possible that the amount of practice may be an influential factor in determining which hemisphere is dominant for a particular task. According to Goldberg and Costa (1981), the right hemisphere is favored for processing

a novel task, whereas the left hemisphere is favored once that task has become well-learned. Therefore, in this study, I will be examining the effects of varying the number of practice trials on the direction of lateral transfer for the inverted-reversed printing task.

Because both theories assume that lateralization of function plays a critical role in the processing of complex information, I will begin by reviewing the literature on lateralization of cerebral function. Several alternative views to that of Goldberg and Costa (1981) will be considered in this section, and then the Goldberg and Costa (1981) model will be presented in some detail. Finally, the role of individual differences in determining the organization of brain functions will be considered, focusing on the role of handedness and gender.

Following this review I will look at several models that have been proposed to account for interhemispheric communication during cognitive processing. Because the measurement of interhemispheric communication is a highly controversial subject, several techniques will be considered before focusing on the lateral transfer of training method used by Parlow and Kinsbourne (1989, 1990).

A discussion of the inverted-reversed printing task used in the present study, particularly as it relates to existing models of brain lateralization, will follow.

Lateralization of Cerebral Function

The concept of lateralization of function within the cerebral cortex has been the subject of much discussion in the field of neuropsychology. Lateralization of function refers to the way the brain is organized, and specifically, the extent to which certain functions can be ascribed to the left or right hemisphere. The idea of lateralization relies on a "structural model" (cf. Bryden, 1982), whereby different functions are lateralized to different hemispheres because of the underlying structure of the brain. A related concept is that of "cerebral dominance", whereby one hemisphere of the brain directs behavior (Springer & Deutsch, 1985). While a number of dichotomies have been proposed in an attempt to characterize the specialization of the right and left hemispheres for cognitive functions, no single dichotomy has been able to account for all features of hemispheric function and thus adequately characterize the differences between the hemispheres (Hellige, 1983).

Many of the conclusions regarding the lateralization of brain function are based on clinical studies reporting the loss of certain functions following localized brain damage (Springer & Deutsch, 1985). Another source of clinical data is from patients who have undergone commissurotomies for intractable epilepsy. This population provides a unique opportunity to study each hemisphere in isolation. Studies of lateralization of cerebral function in normal subjects

typically involve making inferences based on measures of perceptual laterality; primarily dichotic listening and the visual half-field method. By incorporating these measures of perceptual laterality, the advantage of one perceptual field over another is observed. Inferences regarding cerebral lateralization are then based on the observed perceptual laterality for a given task. Although these behavioral methods are widely employed to study cerebral asymmetries, one criticism of their use is that there are many potential sources of variation in observed laterality, only some of which directly indicate the differing activities of the two cerebral hemispheres (Bryden, 1982).

Visual laterality can be studied using the visual half-field technique. The subject is told to fixate on a point straight ahead and stimuli are briefly flashed in one or both of the visual fields. The presentation time must be very brief (usually 100 msec or less) to reduce the likelihood of the both eyes re-aligning on the stimulus; the goal is to provide input to each hemisphere in isolation.

A tachistoscope is used for this purpose. In a series of studies using the tachistoscopic method of stimuli presentation, Kimura and her colleagues (Kimura, 1961, 1966; Kimura & Durnford, 1974) demonstrated a right visual field (left hemisphere) superiority for identifying verbal stimuli (letters) and a corresponding right hemisphere advantage for visual processes such as dot enumeration, perception of line

orientation and stereoscopic depth perception. Many subsequent studies have used this method to investigate hemispheric asymmetries (see review by Bryden, 1982).

Kimura pioneered the use of the dichotic listening technique to study the asymmetry of function through the auditory modality. This method involves the presentation of auditory stimuli, for instance a series of digits or letters, simultaneously to both ears followed by the subject's recall of the stimuli for each ear. In this way, a right or left ear advantage is determined. Kimura (1961,1967) proposed a "structural model" to explain how this technique works. Auditory information travels along both ipsilateral and contralateral pathways. However, when information is presented simultaneously to both ears, the ipsilateral pathway is suppressed and the contralateral pathway assumes priority. Therefore, when a particular stimulus is presented simultaneously to both ears, the advantage will be reported for the ear contralateral to the hemisphere assumed to be dominant for processing that stimulus.

Using this technique, Kimura found a right ear (left hemisphere) advantage for linguistic material, and a left ear (right hemisphere) advantage for digits, and other non-linguistic stimuli such as musical notes (Kimura, 1964, 1967) and nonverbal sounds (Curry, 1967; King & Kimura, 1972). In other studies incorporating the dichotic

listening paradigm, a left ear/right hemisphere processing advantage has been found for musical notes compared with a right ear/left hemisphere advantage for speech sounds (see review by Corballis, 1983). However, subsequent research has shown that music perception probably involves specialized contributions from both hemispheres (Corballis, 1983). There appears to be a right hemisphere advantage in the perception of melody, pitch, timbre and harmony, but a left hemisphere advantage in the perception of rhythm (Corballis, 1983; Bradshaw & Nettleton, 1983).

Verbal versus Nonverbal Dichotomy

Several early clinical reports (Dax, 1865; Broca, 1861; Wernicke, 1874), described language problems following damage to the left hemisphere. For a long time after this, all language functions were ascribed to the left hemisphere. Based on subsequent clinical studies involving commissurotomy patients and normal subjects using visual half-field presentation of stimuli, a verbal/nonverbal dichotomy emerged, with the left hemisphere viewed as dominant for language processing.

Another dichotomy that evolved out of the original verbal/nonverbal distinction may be termed linguistic /visuospatial. In other words, this dichotomy is more specific in its scope than the alternative. With the left hemisphere considered to be the "dominant" one for many important psychological processes, complementary

specializations were sought for the right "non-dominant" hemisphere. While the left hemisphere has been associated with many linguistic functions, the right is viewed as specialized for visuospatial processes such as the perception of visuospatial relationships (Paterson & Zangwill, 1944), spatial analysis and construction (McFie, Piercy, & Zangwill, 1950; Benton, 1967), and mental rotation (Ratcliff, 1979). A right hemisphere visuospatial processing advantage has been observed in split-brain patients and normal subjects using tachistoscopic techniques to study such tasks as the perception of random shapes (Kimura, 1966) and mirror-image letters (Bradshaw, Bradley, & Patterson, 1976).

Based on their clinical studies with split-brain patients, Gazzaniga and LeDoux (1978) concluded that it is a manipulospacial as opposed to visuospatial advantage that characterizes the right hemisphere. Using the block design test from the WAIS intelligence test (Wechsler, 1955), the left hand (right hemisphere) was found to be superior to the right hand in most of the split-brain patients, when they were asked to construct the perceived spatial relations by manipulating the items appropriately. They suggested that this functional advantage arises in the right hemisphere by default as the corresponding area of the left hemisphere is taken over by language functions, thereby sacrificing space

and efficiency for manipulospatial functions (Gazzaniga & LeDoux, 1978).

Overall, the verbal/nonverbal dichotomy, or some variation of it, has been widely employed as a heuristic for characterizing hemispheric differences. However, the idea that this is the most suitable characterization for hemispheric function has been rejected in an important review by Corballis (1983). Corballis (1983) concluded that the verbal/nonverbal dichotomy fails to account for many important findings in laterality research. Firstly, the notion that linguistic information is processed solely by the left hemisphere has recently come into question with research demonstrating the important role of the right hemisphere in certain language functions. Furthermore, the specialization of the left hemisphere is not restricted to language but also extends to motor skills and nonverbal tasks that involve sequential processing.

Characteristic disruptions of written language following right hemisphere damage include spatial alexia and agraphia as well as writing "disautomatisation" (Ardila, 1984). Spatial alexia refers to an acquired inability to comprehend written language (letters, words, or sentences) as a consequence of brain damage (Hecaen & Albert, 1978). An often associated disorder is spatial agraphia, where written expression is disturbed as a result of impairment in visuospatial perception due to right hemisphere damage. As

a consequence, the line of writing may be poorly positioned, the left side of the page neglected, or additional spaces added between graphemes. The right hemisphere also plays an important role in the prosodic and emotional aspects of speech, in the appreciation of humor, utilization of paralinguistic context, and in the use of imagery-based language and semantic processing (Millar & Whitaker, 1983; Wapner, Hamby, & Gardner, 1981). It does not appear to be involved in phonological and syntactic processing of language (Wapner et al., 1981).

Left Hemisphere Dominance for Motor Control

While the left hemisphere has been considered dominant for language functions since the early work of Wernicke, Broca, and others, it was Leipmann who first proposed the left hemisphere to be dominant for motor functions as well. Leipmann and Maas (1907) noted the inability of one patient who, based on post-mortem data, was found to have a combined left hemisphere and callosal lesion, to perform skilled movements and imitate the use of objects with his left hand. On the basis of their observations, it was concluded that in addition to language functions, the left hemisphere must contain "motor engrams" that controlled purposeful movement for both sides of the body. Because the control of movement programs also involves the positioning of body parts in external space over time, Heilman (1979) proposed that the term "visuokinesthetic motor engrams" be used instead.

Because language and motor impairments frequently co-occur following left hemisphere damage, a third dichotomy was proposed (Goldstein, 1948). He suggested that the basis of left hemisphere functional specialization is symbolization; either verbal symbolization (in language) or nonverbal symbolization (in movement imitation).

Therefore, clinical observations such as those cited above have described patients for whom left hemisphere damage resulted in the loss of purposeful motor control in the left hand. This suggests that the left hemisphere may be responsible not only for contralateral motor control, as in the right hemisphere, but also for ipsilateral (left hand) motor control. Thus, the left hemisphere may be dominant for bilateral motor control. The left hemisphere's role in bilateral motor processes has also been extended by some authors to include the control of fine movements and handedness (Bradshaw & Nettleton, 1983; ; Kimura, 1977; Taylor & Heilman, 1980; Wolff, Hurwitz & Moss, 1977). For example, Bradshaw and Nettleton (1983) suggest that the role of the left hemisphere in the bilateral control of movement is also evident in the fine, manipulative movements of the limbs, hands and fingers. If the left hemisphere is specialized for fine motor control, this may account for right hand superiority in the serial organization of movements (eg., rhythmic tapping, Wolff et. al, 1977). Kimura (1977) has postulated that the superiority of the

left hemisphere/right hand in most people may be due to the left hemisphere's control of changes in limb or articulatory posture. According to Kimura (1977), complex verbal and praxic functions are derived from this more basic left hemisphere function. Furthermore, many authors (eg. Taylor and Heilman, 1980) have argued that left hemisphere dominance for motor skill accounts the fact that the majority of the population is right-handed.

Some authors argue that the left hemisphere superiority in motor skill may actually reflect a more basic superiority in the production and perception of sequences, and in making fine temporal judgements (eg. Corballis, 1983). For instance, left hemispheric superiority for the processing of rapidly presented stop consonants in speech may reflect not the verbal nature of the stimuli, but rather the left hemisphere's ability to process the rapidly changing acoustic information that characterizes speech stimuli. This is a basic requirement that underlies the ability to discriminate two sounds in close temporal order (Mateer, 1983; Schwartz & Tallal, 1980; Tallal, 1976). In comparing the performance of patients with right and left hemispheric lesions, Carmon (1978) has concluded that left hemisphere lesions lead to an increase in the time required to perceive order and sequencing, regardless of spatial complexity. In contrast, right hemisphere lesions are suggested to result

in impaired perception in relation to spatial complexity rather than to the perception of sequences.

The superiority for temporal sequencing is also reflected in a left hemisphere advantage for rhythmic perception and production (Corballis, 1983). It has been suggested that the left hemisphere is important for musical abilities that share properties with speech, such as temporal order, duration, and rhythm (Gates & Bradshaw, 1977). Therefore, the left hemisphere is seen as assuming an important role in sequential processing.

Closely related to this is the serial versus parallel distinction proposed by Cohen (1973). She relates processing time to the number of features that make up a particular visual configuration. The left hemisphere, whose processing time is found to increase as a function of additional items for a set of letter stimuli, is viewed as a serial processor. In contrast, the right hemisphere appears to be less dependent on the number of additional items and is therefore considered to process in parallel.

Analytic versus Holistic Dichotomy

An important alternative to the verbal/nonverbal dichotomy has been proposed that appears to account for many of the observed features of hemispheric specialization. It can be broadly characterized as an analytic/holistic distinction. According to this model, as described by Bradshaw and Nettleton (1983), the left hemisphere is

specialized for perceptual processing whereby visual or auditory stimuli are sequentially broken down into separate components, features, or elements. The right hemisphere, in contrast, is considered to process information in a more "immediate and possibly primitive" manner whereby emphasis is on processing the whole configuration and the pattern of interrelationships between. This processing style has been referred to as "global", "holistic" or "gestalt" by other writers.

This particular model of hemisphere specialization is compatible with the notion of a right hemisphere advantage for visuospatial processing and a left hemisphere superiority for sequential or serial processing. Evidence for the latter distinction is derived from clinical studies with commissurotomed (split-brain) patients. On the basis of a series of studies involving part-to-whole matching with circles, geometric shapes and patterns of dots, Nebes (1978) concluded that the right hemisphere is superior in perceiving the relationship between parts of a stimulus and the overall configuration, and subsequently performing the spatial transformation necessary to generate a whole based on partial, fragmentary sensory information. In this way, Nebes suggests, we form the spatial and cognitive map of our surroundings based on incomplete sensory information, without necessitating a detailed analysis.

Additional evidence for a gestalt style of perception by the right hemisphere as opposed to a detailed style of analysis by the left hemisphere is provided by Zaidel and Sperry (1973). They made observations of clinical subjects on the performance of either hand on a tactile form of the Raven's Progressive Matrices. In this study, the subject was required to select from a set of tactile designs hidden from view, the appropriate piece to complete the visual pattern being viewed. While the right hand (left hemisphere) performance favored a strategy focusing on the design details, left hand performance in their sample was found to be superior and reflected a strategy which focused on spatially related wholes. The analytic/holistic distinction is closely related to the notion of a left hemisphere "analytic" compared with right hemisphere "synthetic" approach to information processing proposed by Levy-Agresti and Sperry (1968).

Focal versus Diffuse Dichotomy

Differences in hemispheric specialization may be related to more fundamental neuroatomical differences in neural organization. Semmes (1968) found that in patients with unilateral brain damage, sensorimotor impairment was associated with focal lesions, usually within the sensorimotor areas, in the left hemisphere; whereas in the right hemisphere similar impairment could be caused by lesions both within and beyond the sensorimotor area,

implying diffuse right hemisphere organization of functions. She concluded that focal representation in the left hemisphere is important for the convergence of information in similar processing units resulting in the finely controlled output necessary for functions such as manual control and speech. Thus, the processing of discrete, unimodal stimuli would favor the left hemisphere. The diffusely organized right hemisphere, in contrast, is viewed as specialized for integrating dissimilar elements, such as the visual, kinesthetic, vestibular information required for coordinated visuospatial functions. Such a specialization would therefore result in multi-modal integration. Thus, the focal versus diffuse distinction could be used to characterize these interhemispheric differences.

Relative versus Absolute Specialization

In the traditional conceptualizations of brain function discussed above, lateralization is considered to be absolute in nature; functions are relegated to one or the other hemisphere, but cannot be shared. Many researchers in this field now view lateralization of brain function instead as reflecting the greater relative contribution by one hemisphere for many tasks. (Bradshaw, 1989; Benton, 1975; Joynt & Goldstein, 1975). That is, one hemisphere may be more important in mediating that function, as opposed to being exclusively responsible for its mediation (Benton, 1975). In fact, an observed lateral asymmetry during the

performance of complex tasks may be viewed as the sum of numerous subprocesses, each independently lateralized (Bradshaw, 1989). Thus, lateralization of different aspects of a given task may contribute to the impression of an overall advantage for one hemisphere over the other.

Theory of Goldberg and Costa

Goldberg and Costa (1981) have proposed a model of hemispheric specialization and cognitive processing which is able to account for interactions between the subject and task in a way that is not possible using other models of specialization. Their model assumes that hemispheric specialization is relative, rather than absolute and that the lateralization of a particular task may vary depending upon the level of acquisition. According to this model, the hemispheres are to be seen instead as "suited for different dimensions and stages of processing" (Goldberg & Costa, 1981, p.170).

Their model assumes also that the right hemisphere is best suited for the integration of novel, multimodal information and the left hemisphere suited for processing well-learned, unimodal stimuli. This view is supported by anatomical evidence from LeMay (1976) and Gur et al. (1980). These researchers have shown that the right hemisphere is larger in volume than the left and contains a higher proportion of axonal white matter relative to grey matter composed of cell bodies. The implication of these findings

is that the right hemisphere, because it contains more myelinated (white) fibers, is structurally more suited for the interregional integration of (dissimilar) information. This leads to more extensive connections both ipsilaterally and interhemispherically (in the latter case, via the corpus callosum). The left hemisphere on the other hand, has a greater capacity, by virtue of the greater proportion of grey matter, to process modality-specific stimuli and to provide intra-regional integration of similar elements.

Goldberg and Costa (1981) have argued that the neuroanatomical differences between the hemispheres leads to the different roles for the two hemispheres in the acquisition and use of cognitive strategies. In their model, effective cognitive strategies are remembered and become incorporated into a "descriptive system". A descriptive system is defined as, "any set of discrete units of encoding or rules of transformation which can be successfully applied to the processing of certain classes of stimuli" (Goldberg & Costa, 1981, p. 151). Because the left hemisphere is viewed as specialized for information that can be processed discretely and readily recognized, it will generate strategies that become part of an established descriptive system. The organization of the left hemisphere may also provide for easy access to a compact cognitive code (descriptive system) that has been previously stored.

One type of descriptive system consists of a new code that develops in an individual during the acquisition of a new task. In cognitive tasks for which a task-relevant descriptive system is not immediately available in the subject's cognitive repertoire, a new system must be "assembled". This is the case for the acquisition of a novel skill such as inverted-reversed printing, or in processing unfamiliar stimuli. Goldberg and Costa (1981) argue that the right hemisphere is better suited for the assembling of a new descriptive system through the application of multiple encoding strategies. Elements of these cognitive strategies are subsequently stored in a compact manner, presumably within the left hemisphere, leading to the formation of a new descriptive system for the particular task. Therefore, the right hemisphere would be expected to be superior at processing information during the early stages of skill acquisition, or when a task is novel. The left hemisphere, in contrast, becomes superior for processing the task in the later stages, once the skills necessary for performance have been acquired and routinized as part of an established cognitive system. Therefore, this model predicts a right-to-left shift of relative hemispheric superiority for a task once it has become well-learned.

One implication of Goldberg and Costa's (1981) model is that a novel task is not recognized as being part of an established descriptive system and will consequently be

processed more efficiently by the right hemisphere. Through extensive practice of this skill, elements of effective strategies become coded and stored in a compact manner, forming a new descriptive system. Following extensive practice, the skill would subsequently become part of a new cognitive system and be processed more efficiently by the left hemisphere than by the right. The difference between a novice and an expert, therefore, is whether a task relevant well-elaborated descriptive system is available for processing the components of a particular task.

In addition to the anatomical studies, support for Goldberg and Costa's theory is found in studies of processing face stimuli (Umiltà, Brizzolara, Tabossi, & Fairweather, 1978), where a right visual field advantage is found for well-known or familiar faces and a left visual field advantage is found for unfamiliar faces. Also, several studies using musical stimuli have found a left ear advantage for inexperienced or non-musicians and a right ear advantage for experienced musicians (Bever & Chiarello, 1974; Gordon, 1978; Johnson, 1977; Wagner & Hannon, 1981). More recently, support for Goldberg and Costa's theory has been demonstrated for such tasks as learning Hebrew words (Yoshizaki & Hatta, 1987) and proficiency in face recognition (Ross-Kossak & Turkewitz, 1984).

Task Characteristics

In addition to the influence of task familiarity on hemispheric processing, there are other characteristics which may play a role in determining the lateralization for a particular task. Support for this idea of relative lateralization comes from evidence that various features of a single task may be processed by separate hemispheres. Observed hemispheric asymmetry may vary in complex tasks depending on subtle aspects of the task (Corballis, 1983). Therefore, maybe certain components of tasks are processed differently and thus separately lateralized. In this way, certain spatial characteristics in the stimuli may lead to right hemisphere processing, even for tasks that appear superficially verbal in nature. For example, Bryden and Allard (1976) found the expected right visual field (left hemisphere) superiority for the identification of letters in normal, presumably familiar, print-like typeface but a right hemisphere superiority for processing letters printed in more unfamiliar script-like typeface. This shift to right hemisphere processing for the latter may be accounted for by considering the right hemisphere superiority for spatially elaborate stimuli.

Bryden and Allard also proposed a right hemisphere superiority for the preprocessing required for the more unfamiliar scripts. They suggested that while the familiar letters have direct access to a pattern recognition system

in the left hemisphere, processing of the more elaborate scripts may first have required that the relevant elements be segregated and that irrelevant visual detail be eliminated prior to identification. This implies that the right hemisphere is specialized for processing unfamiliar stimuli, which involves dealing with divergent information, as suggested by Goldberg and Costa's (1981) theory.

Similar results were obtained by Bradshaw, Bradley, and Patterson (1976) for the detection of normally oriented versus mirror-reversed letters. They found a right hemisphere superiority for identifying the letters that were left-right reversed and a left hemisphere superiority for identifying the letters in a normal orientation. The right hemisphere superiority was attributed to a right-hemisphere-mediated spatial rotation component inherent in this task, which is not necessary when the letters are normally oriented. This is an example of how certain characteristics of a task may reverse the expected laterality when using presumed verbal or non-verbal stimuli.

Another example of right hemisphere involvement in a verbal task is the reading of Japanese script. There are two types of written script in the Japanese language; Kana and Kanji. Kana characters are phonetic symbols corresponding to syllables whereas Kanji are non-phonetic, logographic symbols representing lexical morphemes and are more graphically elaborate. In tachistoscopic recognition

studies with normal subjects, a right visual field (left hemisphere) advantage is found for Kana recognition and a left visual field (right hemisphere) advantage for Kanji recognition (Hatta, 1977; Sasanuma, Itoh, Mori, & Kobayashi, 1977).

In another study by Hellige and Webster (1979), target letters to be identified were masked, creating a complex visual display. Although letter recognition is generally thought to be a verbal, left hemisphere task, the right hemisphere proved to be more efficient at extracting the relevant features of letters when they are "perceptually degraded" in this way. Therefore, observed lateralization may depend on subcomponents or subtle features of the task and not on the nature of the stimuli alone (eg. verbal or spatial).

Strategy Effects

The successful solution of a complex task may be achieved by using a variety of strategies, and the cognitive strategy chosen in approaching a task may determine the observed lateralization of that task. Consequently, it is possible that hemispheric specialization of function for a particular task may depend on the style of processing; that is, on the chosen strategy. Different individuals may use vastly different strategies to approach a similar task and the strategy incorporated is an important determinant of measured laterality (Hellige, 1983). As a result, the

direction of laterality may not depend as much on the nature of the stimuli as on how they are processed or encoded by the subject; thus there may be an interaction between task and subject. For example, face identification may be mediated by either the right or left hemisphere depending upon whether 'holistic' or 'analytic' judgements are required (Sergent & Bindra, 1981). It has been suggested that the degree of verbal mediation used by a subject in solving an apparently spatial task will determine the extent to which performance is dependent upon the left hemisphere (Miller, 1972).

Effects of Attention and Arousal

In additions to the variations in observed lateralization due to factors discussed previously, there are individual and hemisphere-related differences in arousal to be considered. For example, the right hemisphere is thought by some researchers to mediate arousal and sustained attention (eg., Dimond & Beaumont, 1973). However, according to another view (Levy, Heller, Banich, & Burton, 1983), there may be individual differences in hemispheric arousal which influence the extent to which stimuli are processed by one hemisphere or another. For example, although the left hemisphere is generally considered to be dominant for visually presented words, one individual may have increased left hemisphere arousal while another may have increased right hemisphere arousal. It has been argued

by Levy et al. (1983) that left hemisphere activation biases attention toward the right side of space and this would therefore maximize the right visual field advantage, whereas right hemisphere activation would bias attention toward the left visual field and thereby reduce the expected right visual field advantage for processing linguistic material. Thus, differences in hemispheric arousal and attention may explain observed hemispheric asymmetry. Although there may be enduring individual differences in the underlying direction of cerebral asymmetries, differential patterns of activation or arousal also play an important role in perceptual laterality tests. This line of evidence lends further support to the notion that hemispheric asymmetries are relative rather than absolute in nature.

Gender Differences in Brain Organization

Variations in the pattern of brain organization as it relates to lateralization of function have been observed within the normal population. Several studies have compared males and females, and it has been argued that, while males have left hemisphere representation of language, females have bilateral representation of language (McGlone, 1980; Wada, Clarke, & Hamm, 1975). For instance, McGlone (1980) has noted that in clinical cases where left hemisphere brain damage has resulted in aphasia (i.e., impairment of language ability), females have a greater speed of recovery. She suggested that, if the right hemisphere in females also

processes language, it may be able to compensate for the left hemisphere damage in this population.

After reviewing selected anatomical data, McGlone (1980) concluded that the right hemisphere is larger in males than females. However, in at least one study, the size of the corpus callosum was larger in females (Holloway & de Lacoste, 1986). This tract is considered to be of major importance in interhemispheric communication. If it is true that the corpus callosum is larger in females (and if one assumes that size is related to efficiency), then bilateral representation of language functions in females may reflect greater interhemispheric communication in females.

In another line of research, right-handed females were shown to be more likely than males to have visuospatial functions lateralized to the left hemisphere and language functions lateralized to the right (Bryden, Hecaen, & DeAgostini, 1983). Therefore, although the left hemisphere is generally viewed as specialized for language-related processes and the right for visuospatial functions, this may be representative of the male brain only, with more variability in lateralization for females.

Handedness and Brain Organization

In addition to gender, differences in hemispheric lateralization are also related to handedness. While the incidence of right-handedness in the population is estimated

at between 85-95% (Bradshaw & Nettleton, 1983), the actual incidence is difficult to obtain because the criteria and measurement techniques are so varied in this literature. Two commonly employed methods of assessment are: (1) direct observation of a subject when manipulating common objects, (2) assessment by questionnaire (self-report). In addition, overall self-reports of handedness (for example, "are you right- or left-handed?") and self-reported hand used for writing are two other common criteria (eg. Bakan, 1973). In fact, writing hand is considered by some to be the best single predictor of hand preference (Provins & Cunliffe, 1972), although critics of this view cite a poor correlation of writing hand with other indices, and suggest that it does not give an accurate picture of consistent hand use across tasks (Bradshaw & Nettleton, 1983).

One questionnaire that is commonly used to measure hand preference is the Edinburgh Handedness Inventory, developed by Oldfield (1971). It has been cited as the most widely used inventory in the handedness literature (Salmaso & Longoni, 1985). In this questionnaire, the preferred hand for a variety of common activities, such as drawing or throwing, is indicated. The overall index which is calculated across a set of items by dividing the difference of right and left-handed scores (R-L) by their sum (R+L) and multiplying by 100, yields a hand preference score ranging from -100 (very left-handed) to +100 (very right-handed).

It refers to the degree of handedness; an indication of the relative use of one hand over the other. Thus, it provides a continuous, rather than dichotomous, measure of handedness. This is advantageous in that it reflects the observation that handedness is not a discrete variable; rather it is a continuum with all degrees of lateralization being represented in the population (Bryden, 1982).

Although there is no direct link between handedness and brain organization, this issue is of much interest because of findings which relate handedness and language organization. Thus, while it is generally acknowledged that, with few exceptions, both motor control and language processes are functions of left hemisphere (eg. Taylor & Heilman, 1980), it is not clear to what extent language abilities and manual skill are functionally associated within the brain. Taylor and Heilman (1980) cite substantial evidence arguing that the neural basis for handedness is in fact distinct from the neural basis of language processes.

Left hemisphere representation of speech is overwhelmingly represented in the right-handed population; it has been estimated at between 90% (Branch, Rasmussen, & Milner, 1964) and 95.5% (Segalowitz, & Bryden, 1983) based on clinical studies of aphasic patients. Other more conservative estimates claim about 70% of this population display a strong left-hemisphere dominance for language and

handedness (Geschwind & Behan, 1974). Whereas most left-handers believed to be left-hemisphere dominant for speech, as are virtually all right-handers (Branch, Rasmussen, & Milner, 1964), they are more likely than right-handers to have speech function represented in both hemispheres. For example, in comparing the incidence of aphasia for right and left-handers, Satz (1980) has concluded that speech is bilaterally represented in 40% of left-handers.

The increased probability of having representation of language functions in both left and right hemispheres for left-handed subjects has been suggested by Levy (1969) to result in a "crowding" of visuospatial functions in the right hemisphere leading to reduced hemispheric asymmetry with respect to spatial abilities. However, this finding has been found difficult to verify and replicate in subsequent studies (Hardyck, 1977; Hardyck & Petrinovich, 1977).

In summary, traditional conceptualizations of brain function have focused on absolute dichotomies in lateralization, the most common of which has been the verbal/nonverbal distinction, or some variation thereof. Recently, however, other interesting alternatives have been proposed. Goldberg and Costa (1981) present a model of hemispheric specialization that emphasizes task familiarity and practice. They suggested that hemispheric

specialization shifts from the right to the left hemisphere as training in a particular skill increases through practice. In addition to other task characteristics which may influence lateralization, individual differences in strategy-use and hemispheric activation may affect observed laterality. Finally, lateralization of brain functions may be related to differences in both gender and handedness.

Interhemispheric Communication

While research to date has predominantly focused on elucidating hemispheric differences, an often overlooked consideration is that the cerebral hemispheres are highly interconnected via forebrain commissures. This provides for extensive interhemispheric communication and collaboration. The most important commissures for this purpose are the anterior commissure and the corpus callosum. It has also been suggested that subcortical channels mediate the communication of cognitive information between the hemispheres, particularly information which is strongly connotative or contextual in nature (Myers & Sperry, 1985). The primary contribution of the anterior commissure is thought to be in the area of visual processing (Gazzaniga, 1970; Gazzaniga & LeDoux, 1978).

The corpus callosum is the larger tract, and is for this reason thought to be of greater importance in mediating interhemispheric transfer of information. Theorists have

often attributed either a facilitory or inhibitory role to this structure. Facilitory models imply that the activity of the corpus callosum leads to increased "cross-talk" and thus may reduce the impact of hemispheric functional specialization, whereas inhibitory models imply that complementary hemispheric specializations are accentuated by contralateral inhibition of functions. The latter has the advantage of eliminating redundancy of function (see review by Cook, 1986).

Two important models will be introduced here. First, an important example of an inhibitory model is that of Cook (1986), who suggests that the corpus callosum may allow activity in one hemisphere to result in the inhibition of very localized, homotopically organized functional units in the opposite hemisphere. Surrounding the inhibitory region is an excitatory region for a complementary function. These representations, one in each hemisphere, are formed in a topographical and mirror-image manner. For example, in terms of language processes, homotopic regions in the left and right hemisphere may each contain identical linguistic information. However, while the left (language) hemisphere contains a "focus" of explicit, denotative language activity, the homotopic region in the right hemisphere may be suppressed via topographical inhibitory projections. With the linguistic "focus" inhibited in this way, the surrounding regions will be activated. As a result, the

"non-language" hemisphere may become actively involved in processing the paralinguistic, connotative aspects of language. In this way, simultaneous arousal of homotopic sites on the left and right may contribute to an ongoing process of hemispheric complementarity.

The second important model of interhemispheric collaboration has been proposed by Levy (1985). According to this model, the major role of the corpus callosum is in the integration of information between hemispheres through both facilitory and inhibitory channels. The corpus callosum maintains a balance in arousal levels between the hemispheres via facilitory mechanisms, while brainstem structures contribute to this balance via inhibitory mechanisms. As well as maintaining arousal levels, she argues that the corpus callosum also plays an important role in the regulation of attention. Evidence from split-brain patients examined by her and her collaborators convinced Levy that when arousal levels become highly asymmetrical, attentional biases are enhanced for one spatial field and reduced in the other. According to Levy's (1985) model, the development of hemispheric specialization is also thought to be achieved through facilitation and inhibition. That is, one hemisphere elaborates its specialized function, or "primary program" while simultaneously inhibiting the same functions in the opposite hemisphere, considered to be "secondary programs".

The advantage of interhemispheric collaboration is highlighted by evidence which demonstrates a processing advantage for bilaterally as opposed to unilaterally presented stimuli (Dimond & Beaumont, 1972; Guiard & Requin, 1977; Liederman, Merola, & Martinez, 1985; Liederman & Meehan, 1986). One method used to investigate interhemispheric collaboration is the visual half-field technique. For example, when stimuli such as upright versus inverted letters are presented simultaneously to both hemispheres, identification is faster and more accurate than when these two types of stimuli are presented to one hemisphere (i.e., visual field) exclusively. The advantages of such integration of information between hemispheres appear to outweigh the disadvantages of the (brief) delay due to transmission time or signal degradation across the corpus callosum (Bradshaw & Nettleton, 1983).

Although the results of these studies do demonstrate a processing advantage for the bihemispheric presentation of stimuli, it may be dependent on the nature of the task. For example, according to Liederman (1986) and Merola and Liederman (1985), the advantages of bihemispheric presentation are greater when the two stimuli or tasks are similar in processing requirements, as when for example, only inverted letters are presented to the right visual field and only upright letters presented to the left. When however a combination of upright and inverted letters are

presented to each hemisphere, no performance advantage occurs for the bilateral as opposed to unilateral, presentation. Furthermore, while interhemispheric coordination of processing has been found to be more advantageous for complex or demanding tasks, such parallel processing may adversely affect the performance of less complex or demanding tasks (Banich & Belger, 1990).

Measurement of Callosal Function

One problem in this literature is that while there are several theories of interhemispheric communication, there are relatively few good measures of interhemispheric transfer of information. The principal research tools used for investigating interhemispheric communication in normal subjects include: (1) electrophysiological methods (eg., EEG, Evoked Potential), glucose metabolism (scanning) and blood flow (rCBF) techniques and, (2) so-called 'split-field' methods. However, there are limitations and disadvantages to the use of each of these methods which will be outlined below.

Physiological techniques such as EEG or measurement of evoked potentials may be used on normal subjects in order to monitor differences in electrical activity in both cerebral hemispheres simultaneously in a non-invasive manner. The activity in one hemisphere can then be compared to the other. The major criticism of this approach (Cook, 1986) is that while recording may be done at high speeds, resulting

in good temporal resolution, the spatial resolution of the electrical activity can be very limited, making accurate localization of activity within a hemisphere difficult. In contrast, methods involving glucose metabolism or regional cerebral blood flow, which generally involve injecting a radioisotope and observing patterns of either metabolic activity or blood flow within the brain, are limited by poor temporal resolution. That is, the summation of activity may take up to several minutes during which time the psychological processes of the subject have certainly changed.

Methods for investigating interhemispheric collaboration using split-field presentation of modality specific stimuli include: (1) visual half-field (tachistoscopic) presentation of visual stimuli (eg., Liederman, Merola, & Martinez, 1985; Liederman & Meehan, 1986), (2) dichhaptic presentation of tactile stimuli (eg., Jones & Elliot, 1988; Koenig, 1987; Potter & Graves, 1988) and, (3) dichotic listening (Raine et al., 1989). In the tactile domain, for example, subjects may be asked to manually identify or match textures presented to both hands simultaneously. Generally, these studies incorporate some measure of reaction time for stimulus identification, and compare scores for unilateral versus bilateral presentation. Inferences may then be made regarding the degree of

interhemispheric collaboration based on performance on this measure of laterality.

Of these methods, the visual half-field technique is probably the most popular. It has been used extensively in research by Liederman and her colleagues (eg., Liederman, 1986; Liederman & Meehan, 1986; Merola & Liederman, 1985). These researchers presented visual stimuli to one or both visual fields and compared speed of identification (see p. 32 for description of procedure). Observations may then be made regarding the advantage of unilateral (one visual field) versus bilateral (both visual fields) to assess the extent of interhemispheric collaboration for a variety of visual stimuli.

There are also technical problems associated with the visual half-field method (Cook, 1986). Within a few milliseconds after presentation of a stimulus to one visual field, both eyes naturally realign on the stimulus, sending the information to both hemispheres. Thus extremely brief (less than 100 msec) presentation times must be used. Although this rapid presentation produces unilateral stimulation, it places severe limitations on the complexity of stimuli that may be used and presents problems of ecological validity. This is an obvious disadvantage if one's objective is to study higher cognitive processes. More importantly, the perceptual half-field techniques were initially developed as a means of reducing hemispheric

interaction and studying each hemisphere in isolation in order to investigate differences in function, not interhemispheric collaboration. For these reasons, alternative non-invasive methods of measuring interhemispheric collaboration are necessary. Specifically, there is a need for measures which allow for the flow of information between the hemispheres, as opposed to attempting to restrict input to one or the other hemisphere. In addition, such measures should also allow for an assessment of coordinated bimanual performance on a particular task.

Lateral Transfer of Training

Lateral transfer of training is an important alternative for investigating interhemispheric communication in the brain (Parlow & Kinsbourne, 1989). It is based on the idea that practice of one part of the body in performing a particular skill increases the ability of the homologous limb in the same skill (Bray, 1928). For example, training one hand in a particular skill, such as inverted-reversed printing, typically facilitates subsequent performance by the opposite, untrained hand. When the transfer of skill occurs between two bilaterally symmetrical parts (e.g. the hands), it is sometimes referred to as "bilateral transfer of training" or simply "lateral transfer of training". Because it is widely accepted that motor control for one hand is controlled by processes in the contralateral side of

the brain, it is possible to link overt performance and brain mechanisms. Specifically, by examining directional effects of transfer, inferences may be made regarding the nature of interhemispheric collaboration for the particular skill.

In the early studies, the term "cross-education" was used to describe the observed transfer of skilled acts such as fencing (Davis, 1898; Scripture, Smith, & Brown, 1894). More recently, the phenomenon has been studied in the context of transfer of learning. In this context, transfer is defined as the extent to which "experience or performance on one task influences performance on some subsequent task" (Ellis, 1965, p.3). Accordingly, investigations in this area concentrate on the transfer of learning within a wider realm of educational settings.

Many early studies demonstrated that the transfer from one hand to the other occurred for a wide variety of motor skills and complex visuo-motor tasks, of which the most extensively studied were rotary pursuit tracking (Ammons, 1947, 1955; Ammons & Ammons, 1951), mirror-tracing and drawing (Bray, 1928; Cook, 1933; Ewert, 1926), and mirror writing (Freeman, 1938). Although not the primary objective, many of these studies showed directional effects, finding more transfer from one hand to the other than vice versa. For example, Davis (1898) found greater right to left transfer of strength in hands following specific

training. Ewert (1926) also demonstrated transfer in a mirror-drawing skill that was greater from the preferred (right) to the non-preferred hand.

Early Models of Transfer

Early investigators sought to answer the broad question: How does transfer occur from trained to untrained hand? Two contrasting theories were proposed in the time period 1900 to 1910, drawn from the related field of transfer from one situation to another, and are reviewed by Bray (1928). The first, the "theory of identical elements", was proposed by Thorndike and Woodworth (1901). According to this theory, transfer from one part of the body to another occurs when the subject learns the part-activities or elements common to both. The "theory of generalization" (Judd, 1908) emphasizes cognitive rather than behavioral factors influencing transfer. It refers to the generalization of aims, methods, and approaches that are learned during training by one part of the body and applied in performance by other parts. According to Bray (1928), these two theories are complementary, and similar enough in principle to be combined as the "theory of common elements" (Bray, 1928). An interesting alternative to this theory is one originally proposed by Davis (1898). He suggested that transfer may occur through direct (but covert) training of the unpracticed part (i.e., hand) by the spread of neural

impulses during training to the motor centers controlling the unpracticed hand.

Issues in the Design and Measurement of Transfer

Many variations in design have been used in transfer studies. Early studies (see Ewert, 1926) typically used a within-subject LRL or RLR design. The advantage of such a design is that it provides a same-hand comparison group prior to opposite-hand training. However, this design is unsatisfactory because it is difficult to determine whether advantages in performance by the final hand, for example left (L), are due to opposite-hand (R) training or may in fact be due to the initial practice trials using the same hand (L). An alternative between-subject design is to have an experimental group practice with one hand for a number of trials followed by performance with the opposite-hand (eg., LR); whereas another (baseline) group only performs the second set of (opposite-hand) trials (eg., - R). However, this design is also inadequate in that the baseline group has not had the same extent of practice.

A similar problem arises with the use of between-subject design where one group shifts from right to left (RL) and a second group shifts in the opposite direction (LR). While this procedure can be used to demonstrate that previous practice does have an effect (Bray, 1928; Ewert, 1926; Hicks, 1972), it cannot be used to demonstrate directional effects (Bray, 1928). For instance, if a

comparison is made between the two right-hand groups, the group receiving initial right-hand practice (i.e., RL) has not had the same extent of practice as the comparable "post-shift" right hand (i.e., LR). Furthermore, there is the possibility of baseline hand differences in performance and unequal rates of learning between hands. This highlights the necessity to include a same-hand training group for comparison.

Hicks (1974) and more recently, Parlow and Kinsbourne (1989), have utilized a design which incorporates same-hand training control groups for comparison. This is a between-subject design where opposite-hand training is assessed relative to a group receiving an equal amount of practice, but using the same hand. That is, it compares, for example, the left hand after same and after opposite hand training, and does not need to contrast the left and right hands directly to each other. Therefore the design would include the following groups: RL LL and LR RR. This design was chosen for the present project.

The measurement of transfer may be made in several ways (see review by Gagne, Forster, & Crowley, 1948). In fact, the diversity of formulae for measuring the effects of transfer was a major limitation for the systematic advancement of the research in this area because it made comparison of results across different studies difficult. Overall, some comparison of opposite hand training with the

optimum performance of the same hand (i.e., following same hand training) is fundamental to the measurement of transfer. Most recently, using the between-subject design described above, Parlow and Kinsbourne (1989) assessed transfer in the following way. They calculated a percentage gain score for the left hand by taking the difference between left-hand scores following opposite-hand (right) practice and the average score for subjects using the left-hand on trial 1 for the first time in a same-hand training group. This score provides an estimate of the amount of transfer to that hand relative to a baseline level. The difference score obtained above may be further divided by the difference between left-hand scores following same-hand (left) practice and left-hand performance on trial 1 following same-hand (left) practice, and multiplied by 100. The latter measure provides an estimate of transfer gain for opposite-hand training relative to same-hand training (i.e., relative to maximal transfer possible for that hand). Right hand scores were obtained in a similar fashion.

Additional Factors Influencing Transfer

In the transfer of training paradigm, as with other studies of skill acquisition, the possibility of performance plateaus in the learning curve and their implications should be considered. In general, a plateau in acquisition occurs when performance levels off at some point in group or individual data. It has been suggested (Singer, 1980) that

a plateau may occur in the acquisition of complex skills when the learner has reached a transitional point where the integration and consolidation of "first-order" information must occur before further acceleration to the next level. In the context of the present study, the presence of a plateau in skilled performance would be regarded as an important indicator that accuracy has reached an maximal level and has begun to level off, and that the task has thus become well-learned.

Another consideration is how much rest is necessary between trials as well as in the interval that separates practice/test trials. A phenomenon referred to as "reactive inhibition" or "Ir" has been suggested by some researchers (e.g., Archer & Bourne, 1956; Hicks, 1972) to play a role in motor skill performance. This inhibition, which is speculated to involve both central and perceptual systems (Hicks, 1972), may lead to temporary decrements in performance. Thus, the dissipation of this inhibition is thought to be necessary for facilitating test performance. It is thought that reactive inhibition accumulated during continuous practice will dissipate when a rest is provided between trials. For this reason, experimental conditions under which discrete as opposed to continuous training is provided (for example, when printing letters over a series of trials) are optimum for reducing inhibition (Archer & Bourne, 1956; Meier & French, 1965). Archer and Bourne

(1956) investigated the effects of varying the amount of time between trials for a printing task and found that 30 seconds is sufficient. However, the time needed to dissipate this inhibitory phenomenon may also depend on the length of the trials themselves. According to Ammons (1947), the dissipation of inhibitory effects reaches an asymptote after 4-5 minutes. Therefore, in the present study, I elected to use a discrete training procedure with 15 second intervals between each trial and a 2-minute interval separating practice and test trials.

Two additional factors to consider in the investigation of transfer of training are the magnitude and direction of transfer (see Parlow, 1983; Parlow and Kinsbourne, 1990). In general, one can expect that the magnitude of transfer will be greatest when performance by one hand follows task-specific training of that hand (i.e., same hand training). This is referred to as ipsilateral transfer (as compared to contralateral transfer or bilateral transfer), and is the mechanism by which learning normally takes place. In other words, most people practice with the hand they intend to ultimately use. In addition, same hand training is often more effective for the right hand; there is often greater right hand than left hand improvement across trials (Hicks, 1974; Taylor & Heilman, 1980). Directional effects will be considered in a separate section, below. An understanding

of this factor is critical to the development of this thesis.

Directional Effects in Lateral Transfer

Some researchers (Freeman, 1938; Hicks, 1972, 1974; Meier & French, 1965; Taylor & Heilman, 1980) have argued that transfer of training is greater when subjects perform a skill with the right hand following left hand practice than when they use the left hand following right hand practice. Hicks (1974) reported this to be the case for inverted-reversed printing. However, Parlow and Kinsbourne (1989) argue that this is not true; their results demonstrate greater transfer from the right hand to the left in the inverted-reversed printing task. This task is the one used in the present study.

The issue of directional effects is important because the explanations offered by these and other researchers to explain their results are very different. If there is better transfer of training from the left to the right hand, a "direct access" model of interhemispheric communication would explain the finding (Parlow & Kinsbourne, 1989; Taylor & Heilman, 1980). This model is based on the assumption that the left hemisphere is dominant for motor control; that it stores information for motor tasks regardless of the hand used for a particular task. According to this model, training with the left hand leads to the formation of an internal representation of that skill within the left

hemisphere. Subsequent performance by the right hand is facilitated by having direct access, to those skills learned by the left hand and stored in the left (dominant) hemisphere. However, during training with the right hand, the skills which are represented in the left hemisphere are accessible to the left hand only indirectly via the corpus callosum. As a result, the left hand is not facilitated during subsequent performance. According to this model, the timing of transfer of training occurs relatively late, when the subject switches from one hand to the other; that is, after training has been completed and the engram formed in the left hemisphere.

If there is better transfer of training from the right to the left hand, a "proficiency" model of interhemispheric communication would explain the finding (Ammons, 1958; Laszlo, Baguley, & Bairstow, 1970). This has been demonstrated for mirror drawing (Bray, 1928; Ewert, 1926), rotor pursuit (Ammons, 1958) and tapping tasks (Laszlo, Baguley, & Bairstow, 1970). Ammons (1958) attributed this effect to the greater proficiency of the right hand relative to the left hand in these tasks. Because of this, the right hand may be able to learn more elements during practice which can be transferred to the left hand. Alternatively, but still related to the idea of proficiency, Laszlo, Baguley and Bairstow (1970) suggested that this directional effect reflects the ability of the non-preferred (left) hand

to make good use of a superior performance standard formed during training by the preferred (right) hand and specialized (left) hemisphere. Parlow and Kinsbourne's (1989) results were found to be generally compatible with the proficiency model.

However, problems with this model were noted by these researchers. For example, according to a strict interpretation of the proficiency model, intertrial correlations between practice and test trials (trials 10 and 11 in their experimental procedure) were expected to be high in those groups showing high transfer. That is, greater proficiency on trial 10 should be associated with greater proficiency on trial 11. Contrary to expectation however, transfer scores were found to be higher for groups showing poor correlations between the hands on trials 10 and 11. Thus, the findings from this correlational data argued against prior proficiency in the mediation of transfer.

To account for these problems, an alternative explanation for these findings was proposed by Parlow and Kinsbourne (1989) using a "cross-activation" model. They argued that in some circumstances two engrams may be independently formed in the cortex and in others, only one engram is formed. According to this model, training of the hand contralateral to the hemisphere specialized for a particular skill may lead to the formation of dual "engrams" or internal representations by a process they call co-

activation. Thus, in right handed subjects using the right hand, activation of the dominant (left) hemisphere during acquisition of a "left-hemisphere" skill may co-activate the non-dominant hemisphere, increasing the contribution of that hemisphere. During left hand skill acquisition however, a single engram is formed in the right hemisphere without co-activation of the opposite hemisphere. Thus, performance of the right hand following left hand training is not as favorable as in the opposite direction for a left-hemisphere skill.

One important implication of the cross-activation hypothesis is that the direction of transfer should be reversible in a predictable way depending upon task characteristics. That is, when a left hemisphere task is used, transfer should be greatest from right to left. However, for a right hemisphere task (e.g., tactile discrimination of braille stimuli, see Parlow and Kinsbourne, 1990), cross-activation of the left (in this case non-dominant) hemisphere should occur during skill acquisition by the left hand. By the formation of dual engrams through this left hand training, the left hemisphere is 'prepared' for a higher level of performance by the right hand following the switch. In this way, transfer may be greater from left hand to right hand for a right hemisphere task.

A third possible explanation for the asymmetrical transfer effects described above is that a subject's familiarity with the task may affect the direction of transfer in the inverted-reversed printing task. Parlow and Kinsbourne's (1989) results could be interpreted as support for the idea that there is greater transfer from right to left hand when the task is highly practiced one. This would reflect a greater contribution by the left hemisphere in the acquisition of a highly practiced skill. Whether the reverse would be found for a novel task has not been established, but recent work using braille stimuli in a tactile learning task suggests that transfer of this kind of information is better from the left hand to the right hand (Parlow & Kinsbourne, 1990). That is, the braille task used in Parlow and Kinsbourne's (1990) study may be seen as novel, at least for their sighted subjects. Thus, the degree of familiarity the subject has with the task may be a critical factor in determining the direction of greater skill transfer.

Goldberg and Costa (1981) suggest that familiarity may be relevant to the study of skill acquisition (refer to previous section, p.16). The model of hemispheric specialization proposed by Goldberg and Costa (1981) assumed that processing depends not only on the nature of the hemispheres but also on the interaction between subjects and task. Tasks which are novel to the subject are, according

to this model, processed by the right hemisphere; well-learned tasks are processed more efficiently by the left hemisphere. This suggests the distinctive characteristics influencing transfer may not be related to the verbal/nonverbal nature of the task, as implied by Parlow and Kinsbourne (1989,1990), but rather degree of novelty of the material to the subject. It is this explanation of directional transfer effects that is being investigated in the present thesis.

Inverted-Reversed Printing Task

The present experiment was designed to examine the effects of low, intermediate, and high levels of practice on the direction of skill transfer for the inverted-reversed printing task used by Hicks (1974) and Parlow and Kinsbourne (1989). This skill is relatively unfamiliar, in that it involves printing letters in an unfamiliar orientation. In previous studies (for example, Parlow & Kinsbourne, 1989) the inverted-reversed printing task is considered to be a novel one. Although the printing of the alphabet is a well-practiced skill for most subjects (and is expected to be so in all university students), the fact that the letters must be rotated adds an unfamiliar element to a familiar printing skill involving routinized subcomponents. Therefore, the task represents a novel variant of a familiar skill.

The procedure used in the present study is a modification of the procedure used by Parlow and Kinsbourne

(1989). It requires that the subject print a subset of the alphabet in an inverted and reversed orientation. The specific sequence of letters, which do not form a word, were presented on a card in front of the subject. Two dependent measures were obtained: (1) the number of correctly printed letters; (2) the number of incorrectly printed letters (errors). These are the same measures that were used in Parlow and Kinsbourne's (1989) study.

Due to the inherent linguistic factors involved in manually printing a series of letters, this task may be considered to be mediated to some extent by the left hemisphere. This left hemisphere contribution would be enhanced if verbal mediation comprises an important part of the strategy used (Kinsbourne, 1975). However, the linguistic nature of the inverted-reversed printing task is somewhat limited because the chosen letter sequence did not form a word.

Other aspects of the inverted-reversed printing task are visuospatial and probably are mediated by the right hemisphere. The requirement to simultaneously invert and reverse the letters relies heavily on the ability to spatially orient them. The process of mental rotation, which has been attributed to the right hemisphere (Ratcliff, 1979), is required before the letters can be successfully printed in the new orientation. However, using a strategy of mental rotation does not appear to be necessary for the

identification of letters in varying orientations (Corballis, Zbrodoff, Shetzer, & Butler, 1978) so its use in this case is questionable. Therefore, although some aspects of the inverted-reversed printing could be considered as lateralized to one hemisphere or the other, the task overall is not considered to be a highly lateralized one.

Rationale for Experiment

Parlow and Kinsbourne (1989) reported that the transfer of training in an inverted-reversed printing task favors the left hand in right-handed subjects. That is, that subjects who practiced with the right hand and subsequently switched to the left for test trials (RL) performed comparably to those who had received same hand training (LL). In contrast, those subjects who practiced the skill with their left hand and then switched to the right (LR) did not attain the level of performance of the same hand training group (RR). They argued that this is linked to the superiority of the left hemisphere/right hand for the performance of this printing task. They proposed that during training of the right hand, cross-activation of the opposite (right) hemisphere by the (specialized) left hemisphere may have resulted in the formation of dual engrams, one in each hemisphere, and that this facilitated subsequent left hand performance by "preparing" the right hemisphere in this way. Parlow and Kinsbourne's explanation for the observed directional effect relies on the assumption of superiority

of the left hemisphere for mediating motor control and processing verbal material. For a right-hemisphere specialized task, the opposite effect (i.e., co-activation of the left hemisphere during training) would be predicted. Therefore, according to this model, hemispheric specialization is the key to understanding the directional effects.

However, an important alternative interpretation is that the direction of transfer may depend on the degree of novelty represented by a given task; that novel tasks may be processed differently than well-learned tasks. According to this view, the directional effects in transfer are linked, not with the nature of the task itself, but to the novelty of the task. Thus, the Parlow and Kinsbourne (1989) finding can be explained by arguing that this task was not novel (or at least not following the amount of training the subjects received). This thesis will directly contrast the two theories by examining the direction of greater transfer after various amounts of practice.

Hypotheses

The present study was designed to test the following two hypotheses:

Hypothesis One: If the Goldberg and Costa (1981) model is correct, transfer of the inverted-reversed printing task will favor the right hand at low levels of training and the left at high levels.

A shift in the direction of transfer as the task becomes well-learned would support the view that task novelty is the key to directional effects, and support Goldberg and Costa's model of hemispheric function. Their model accords the right hemisphere a critical role in the early stages of acquisition whereas the role of the left hemisphere is viewed as more prominent during later stages when the skill has become well-learned.

This model predicts that subjects completing only two practice trials will show a greater amount of transfer when switching from left hand to right hand than vice versa because the right hemisphere will make a greater contribution to processing the skill when it is a novel one. This is the reverse of the findings of Parlow and Kinsbourne (1989). Conversely, for subjects completing 22 practice trials, transfer will be greatest in the right to left direction due to the greater specialization of the left hemisphere during the training of well-practiced skill. Thus, this group should replicate the findings of Parlow and Kinsbourne (1989).

How the intermediate practice group will fare according to this model depends on whether 12 trials are sufficient practice to make this a "left-hemisphere" task (as 10 trials seemed to be in the original Parlow and Kinsbourne (1989) study) or whether task modifications have made this task less familiar (i.e., "right-hemispheric). If this group

performs as if the task is completely unfamiliar (and thus, "right-hemispheric"), then subjects completing 12 practice trials will be most similar to those completing only 2 practice trials and should show a greater amount of transfer when switching from left hand to right hand than vice versa. Conversely, subjects completing 22 practice trials will show a greater amount of transfer when switching from right hand to left hand, which is compatible with the notion of greater left hemisphere specialization during the training of a well-practiced skill. Thus, in this case, the reversal would occur between 12 and 22 trials of practice.

Alternatively, if those subjects completing 12 practice trials perform the task as if it is a well-learned (and thus, "left-hemispheric"), like those in Parlow and Kinsbourne's (1989) study, then this group would show greater transfer when switching from right hand to left hand. Thus, their performance would be most similar to those subjects who have completed 22 trials of practice. Conversely, those who have completed only 2 practice trials would show greater amount of transfer when switching from the left hand to the right hand, reflecting the greater contribution of the right hemisphere. As a result, the shift in direction of transfer (and hemispheric superiority) in this case would occur between 2 and 12 practice trials.

Hypothesis Two: If the model proposed by Parlow and Kinsbourne (1989) is correct, transfer will favor the left hand at all three levels of training.

Parlow and Kinsbourne's original proficiency model would be supported if the direction of transfer favors the left hand at all three levels of practice. This would imply that greater transfer of training occurs when right hand practice in the inverted-reversed printing task is followed by left hand performance at all levels of skill acquisition. This predicted outcome is the alternative to that of hypothesis one above. Thus, they comprise two possible outcomes based on opponent views.

Those subjects completing 12 practice trials would be comparable to subjects in Parlow and Kinsbourne's (1989) study in which there were 10 practice trials for each group. The demonstration of transfer favoring the left hand in this group would serve to replicate the results of Parlow and Kinsbourne (1989).

EXPERIMENTAL DESIGN AND TASK

In order to test the two hypotheses, the following completely between-subject design was used (see previous section, "Issues in the Design and Measurement of Transfer"). The design calls for 12 groups, 6 experimental and 6 control groups, and is outlined on the following page in Table 1. The first letter refers to the hand used for

Table 1

Experimental and Control Groups for Letter Task

Group No.	Practice Hand	No. of Practice Trials	Test Hand
Experimental Groups (Opposite Hand Training)			
1	R	2	L
2	R	12	L
3	R	22	L
4	L	2	R
5	L	12	R
6	L	22	R
Control Groups (Same Hand Training)			
7	R	2	R
8	R	12	R
9	R	22	R
10	L	2	L
11	L	12	L
12	L	22	L

the practice trials (right or left, R or L) and the second (R or L) refers to the hand used for the test trials. All groups completed two test trials, but the number of practice trials varied, as indicated. Subjects in the control groups (7-12) used the same hand for practice and test trials; those in the experimental groups (1-6) switched to the opposite hand for the test trials. Three levels of practice were investigated: 2, 12, or 22 trials. These will be referred to as Level 1, Level 2, or Level 3 respectively. Only right-handed subjects were included in the sample, to minimize the possibility of handedness effects (see previous section, "Handedness and Brain Organization").

The task practiced by the subjects was inverted-reversed printing. The procedure was based on the one described previously by Parlow and Kinsbourne (1989), with minor modifications. The most important of these was a change in the stimuli used. Specifically, in the previous study (Expt. 2), the six-letter sequence "BJLNRS" was studied (in Expt. 1 the entire alphabet was used). Because the present study involved adult subjects (the previous study used children as well as adults), this sequence was combined with another subset of letters, "DFGPQZ", chosen for their inversion and rotational properties. Therefore, by increasing the length of the sequence and by disturbing the familiar alphabetical sequence, I hoped to increase the memory load required and also to make the sequence more

difficult to automatize (i.e., less familiar). This was important so that any effects could be specifically attributed to increased training on this task and the influence of prior skill or practice minimized.

Transfer of Training to Numbers

In order to examine whether transfer of training was specific to the targeted sequence of letters or involved a more general transfer effect, a second task was incorporated into the design of the experiment. This task consisted of printing a sequence of nine randomly ordered numbers in the inverted-reversed orientation. It was decided to use a single massed trial for the number task instead of the distributed training used for the letter task for simplification of design. The complete design, with both tasks, is outlined in Table 2. The test trials for the number task were performed with the same hand as that used in the practice trials of the letter task (for example, subjects in group RLR used their right hand). The first two 30 s intervals were considered as the test trials for this task, with the final two test trials from the letter task considered as practice trials for the present one.

Table 2

Complete Experimental Design

Group No.	Practice	Practice Trials	Test Hand	Numbers Hand
1	R	2	L	L
2	R	12	L	L
3	R	22	L	L
4	L	2	R	R
5	L	12	R	R
6	L	22	R	R
7	R	2	R	L
8	R	12	R	L
9	R	22	R	L
10	L	2	L	R
11	L	12	L	R
12	L	22	L	R

METHOD

Subjects

A total of 120 right-handed subjects, including 60 females and 60 males were included in the study. They ranged in age from 18 yrs, 3 mos to 44 yrs, 2 mos ($M=22$ yrs 1 mo; $SD=2.2$). Three others were tested but had to be excluded from the sample because they failed to understand the requirements of the task. One subject was not able to print more than one letter in the appropriate orientation after 6 trials despite several demonstrations by the experimenter. The other two did not have a sufficient facility with the written english alphabet to successfully complete the task. All subjects were undergraduate students participating in the experiment to fulfill course requirements for Psychology 100. Subjects were assigned to the experimental and control groups in a quasi-random manner, which ensured an equal number of male and female subjects in each group. Handedness was assessed using the Edinburgh Handedness Inventory (Oldfield, 1970 - Appendix A). Laterality Quotients (L.Q.), based on the inventory ranged from 0.00 (no preference) to 100 (completely right-handed) for this sample. Most subjects in the sample were strongly right-handed according to this measure ($M = 73.25$, $SD = 23.42$).

Materials

Two stimulus cards were made up similarly, one of letters and one of numbers. A sequence of twelve upper-case letters consisting of the letters "BJLNRSDFGPQZ" and nine numbers consisting of the numbers "931726854" ("geotype" brand, Geographics, Inc.) were adhered to white index cards, dimensions 15.2 X 5.5 cm. Subjects were provided with several sheets of white, unruled paper (27.6 X 21.3 cm) and an HB pencil. The trials were timed using an electronic timer (Lafayette Instrument co., model 58010) connected to an auxiliary relay (model 58013) and repeat cycle timer (model 51013) for the letters task, and an Aristo stopwatch (Appollo 12 1/2) for the numbers task.

Procedures

All subjects were tested individually. After completing a consent form and the Edinburgh Handedness Inventory (see Appendix A), subjects were told that they would practice a sequence of letters in inverted-reversed orientation (i.e., upside-down and backwards). The experimenter demonstrated how the letters "ABC" would look in the novel orientation. The subjects were then shown the 12-letter sequence and instructed to begin on the bottom right side of the page, proceeding from right to left and from bottom of the page to the top. Half of the subjects were asked to use their left hand to print the letters, and the others asked to use their right. They were told to

print as many letters as possible while trying not to make mistakes. Each trial was 30 s in duration. The beginning and end of each trial was indicated by a tone from an electronic timer. There was a 15 s rest interval between trials during which the paper was turned 180° to provide the subjects with visual feedback on their performance. They were not allowed to correct or change their output during or between trials. Immediately prior to beginning the next trial, the experimenter folded the paper under so that the previous trials were no longer visible. This was done to prevent direct copying of the letters from one trial to the next. Subjects began each trial printing the letters from the beginning of the sequence (i.e., they always started with the letter B).

Following completion of the specified number of acquisition trials (2, 12, or 22, corresponding to level 1, 2, or 3), there was a two-minute, "unfilled" rest interval, where the subjects did not print or have exposure to the stimulus letters. During this time the experimenter verbally obtained the necessary information (i.e., name, student number, etc.) to complete the experimental credit receipts. Subsequently, two test trials were completed, using the same procedure as for the practice trials. Those in the experimental groups (1-6) used the opposite hand for the test trials (i.e., subjects in RL switched from right to left at this point and subjects in LR switched from left to

right), while those in the control groups (7-12) used the same hand as in the practice trials (i.e., RR or LL).

Numbers. After completing the printing task, the numbers sequence was introduced and subjects were asked to print the numbers on the card in the same fashion, i.e., upside-down and backwards. The procedure was similar to the letter task, but instead of a distributed training schedule, a single two-minute massed trial was used. Small timing marks were made on the page by the experimenter every 15 s. Subjects were informed that this would occur prior to beginning the task, and the change in procedure was not found to be distracting or disruptive. Each subject performed the new task with the same hand as that used in the practice trials of the letter task (for example, subjects in group RLR used their right hand). The first two 30 s intervals were considered as the test trials for this task, with the final two test trials from the letter task considered as practice trials for the present one. Following the completion of the massed trial, the page was rotated by 180° to provide an opportunity for visual feedback on task performance. As before, no corrections were allowed.

Finally, subjects printed the uppercase letters of the alphabet (from A to Z) in the normal orientation. They were told to print them as quickly as possible, using the right

hand. The time required for this task was recorded. This was included as a control for motor speed.

RESULTS

Preliminary Analyses

The design of this study was a 2 (type of training, opposite-hand training vs. same-hand training) x 2 (test hand, left vs. right) x 3 (number of practice trials = 2, 12, or 22, corresponding to levels 1, 2, and 3) between-subject factorial design. Two dependent measures, chosen to facilitate comparison to a previous study (Parlow & Kinsbourne, 1989), were obtained: (1) the total number of letters or numbers correctly formed and, (2) the number of incorrectly formed letters or numbers. A letter or number was considered to be correct if it was printed in the appropriate orientation. Poorly formed letters were scored as correct as long as they were oriented properly and recognizable. Letters or numbers were considered to be incorrect if not printed in the correct orientation or completely unrecognizable. Because the number of incorrectly printed letters was extremely low for level 3 ($M = .84$ letters), the error data were dropped from the analyses of the test data. Thus, the results are reported for only one dependent measure per task, number of correct letters (NCL) and number of correct numbers (NCN).

Letter task. Correlations of several variables with the dependent measure (NCL) were investigated to determine whether their contribution was significant. Neither L.Q. ($r = -.08$, $p < .20$) nor gender ($r = .009$, $p < .50$) were significantly correlated with the first dependent measure (NCL). However, the correlation of printing speed with NCL was significant ($r = -.306$, $p < .0001$). As expected, subjects who printed the regular alphabet sequence (complete, in the conventional orientation) quickly, also printed more letters correctly in the experimental task. Further examination of this variable revealed that it was distributed evenly between groups. Because the corrected means did not contribute to the observed effects, the uncorrected means were used in the analyses reported here.

Test performance, averaged across two trials, was investigated for the number of correctly printed letters (NCL). The cell means and standard deviations are presented in Table 3 and illustrated in Figure 1. As expected, right hand performance was better than left hand performance for this task, and this was observed at all three levels of practice. Also, same hand training was superior to opposite hand training. Visual inspection of the means suggested that the latter finding became more pronounced with increasing practice. In addition, inspection of the means for performance on the first two practice trials shows a considerable increase from practice for the same hand

Table 3

Number of Correctly Printed Letters (NCL) for Test Trials
and Initial Practice Trials

Hand Used:		Right			Left		
		-----			-----		
Type of Training:		Practice	Same	Opp.	Practice	Same	Opp.
Level 1	M	10.10	13.90	13.70	9.40	11.60	11.10
	<u>SD</u>	5.17	6.19	4.16	2.37	2.83	3.32
Level 2	M	10.15	22.30	19.90	8.80	18.08	13.20
	<u>SD</u>	3.57	5.36	4.28	2.92	3.59	4.40
Level 3	M	10.20	26.60	19.40	9.30	19.20	16.40
	<u>SD</u>	3.77	7.26	5.31	3.69	4.85	2.38

Figure 1. Mean number of correctly printed letters on practice and test trials as a function of hand and type of training, at three levels of training.

training groups on the test trials at all three levels. Post-hoc comparisons were conducted to confirm this difference for level one. Two-tailed t-tests showed this difference to be significant for both the right hand, $t(9) = 5.88$, $p < .0001$ and the left hand, $t(9) = 2.92$, $p < .02$. This confirms that learning did occur with practice, even at the lowest level.

Practice Trial Data. In order to determine whether there were baseline hand differences in performance, and whether the inclusion of 2, 12, and 22 practice trials was suitable for differentiating the groups on the basis of practice, the practice trial data were examined. For the purpose of examining the acquisition of the inverted-reversed printing skill at the three levels of practice for each hand separately, learning curves were derived for each group and are presented in Figures 2 and 3. These data illustrate learning curves across practice trials, based on number correct and percent error, for each hand. In this way, the effect of additional same hand practice on performance as well as hand differences can be seen. These curves clearly indicate the expected effect of increased practice on the acquisition of this printing skill. The greatest increase in accuracy (i.e., reduction in number of errors) occurred between trials 2 and 12. Between trials 12 and 22, the average number of errors per trial decreased by less than 5%. However, a minimum was not reached until

Figure 2. Right and left hand acquisition curves for the number of letters correct on practice trials.

Right Hand

70

Left Hand

Figure 3. Right and left hand acquisition curves for the percentage of letters incorrect on practice trials.

trial 22. Thus, although the greatest increase in accuracy occurred between trials 2 and 12, some improvement in skill is also evident between trials 12 and 22. These findings clearly indicate that learning is occurring with this inverted-reversed printing procedure.

Hand differences were apparent during the practice trials. Although the error rate began at a higher level in the right hand, accuracy for this hand rapidly improved and performance by this hand exceeded that of the left hand by trial 6. Following trial 6, performance of the right hand seemed to level off, although there was still gradual improvement. In contrast to the right hand, performance of the left hand showed a relatively low rate of error rate initially. However, accuracy improved more gradually in the left hand and only began to level off after trial 9. In general, more rapid improvement took place in the left hand than in the right hand between trials 2 and 12. Overall, examination of the practice trial data suggests not only that improvement in performance was generally continuous and observable in each hand at all levels of training, but that additional skill improvement did occur after 12 practice trials. This highlights the importance of incorporating 22 practice trials in order to investigate transfer in a well-learned task. Interestingly, a left hand superiority in accuracy was observed over the first five trials, which then

shifted to a right hand superiority. A right hand advantage was observed for NCL throughout.

Planned Comparisons

In order to test the two a priori hypotheses outlined on pages 52-55, the following planned comparisons were performed. One-tailed t-tests were used because the group differences were expected to be in a predictable direction; with same hand training greater than opposite hand training.

Hypothesis one. According to hypothesis one, transfer was expected to favor the right hand at the low level of training, and favor the left hand at the high level of training. This implies that same hand training should be significantly greater than opposite hand training for the left hand, but not for the right hand, at level 1. In contrast, same hand training was should be significantly greater than opposite hand training for the right hand, but not for the left hand, at level 3. This hypothesis was partially supported by the results from level 3. As expected, at level 3, there was a significant difference between same and opposite hand training for the left hand, $t(18) = 2.53$, $p < .01$, whereas there was no significant difference for the right hand, $t(13.09) = 1.64$, $p < .07$. However, results from level 1 showed virtually no difference between same and opposite hand training for either the right hand, $t(18) = .11$, n.s., or the left, $t(18) = .36$, n.s.

Thus, the expected directional effects were not found at level 1; same and opposite hand training were found to be comparable for both hands at this level of training.

Therefore, a modified version of hypothesis one was tested by comparing level 2 and level 3. According to this modified version of hypothesis two, same hand training should be significantly greater than opposite hand training for the left hand at level 2. In contrast, same hand training should be significantly greater than opposite hand training for the right hand, but not for the left hand, at level 3.

This modified hypothesis was supported by the following comparisons. At level 2, there was no significant difference between the type of training groups for the right hand, $t(18) = 1.13$, $p < .20$, whereas the group difference was significant for the left hand, $t(18) = 3.09$, $p < .003$. Thus, for the right hand, opposite hand training and same hand training were comparable, but for the left hand they were not comparable. In other words, the right hand benefitted more from opposite hand training than the left at level 2.

In contrast, at level 3, there was no significant difference between the types of training for the left hand, $t(13.09)^1 = 1.64$, $p < .07$; whereas the comparison was significant for the right hand, $t(18) = 2.53$, $p < .01$.

¹ based on separate estimates of variance.

Thus, for the left hand, opposite hand training and same hand training were comparable, but for the right hand they were not comparable.

Hypothesis two. According to hypothesis two, transfer was expected to favor the left hand at all three levels of training. That is, same hand training should be significantly greater than opposite hand training for the right hand, but not for the left hand, at all three levels of training.

This direction of transfer was confirmed by planned comparisons for the level 3 data. As noted above, there was a significant difference for these subjects between the type of training groups for the right hand, whereas the group difference was not significant for the left hand. Thus, same hand training was significantly greater than opposite hand training for the right hand, but not for the left hand.

However, the directional effect expected according to hypothesis two was not found at levels 1 and 2. As noted previously, at level 1 there was no significant difference between same and opposite hand training for either the right hand, $t(18) = .11$, n.s., or the left, $t(18) = .36$, n.s. That is, no directional effect was apparent. The results from level 2 showed a significant difference between the type of training groups for the left hand, $t(18) = 3.09$, $p < .003$., whereas the group difference was not significant for the right hand, $t(18) = 1.13$, $p < .20$. Thus, same and

opposite hand training were comparable for the right hand, but not for the left. Therefore, transfer was found to favor the right hand, not the left hand at level 2.

Overall, the direction of transfer predicted by hypothesis two was not found at all levels of training, although it was evident at level 3.

Transfer Due to Opposite Hand Training

To permit comparison of transfer in the opposite hand training groups across hands, a second dependent variable was calculated. Using this variable, the effect of opposite hand training relative to same hand training can be directly compared across levels of training. A measure of percentage transfer relative to same hand training after comparable amounts of practice was first established for subjects in the opposite hand training groups. This score was based on their (opposite hand) performance at test divided by the average test trial score for the comparable same hand training groups (RR or LL), expressed as a percentage (i.e., multiplied by 100). One score was calculated for each individual in each of the six groups. In Table 4, the equations used for calculating left and right hand scores, as well as the same hand mean scores used as the denominator in these calculations, are presented; the "X" represents an individual test score. In the first case (group RL), for example, an individual with a test score of 11.60 would receive an overall score of 100%. An individual in the

Table 4

Calculation of Percentage Transfer Scores

Group	Level	Ave. RR or LL Score	% Transfer
RL	(1)	11.60 (for LL)	$Y = \frac{\text{Test Score } (X_{RL})}{11.60} \times 100$
LR	(1)	13.90 (for RR)	$Y = \frac{\text{Test Score } (X_{LR})}{13.90} \times 100$

second group (LR) with a test score of 6.95 would receive an overall score of 50%.

The means for each level of training are graphically illustrated in Figure 4. An ANOVA was performed using Test hand and Level as independent variables. No effects were significant in this analysis. However, the means were very high for both the right (98.2%) and left (95.7%) hands at level 1. This finding is compatible with the preceding analysis which showed no significant difference between opposite hand and same hand training at level 1. Because the data for level 1 might represent ceiling effects which would obscure possible group differences, these data were not investigated further.

Because the initial ANOVA indicated a reversal for levels 2 and 3, the analysis was repeated after dropping level 1. In order to confirm the interaction for levels 2 and 3 suggested by the both the ANOVA and the planned comparisons above, the present data were analyzed using a 2 x 2 (Test Hand x Level) ANOVA.

The results of this analysis revealed an interaction of hand and level, $F(1,36) = 6.57$, $p < .05$. There was greater transfer of training for the right hand (89.01%) than for the left (70.4%) at level 2. In contrast, transfer is greater for the left hand (85.4%) than for the right (72.9%) at level 3. This analysis confirmed the preceding one using planned comparisons, again supporting Hypothesis One.

Figure 4. Percentage of opposite hand transfer as a function of level of training and hand used for test trials.

Intertrial Correlations

In Parlow and Kinsbourne's earlier (1989) study, correlations between the last practice trial and initial test trials were investigated. This was done in order to test the assumption underlying the proficiency model, that greater proficiency on the last practice trial should be associated with greater proficiency on the initial test trial, regardless of the direction of transfer. A high correlation between these trials was found to be associated with poor transfer in their study, whereas a low correlation was found to be associated with good transfer, for the opposite hand training groups.

A similar pattern of correlations for opposite hand training groups was found in the present study for level 3 only. That is, at level 3, a high correlation was observed for group LR, ($r = .88$, $p < .0001$). In the ANOVA reported above, this was the group which showed the lower transfer. In contrast, a low correlation was observed at level 3 in the group RL, ($r = .16$, $p < .40$). This group showed higher transfer in the above analyses. Thus, the pattern of correlations observed for level 3 closely compares with the findings of the previous study.

The correlations calculated for level 2 were high for the group LR, ($r = .74$, $p < .007$), as well as for the group RL, ($r = .81$, $p < .002$). The pattern for group RL was similar to that seen for the same group at level 3. That

is, the high correlation was associated with relatively low transfer only in group RL. However, group LR showed both high transfer and a high correlation at level 2.

At level 1, the intertrial correlations were also found to be high for both LR, ($r = .62$, $p < .05$), and RL groups, ($r = .66$, $p < .05$), and were associated with high transfer scores in both groups. According to Parlow and Kinsbourne (1989), these correlations would be compatible with low transfer scores in these groups.

To summarize, the pattern of correlations found in the study by Parlow and Kinsbourne (1989) were observed in the present study in only three out of the six opposite hand training groups (group RL at levels 2 and 3, and group LR at level 3). The same pattern was not observed at level 1, or for group LR at level 2.

Transfer of Training to Numbers

In order to investigate where there was a general effect of transfer of training from letters to numbers, the massed 2-minute trial was arbitrarily broken into 15 segments. Learning curves for the number task are presented in Figures 5 and 6. In contrast to performance during training trials for the letter task, little improvement was seen across trials in any group. For a comparison with the other task, an analysis was performed to investigate transfer to the number task. The first two 30 sequences were examined and arbitrarily used as the test trials in

Figure 5. Right and left hand acquisition curves for the number of numbers correct on practice trials for the numbers task.

Figure 6. Right and left hand acquisition curves for the percentage of numbers incorrect on practice trials for the numbers task.

this analysis. The means and standard deviations for the test trial data, averaged across two trials, are outlined in Table 5 and illustrated in Figure 7.

The test trial (NCN) data were entered into an ANOVA based on a 2 (type of training, opposite-hand training vs. same-hand training) $\times$ 2 (test hand, left vs. right) $\times$ 3 (number of practice trials = 2, 12, or 22, corresponding to levels 1, 2, and 3) design. A main effect was observed for hand, $F(1,108) = 6.59$, $p < .05$, with right hand performance superior to that of the left. There was no effect of previous training level (i.e., level 1 = 2 = 3), suggesting no group differences for this factor. That is, there was no effect of the number of letter training trials on the number task. There were no interactions.

In comparing the results of this analysis to the prior one, there are some important problems which became apparent. Firstly, the number correct for the numbers (NCN) was much lower than the mean number of letters printed correctly overall (NCL). In the right hand, the mean NCN was 8.49 ($SD = 4.75$) compared with 19.27 ($SD = 6.99$) for the letter task. Similarly, in the left hand, the mean NCN was 6.58 ($SD = 2.96$) in contrast to the mean NCL of 15.03 ($SD = 4.79$). This illustrates the poor performance on the number task compared with the letter task, and suggests that the two tasks may not have been of equal difficulty.

Table 5

Number of Correctly Printed Numbers (NCN) for Test Trials

Hand Used:		Right			Left		
		-----			-----		
Type of Training:		Practice	Same	Opp.	Practice	Same	Opp.
Level 1	<u>M</u>	13.90	7.95	8.20	11.60	6.45	5.45
	<u>SD</u>	1.96	5.16	4.28	0.89	2.99	2.54
Level 2	<u>M</u>	22.30	8.00	8.60	18.75	6.90	5.95
	<u>SD</u>	1.70	2.16	2.81	1.14	2.70	2.71
Level 3	<u>M</u>	26.55	8.90	9.30	19.15	7.50	7.20
	<u>SD</u>	2.30	5.37	7.75	6.35	2.49	4.24

Figure 7. Mean number of correctly printed numbers on practice and test trials as a function of hand and type of training, at three levels of training.

Also notable was the high error rate observed in the number task. Compared to a mean percent error of 13% in the test trials of the letter task measured across the two test trials for level 1, the mean percent error in test performance for the number task was 37%. This suggests that subjects may have found the number task more difficult. Thus, in contrast to the letter task where an increase was observed from practice trials to test trials at all three levels, there was in fact a decrement in performance from practice to test in the number task.

DISCUSSION

Two hypotheses were investigated in this study. The first, based on the Goldberg and Costa model of hemispheric specialization, predicted that transfer would be greatest from left hand to right hand at low levels of training, and from right hand to left hand at high level. The second and competing hypothesis was based on Parlow and Kinsbourne's (1989) study, and predicted transfer to be greatest from right hand to left hand at all levels of training.

The results of the present study generally supported hypothesis one. The results of the planned comparisons suggested a reversal which shows greater transfer of training from left hand to right hand at level 2 (12 practice trials) and the left hand at level 3 (22 practice trials). At level 1 (2 practice trials) no directional

effect was observed, although there was same hand transfer at this level, and opposite hand training was found to be comparable to same hand training. Thus, although no directional effect was evident at level 1, the directional effect at levels 2 and 3 did emerge as predicted for lower versus higher amounts of training. The reversal was confirmed when an ANOVA was performed on the percentage transfer scores representing opposite hand performance relative to same hand performance. This confirmed an interaction between level 2 and 3 in the direction predicted by hypothesis one. In addition, ceiling effects showing no clear directional effects were observed at level 1. The alternative hypothesis, that transfer of training should favor the left hand at all three levels of training, was not supported.

Thus the present results supported the shift in direction of transfer predicted by the Goldberg and Costa model. According to this model, when a task is novel (or, as in the present study, with little chance to practice), it is more likely to be processed by the right hemisphere. Through extensive practice of this skill, elements of effective strategies become encoded as part of an established descriptive system. Once the skill has become well-learned through extensive practice it becomes more efficiently processed by the left hemisphere.

Such a shift in hemispheric processing is compatible with the reversal in direction of transfer for the inverted-reversed printing skill following low versus high levels of practice. The results for level 2 (low level) indicate greater transfer from the left to right hand for the unpracticed, novel skill whereas those for level 3 (high level) indicate the opposite effect for the well-practiced, familiar skill.

Comparisons to Previous Study

In the present study, the group with 12 practice trials (level 2) was intended to provide a basis for comparison with Parlow and Kinsbourne's (1989) study, where 10 practice trials were completed by all participants. Thus, a comparable directional effect was anticipated for this training group. However, the results for level 2 suggested that transfer of training favored the right hand, not the left hand as originally demonstrated by Parlow and Kinsbourne (1989). Therefore, these findings (at level 2) failed to replicate the directional effect for transfer found by Parlow and Kinsbourne, and in fact, demonstrated the opposite effect.

One reason for this discrepancy may be that the tasks were not comparable in difficulty. In the previous study, the subjects were required to print all letters of the alphabet consecutively, whereas in the present study they were required to print a subset of letters, specifically

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chosen for their inversion and rotational properties, presented out of sequence and on a stimulus card. In other words, the rote or over-learning of a familiar motor sequence is more disrupted in the present study. Also, the present task may have been more demanding due to the need to continually refer to the stimulus card or to remember the set, in addition to the printing of a non-alphabetic sequence. In addition, there were no "simple" letters, such as H or I, which are the same in the novel orientation as in the standard orientation, included in the set used in this study. As a result, the present task may have been more novel, or less easily routinized, than the one used by Parlow and Kinsbourne.

Support for the idea that the skill in this study was more difficult to routinize is demonstrated by the results of level 1, where no directional transfer effects were observed. Whereas ten trials may have been sufficient to provide routinization of learning for the alphabetic sequence in the previous study, the current results indicate that the printing skill is still processed as a novel one following 12 trials of practice. It is only after 22 trials of practice that training is sufficient to produce routinization of the skill, as evidenced by the high level of accuracy at this stage in skill acquisition. Once again, this highlights the possibility that the present task was

more difficult to learn than the variant previously incorporated.

A strict interpretation of Goldberg and Costa's (1981) model, would lead to the prediction that level 1 should have shown the direction of transfer observed instead at level 2. At level 1, the considerable improvement from practice to test trial performance indicates that some learning of this task did occur in the same hand groups. As well, one may argue that there was indeed transfer to the opposite hand at this level, due to the fact that opposite hand training was equivalent to same hand training. Unexpectedly however, transfer at this level showed no directional effects. One may speculate that transfer at this level consisted only of general factors such as would be involved in learning a strategy for inverting and rotating the symbols and committing this information to memory. Thus, directional factors (and hemispheric differences) may not play a role in general transfer. It may not be until later in the acquisition sequence (i.e., learning curve) that type of training differences emerge in test performance and only then, with the transfer of more specific information, are directional effects observed. Alternatively, the amount of practice at level 1 may have been too short for the specific components of skill acquisition to be retained over the subsequent two-minute interval. This would lead to a situation in which consolidation of the task components

required to elicit hand and training effects is not effective. If so, it would be of empirical interest to address the question of time delay before test performance in future research. In addition, it may also be speculated that at level 1, the group means do not adequately represent performance due to relatively high variability. That is, performance may be less predictable at this early stage because individual differences obscure the group differences.

Cross-Activation Model

This study showed that the proficiency model of transfer, which was based on the assumption of left hemisphere dominance (and greater transfer from the dominant to non-dominant hemisphere) for the inverted-reversed printing task, was not supported. The present findings demonstrate that the amount of practice given subjects in this skill is an influential factor in determining whether transfer of training will be greater in one direction of the other. This is compatible with Goldberg and Costa's idea that the hemisphere superiority for processing a particular task may reverse depending upon the subject's familiarity with it.

An alternative to the proficiency model of interhemispheric communication was proposed by Parlow and Kinsbourne (1989), called the cross-activation model. According to this model, the direction of transfer will

reverse predictably, depending upon characteristics of the task. Thus, when a predominantly left hemisphere task is used, transfer should be greatest from right hand to left hand. However, the opposite would be true for a right hemisphere task, where transfer is greater from left hand to right.

This model of cross-activation can be extended and applied to the present study where it was found that task familiarity does influence the direction of transfer and, by implication, the hemispheric superiority for processing it. That is, processing of the novel, unpracticed printing skill can be assumed to be initially mediated by the right hemisphere. At this lower level of training transfer favors the right hand, as demonstrated in the present study at level 2. However, once the printing task has become well-practiced, it is processed more efficiently by the left hemisphere and transfer of training is found to favor the left hand. Therefore, increasing practice has the effect of reversing the observed hemispheric superiority for a given skill. In this way then, the novel task may be considered a right hemisphere task, whereas the well-practiced one may be considered a left hemisphere task.

By speculating on the mechanisms by which this interhemispheric communication takes place, the applicability of cross-activation model to the present study becomes clear. At a low level of training, the right

(dominant) hemisphere plays a role in initially learning the components of the novel task such as rotation and committing the list of letters to memory. As a result of increased right hemisphere activation during this skill acquisition phase, the left hemisphere is co-activated. Through this co-activation, dual engrams are formed, one in each hemisphere. By the formation of dual engrams through this left hand training, the left hemisphere is 'prepared' for a higher level of performance by the right hand following the switch. As a result, transfer of training is observed to be greatest from left hand to right hand. This illustrates the observed right hand advantage for transfer in the novel, right hemisphere skill.

In contrast, following 22 practice trials, the printing skill becomes well-learned and the routinized elements of performance form part of an established descriptive system specific to that skill. As a result, the left hemisphere assumes a dominant role in the skill acquisition. Thus, during the training of this well-learned task in the right hand, dual engrams may be formed. This has the effect of co-activating the right hemisphere which, in turn, facilitates the performance of the left hand following the switch. Subsequently, the direction of transfer is observed to favor the left hand at the higher level of training, once the printing skill has been well-learned and processed more efficiently by the left-hemisphere. This illustrates the

way in which the cross-activation model may be used to explain the reversal of transfer effects following increased amounts of skill training.

The cross-activation model represents a theoretical mechanism by which this shift in hemispheric preference occurs through the communication of information regarding skilled performance between the hemispheres. This model implies that the processing advantage of one hemisphere over the other, and thus the direction of greater transfer of training, can reverse depending upon the nature of the task (i.e., a putatively "right" or "left" hemisphere task). In contrast, the Goldberg and Costa model (1981), as illustrated by the present results, accounts for the shift from right to left hemisphere advantage through the process of routinizing the components of a given task. Thus, the factors underlying such a transition within one particular task for the same subject are not dealt with in the cross-activation model as they are in the Goldberg and Costa (1981) model. Therefore, while the two models are compatible with respect to the notion of a shift in hemispheric dominance, the current application of the Goldberg and Costa model may be viewed as an extension of the cross-activation theory by specifically addressing the issue of task novelty as an important factor underlying this hemispheric reversal.

In summary, despite the fact that the right to left direction of transfer was found at level 3, following 22 trials of practice, the proficiency model was not supported. A modified version of hypothesis two based on Goldberg and Costa's (1981) model, which predicted a reversal in direction of transfer between level 2 and level 3, was conclusively supported. A strict proficiency model would imply absolute proficiency of one hemisphere/hand which is always dominant for a particular task. This type of model was clearly not supported in the present study. Alternatively, both the Goldberg and Costa (1981) model and the cross-activation model proposed by Parlow and Kinsbourne (1989) assume that hemisphere/hand proficiency may vary depending upon characteristics of the task. More specifically, Goldberg and Costa (1981) emphasize the importance of task familiarity and suggest that the left hemisphere may assume superiority for processing a task once it has become well learned.

In the context of the present study then, one may speculate that when the printing skill is completely novel, both hemispheres may contribute to the performance of the skill and thus directional effects in transfer are not yet evident. At higher levels of skill acquisition however, hemispheric differences begin to emerge, as reflected by the directional transfer which favors the right hand following 12 practice trials. This may indicate the greater

involvement of the right hemisphere at this early stage in the learning process. At later stages in the acquisition of the printing skill, for example after 22 practice trials, the role of the left hemisphere assumes greater importance, as those processes specialized to the left hemisphere begin to make a greater contribution to the overall performance of this skill.

Transfer of Training to Numbers

The use of a second inverted-reversed task which involved numbers instead of letters was intended to provide some insight into whether transfer is task-specific or whether a more general skill or strategy is implicated in the process of transfer. There was essentially no transfer from practice on the inverted-reversed printing skill for letters to performance of the same skill using numbers. At all three levels, the average test trial performance was considerably lower for the numbers than for the corresponding "practice" trials using letters. The number of correctly printed numbers was considerably lower and group variability was relatively higher than for letters. This was true for both hands. This suggests that training on inverted-reversed letters did not facilitate subsequent performance of the same skill, using numbers. In fact, the opposite effect was observed; even fewer numbers than letters were printed correctly. This suggests that the learning demonstrated for the letter task did not transfer

to the number task. The expected superiority for same hand performance demonstrated in the letter task was not found in the number task; there was no type of training effect for this task.

The performance on the number task was less accurate than the level 1 performance on the letter task. Performance with respect to accuracy for the numbers was not comparable to that of the letters, even at the lowest level of training. This further demonstrates that the number task may have been more difficult than the letter task.

Therefore, it appears that the nature of the task, in this case the particular symbol being used, has an effect on the transfer of training. In the present study, training of an inverted-reversed printing skill using letters did not benefit from subsequent performance on a numbers task. Thus, these results suggest that transfer of training in this case appears to be specific to the learning of a specific sequence of letters rather than the transfer of a more general strategy for inverting and rotating symbols.

However, there are task and design factors that may have contributed to the findings for the number task. Firstly, the number and letter tasks may not have been equally familiar to the subjects. That is, university students in this sample may have had more experience printing letters than numbers. Evidence for this suggestion comes from a comparison of numbers printed correctly versus

numbers printed incorrectly (errors). Overall, the errors in the number task were very high relative to the number correct suggesting that the task itself was difficult and possibly more novel than the letter task had been. This is also supported by informal observations that the participants who did much better than average on this task were found to be in engineering or architecture, disciplines where number symbols are commonly used. The printing skill was intended to be equally familiar to all subjects based on the typical experience of university students with such a written skill. However, there is some evidence that the number task may not have been as familiar as the letter task to the vast majority of subjects.

Factors related to experimental design in the number task may also have contributed to the results obtained. One massed 2-minute test trial, incorporated for simplification of design, did not provide any opportunity for feedback on performance as there had been for the letter task. An additional effect of this design was that errors made on the first row of numbers were repeated on each subsequent row by almost all subjects as a result of copying from the previous trials.

Therefore, the existing evidence lends support to the notion that transfer of training is task-specific. However, this interpretation is subject to the effect of confounds in experimental design and, of drawing comparisons between two

tasks of unequal difficulty. For example, in order to adequately assess transfer between tasks, transfer should first be demonstrated within tasks, to ascertain their comparability. In the present study, this was not possible due to the lack of a baseline training condition for the second task. Further investigation of this issue is required before it can be conclusively determined that transfer of training does not rely on the transfer of such general aspects of strategy as rotating and inverting symbols.

To conclude, the present study shows that there is a reversal of transfer of training at low versus high levels of training for an inverted-reversed printing task. Transfer was found to favor the right hand at a low level of skill acquisition and the left hand at a high level. This is suggested to reflect a shift in relative specialization from the right hemisphere to the left hemisphere as the printing skill becomes well-learned. This is compatible with both the Goldberg and Costa (1981) of hemisphere specialization and the cross-activation model of interhemispheric communication proposed by Parlow and Kinsbourne (1989). A strict proficiency model, as incorporated by Parlow and Kinsbourne (1989), was only partially supported by these findings.

Future research in this area could address several issues. Firstly, it would be beneficial to increase the

left hemisphere component in the task stimuli (for example, using words instead of letters) to see whether group differences emerge earlier in skill acquisition. In addition, it would be valuable to investigate the effect of varying the delay between practice and test trials to see whether this is a critical factor influencing transfer at low levels of practice. Furthermore, the present results indicate that transfer is task-specific, although at early stages of acquisition it may be that transfer involves only more general aspects of skilled performance. More investigation of this general versus specific issue is necessary, by comparing transfer between two tasks which are comparable in difficulty.

REFERENCES

- Ammons, R.B. (1947). Acquisition of motor skill: II. Rotary pursuit performance with continuous practice before and after a single rest. Journal of Experimental Psychology, 37, 393-411.
- Ammons, R.B. (1955). Performance within short practice periods as affected by warm-up decrement and temporary work decrement. Year Book of the American Philosophical society, 181-185.
- Ammons, R.B. (1958). Le mouvement. In G.S. Seward and J.P. Seward, (Eds.). Current Psychological Issues (pp. 146-183). New York: Holt.
- Ammons, R.B., & Ammons, C.H. (1951). Bilateral transfer of rotary pursuit skill. American Psychologist, 6, 294-301.
- Archer, E.J., & Bourne, L.E. (1956). Inverted alphabet printing as a function of intertrial rest and sex. Journal of Experimental Psychology, 52, 322-329.
- Ardila, A. (1984). Right hemisphere participation in language. In A. Ardila and F. Ostrosky-Solis (Eds), The

right hemisphere: Neurology and neuropsychology. New York: Gordon & Breach.

Bakken, P. (1973). Left-handedness and alcoholism.

Perceptual and Motor Skills. 36, 514.

Banich, M.T., & Belger, A. (1990). Interhemispheric interaction: How do the hemispheres divide and conquer a task? Cortex, 26, 77-94.

Benton, A.L. (1967). Constructional apraxia and the minor hemisphere. Confina Neurologica, 22, 1-16.

Benton, A.L. (1975). On cerebral localization and dominance. Bulletin of the International Neuropsychological Society.

Bever, T.G., & Chiarello, R.J. (1974). Cerebral dominance in musicians and nonmusicians. Science, 185, 537-539.

Bradshaw, J.L. (1989). Hemispheric specialization and psychological function. Chichester, England: Wiley.

Bradshaw, J.L., Bradley, D., & Patterson, K. (1976). The perception and identification of mirror-reversed patterns. Quarterly Journal of Experimental Psychology, 28, 221-246.

- Bradshaw, J.L., & Gates, E.A. (1978). Visual field differences in verbal tasks: Effects of task familiarity and sex of subject. Brain and Language, 5, 166-187.
- Bradshaw, J.L., & Nettleton, N.C. (1981). The nature of hemispheric specialization in man. The Behavioral and Brain Sciences, 4, 51-91.
- Bradshaw, J.L., & Nettleton, N.C. (1983). Human cerebral asymmetry. Englewood Cliffs, NJ: Prentice-Hall.
- Branch, C., Milner, B., & Rasmussen, T. (1964). Intracarotid-sodium amytal for the lateralization of cerebral speech dominance. Journal of Neuropsychology, 21, 399-405.
- Bray, C.W. (1928). Transfer of learning. Journal of Experimental Psychology, 2, 443-467.
- Broca, P. (1861). Remarques sur le siege de la faculte du langage articule, suivies d'une observation d'aphemie (perte de la parole). Bulletins de la Societe Anatomique, 6, 330-357.
- Bryden, M.P., Hecaen, H., & DeAgostini (1983). Patterns of cerebral organization. Brain and Language, 20, 249-262.

Bryden, M.P. (1982). Laterality: Functional asymmetry in the intact brain. New York: Academic Press.

Bryden, M.P., & Allard, F. (1976). Visual hemifield differences depend on typeface. Brain and Language, 3, 191-200.

Carmon, A. (1978). Spatial and temporal factors in visual perception of patients with unilateral cerebral lesions. In M. Kinsbourne (Ed.), Asymmetrical function of the brain (pp.86-98). Cambridge: Cambridge University Press.

Cohen, G. (1973). Hemispheric differences in serial versus parallel processing. Journal of Experimental Psychology, 97, 349-356.

Cook, N.D. (1986). The brain code: Mechanisms of information transfer and the role of the corpus callosum. London: Methuen & Co.

Cook, T.W. (1933). Studies in cross education, I. Mirror tracing the star-shaped maze. Journal of Experimental Psychology, 16, 144-160.

Corballis, M.C. (1983). Human laterality. New York: Academic Press.

- Corballis, M.C., Zbrodoff, N.J., Shetzer, L.I., & Butler, P.B. (1978). Decisions about identity and orientation of rotated letters and digits. Memory and Cognition, 6, 98-107.
- Curry, F.K.W. (1967). A comparison of left-handed and right-handed subjects on verbal and nonverbal listening tasks. Cortex, 3, 343-352.
- Davis, W.W. (1898). Researches in cross-education. Studies from the Yale Psychological Laboratory, 6, 6-50.
- Davis, W.W. (1900). Researches in cross-education. Studies from the Yale Psychological Laboratory, 8, 64-109.
- Dax, M. (1865). Lesions de la moitie gauche de l'encephale coïncident avec l'oubli des signes de la pensee. Gazette Hebdomadaire de Medecine et de Chirurgie (Paris), 2, 259-260.
- Dimond, S.J., & Beaumont, J.G. (1972). Processing in perceptual integration between and within the cerebral hemispheres. British Journal of Psychology, 63, 509-514.

- Dimond, S.J., & Beaumont, J.G. (1973). Differences in the vigilance performance of the right and left hemispheres. Cortex, 9, 259-266.
- Ellis, H.C. (1965). The transfer of learning. New York: Macmillan.
- Ewert, P.H. (1926). Bilateral transfer in mirror drawing. Pedagogical Seminary, 33, 235-249.
- Freeman, G.L. (1938). Studies in the psycho-physiology of transfer: III. Bilateral practice effects in normal and mirror-writing. Journal of Psychology, 5, 85-289.
- Gagne, R.M, & Foster, H. (1948). Transfer of training from practice on components in a motor skill. Journal of Experimental Psychology, 39, 47-68.
- Gagne, R.M, Foster, H., & Crowley, M.E. (1948). The measurement of transfer of training. Psychological Bulletin, 45, 97-130.
- Gates, A., & Bradshaw, J.L. (1977). The role of the cerebral hemispheres in music. Brain & Language, 4, 403-431.

Gazzaniga, M.S. (1970). The bisected brain. New York: Appleton-Century-Crofts.

Gazzaniga, M.S., & LeDoux, J. (1978). The integrated mind. New York: Plenum Press.

Geschwind, N., & Behan, P. (1984). Laterality, hormones, & immunity. In N. Geschwind and A. Galaburda (Eds.), Cerebral dominance: The biological foundation. (pp.211-223). Cambridge, MA: Harvard University Press.

Goldberg, E., & Costa, L.D. (1981). Hemisphere differences in the acquisition and use of descriptive systems. Brain and Language, 14, 144-173.

Goldstein, K. (1948). Language and language disturbances. New York: Grune and Stratton.

Gordon, H.W. (1978). Hemispheric asymmetry for dichotically presented chords in musicians and non-musicians, males and females. Acta Psychologica, 42, 383-395.

Guiard, Y., & Requin, J. (1977). Interhemispheric sharing of signals and responses and the psychological refractory period. Neuropsychologia, 15, 427-437.

- Gur, R.C., Packer, I.K., Hungerbuhler, J.P., Reivich, M., Obrist, W.D., Amarnek, W.S., & Sackheim, H.A. (1980). Differences in the distribution of gray and white matter in human cerebral hemispheres. Science, 207, 1226-1228.
- Hardyck, C.A. (1977). A model of individual differences in hemispheric processing. In H. Whitaker and A.H. Whitaker (Eds.), Studies in neurolinguistics, vol.3 (pp. 223-256). New York: Academic Press.
- Hardyck, C.A., & Petrinovich, L.F. (1977). Left-handedness. Psychological Bulletin, 84, 385-404.
- Hatta, T. (1977). Recognition of Japanese Kanji in the left and right visual fields. Neuropsychologia, 15, 685-688.
- Hecaen, H., & Albert, M.L. (1978). Human neuropsychology. New York: Wiley.
- Heilman, K.M. (1979). Apraxia. In K.M. Heilman and E. Valenstein (Eds.), Clinical Neuropsychology. (pp.131-150). New York: Oxford University Press.
- Hellige, J.B. (1980). Effects of perceptual quality and visual field of probe stimulus presentation on memory

search for letters. Journal of Experimental Psychology: Human Perception and Performance, 6, 639-651.

Hellige, J.B. (1983). The study of cerebral hemisphere differences: Introduction and overview. In J.B. Hellige (Ed.), Cerebral Hemisphere Asymmetry. (pp.1-17). New York: Praeger.

Hellige, J.B., & Webster, R. (1979). Right hemisphere superiority for initial stages of letter processing. Neuropsychologia, 17, 653-660.

Hicks, R.E. (1972). Bilateral reminiscence in inverted-reversed printing: Effects of interpolated activity and printing-hand sequence. Journal of Motor Behavior, 4, 241-250.

Hicks, R.E. (1974). Asymmetry and bilateral transfer. American Journal of Psychology, 87, 667-674.

Hicks, R.E., & Kinsbourne, M. (1978). Human handedness. In M. Kinsbourne (Ed.), Asymmetrical function of the brain. (pp. 523-549). Cambridge: Cambridge University Press.

- Holloway, R.L., & de Lacoste, M.C. (1986). Sexual dimorphism in the human corpus callosum: An extension and replication study. Human Neurobiology, 5, 87-91.
- Hung, D.L., & Tzeng, O.J.L. (1981). Orthographic variations and visual information processing. Psychological Bulletin, 90, 377-414.
- Johnson, P. (1977). Dichotically stimulated ear differences in musicians and nonmusicians. Cortex, 13, 385-389.
- Jones, R., & Elliot, D. (1988). Intra- and interhemispheric integration of tactual and visual spatial information. Bulletin of the Psychonomic Society, 26, 229-231.
- Joynt, R.J., & Goldstein, M.N. (1975). Minor cerebral hemisphere. In W.J. Friedlander (Ed.), Advances in Neurology, vol.7. New York: Raven Press.
- Judd, C.H. (1908). The relation of special training and general intelligence. Educational Review, 36, 42-48.
- Kimura, D. (1961). Cerebral dominance and the perception of verbal stimuli. Canadian Journal of Psychology, 15, 166-171.

- Kimura, D. (1964). Left-right differences in the perception of melodies. Quarterly Journal of Psychology, 16, 355-358.
- Kimura, D. (1966). Dual functional asymmetry of the brain in visual perception. Neuropsychologia, 4, 275-285.
- Kimura, D. (1967). Functional asymmetry of the brain in dichotic listening. Cortex, 3, 163-178.
- Kimura, D. (1977). Acquisition of a motor skill after left hemisphere damage. Brain, 100, 527-542.
- Kimura, D., & Archibald, Y. (1974). Motor functions of the left hemisphere. Brain, 97, 337-350.
- Kimura, D., & Durnford, M. (1974). Normal studies on the function of the right hemisphere. In S.J. Dimond and J. Beaumont (Eds.), Hemisphere function in the human brain (chap. 3). London: Elek Science.
- King, F.L., & Kimura, D. (1972). Left-ear superiority in dichotic perception of vocal nonverbal sounds. Canadian Journal of Psychology, 26, 111-116.

- Kinsbourne, M. (1975). The mechanism of hemispheric control of the lateral gradient of attention. In P.M.A. Rabbit and S. Dornic (Eds.), Attention and Performance V (pp. 81-97). New York: Academic Press.
- Kinsbourne, M. & Hicks, R.E. (1978). Mapping cerebral functional space: Competition and collaboration in human performance. In M. Kinsbourne (Ed.), Asymmetrical function of the brain. Cambridge: Cambridge University Press.
- Koenig, O. (1987). Dichhaptic recognition of textures in normal adults. Neuropsychologia, 25, 295-298.
- Laszlo, J.I., Baguley, R.A., & Bairstow, P.J. (1970). Bilateral transfer in tapping skill in the absence of peripheral information. Journal of Motor Behavior, 2, 261-271.
- LeMay, M. (1976). Morphological cerebral asymmetries of modern man, fossil man, and nonhuman primate. In S.R. Harnad, H.D. Steklis, and J. Lancaster (Eds.), Origins and evolution of language and speech. Annals of the New York Academy of Sciences, 280, 349-366.

Levy, J. (1969). Possible basis for the evolution of lateral specialization of the human brain. Nature, 224, 614-615.

Levy, J. (1985). Interhemispheric collaboration: Single-mindedness in the asymmetric brain. In C.T. Best (Ed.), Hemispheric function and collaboration in the child. (pp. 11-31). New York: Academic Press.

Levy-Agresti, J., & Sperry, R.W. (1968). Differential perceptual capacities in major and minor hemispheres. Proceedings of the National Academy of Science U.S.A., 61, 1151.

Levy, J., Heller, J., Banich, M.T., & Burton, L.A. (1983). Are variations among right-handed individuals caused by characteristic arousal differences between the hemispheres? Journal of Experimental Psychology: Human Perception and Performance, 9, 329-359.

Liederman, J. (1986). Subtraction in addition to addition: Dual task performance improves when tasks are presented to separate hemispheres. Journal of Clinical and Experimental Neuropsychology, 8, 486-502.

- Liederman, J., & Meehan, P. (1986). When is between-hemisphere division of labor advantageous? Neuropsychologia, 24, 863-874.
- Liederman, J., Merola, J., & Martinez, S. (1985). Interhemispheric collaboration in response to simultaneous bilateral input. Neuropsychologia, 23, 673-683.
- Leipmann, H., & Maas, O. (1907). Fall von Linksseitiger agraphie und apraxie bei rechtsseitiger lahmung. Z.L. Psychologie u. Neurol., 10, 214-227.
- Mateer, C.A. (1983). Motor and perceptual functions of the left hemisphere and their interaction. In S.J. Segalowitz (Ed.), Language functions and brain organization. New York: Academic Press.
- McFie, J., Piercy, M.F., & Zangwill, O.L. (1950). Visual spatial agnosia associated with lesions of the right cerebral hemisphere. Brain, 73, 167-190.
- McGlone, J. (1980). Sex differences in human brain activity: A critical review. Behavioral and Brain Science, 3, 215-246.

Meier, M.J., & French, L.A. (1965). Lateralized deficits in complex visual discrimination and bilateral transfer of reminiscence following unilateral temporal lobectomy.

Neuropsychologia, 3, 261-272.

Merola, J.L., & Liederman, J. (1985). Developmental changes in hemispheric independence. Child Development, 56, 1184-1194.

Millar, J.M., & Whitaker, M.A. (1983). The right hemisphere's contribution to language: A review of the evidence from brain-damaged subjects. In S.J. Segalowitz (Ed.), Language functions and brain organization. (pp. 87-113). New York: Academic Press.

Miller, E. (1972). Clinical neuropsychology. Harmondsworth, Middlesex: Penguin Books.

Myers, J.J., & Sperry, R.W. (1985). Interhemispheric communication after section of the forebrain commissures. Cortex, 21, 249-260.

Nebes, R.D. (1978). Direct examination of cognitive function in the right and left hemispheres. In M. Kinsbourne (Ed.), Asymmetrical function of the brain. (pp. 99-137).

- Oldfield, R.C. (1971). The assessment and analysis of handedness: The edinburgh inventory. Neuropsychologia, 9, 97-113.
- Parlow, S.E. (1990). Asymmetrical movement overflow in children depends on handedness and task characteristics. Journal of Clinical and Experimental Neuropsychology, 12, 270-280.
- Parlow, S.E., & Kinsbourne, M. (1990). Asymmetrical transfer of braille acquisition between hands. Brain and Language, 33, 1-12.
- Parlow, S.E., & Kinsbourne, M. (1989). Asymmetrical transfer of training between hands: Implications for interhemispheric communication in normal brain. Brain and Cognition, 11, 98-113.
- Paterson, A., & Zangwill, O.L. (1944). Disorders of visual space perception associated with lesions of the right hemisphere. Brain, 67, 331-358.
- Piccirilli, M., Finali, F., & Schiarma, T. (1989). Negative evidence of differences between right and left handers in interhemispheric transfer of information. Neuropsychologia, 27, 1023-1026.

Potter, S.M., & Graves, R.E. (1988). Is interhemispheric transfer related to handedness and gender?

Neuropsychologia, 26, 319-325.

Provins, K.A., & Cunliffe, P. (1972). The reliability of some motor performance tests of handedness.

Neuropsychologia, 10, 199-206.

Raine, A., Andrews, H., Sheard, C., Walder, C., & Manders, D. (1989). Interhemispheric transfer in schizophrenics, depressives, and normals with schizoid tendencies.

Journal of Abnormal Psychology, 98, 35-41.

Ratcliff, G. (1979). Spatial thought, mental rotation and the right cerebral hemisphere. Neuropsychologia, 17, 49-54.

Ross-Kossak, P., & Turkewitz, G. (1984). Relationship between changes in hemispheric advantage during familiarization to faces and proficiency in facial recognition. Neuropsychologia, 22, 471-477.

Salmaso, D., & Longoni, A.M. (1985). Hand preference in an Italian sample. Perceptual and Motor Skills, 57, 1039-1042.

Sassanumo, S. (1975). Kana and Kanji processing in Japanese aphasics. Brain and Language, 2, 369-383.

Sasanuma, S., Itoh, M., Mori, K., & Kobayashi, Y. (1977). Tachistoscopic recognition of Kana and Kanji words. Neuropsychologia, 15, 547-553.

Satz, P. (1980). Incidence of aphasia in left-handers: A test of some hypothetical models of cerebral speech organization. In J. Herron (Ed.), Neuropsychology of left-handedness. New York: Academic Press.

Schwartz, J., & Tallal, P. (1980). Rate of acoustic change may underlie hemispheric specialization for speech perception. Science, 207, 1380-1381.

Scripture, E.W., Smith, T.L., & Brown E.M. (1894). On the education of muscular control and power. Studies of the Yale Psychological Laboratory, 2, 115.

Segalowitz, S.J., & Bryden, M.P. (1983). Individual differences in hemispheric representation of language. In S.J. Segalowitz (Ed.), Language functions and brain organization. (pp. 341-372). New York: Academic Press.

- Semmes, J. (1968). Hemispheric specialization: A possible clue to mechanism. Neuropsychologia, 6, 11-26.
- Sergent, J., & Bindra, D. (1981). Differential hemispheric processing of faces: Methodological considerations and reinterpretation. Psychological Bulletin, 89, 541-554.
- Singer, R.N. (1980). Motor skills. New York: Harper and Row.
- Springer, S.P., & Deutsch, G. (1985). Left Brain, Right Brain (revised edition). New York: Freeman.
- Tallal, P. (1976). Auditory perceptual factors in language and learning disabilities. In R.M. Knights and D.J. Bakker (Eds.), The neuropsychology of learning disorders: Theoretical approaches. Baltimore: University Park Press.
- Taylor, H.G., & Heilman, K.M. (1980). Left-hemisphere motor dominance in right handers. Cortex, 16, 587-603.
- Thorndike, E.L., & Woodworth, R.S. (1901). The influence of improvement in one mental function upon the efficiency of other functions. Psychological Review, 8, 247-261.
- Umiltà, C., Brizzolara, D., Tabossi, P., & Fairweather, H. (1978). Factors affecting face recognition in the

cerebral hemispheres: Familiarity and naming. In J. Requin (Ed.), Attention and performance VII, Hillsdale, NJ: Lawrence Erlbaum.

Wagner, M.T. & Hannon, R. (1981). Hemispheric asymmetries in faculty and student musicians and non-musicians during melody recognition tasks. Brain & Language, 13, 379-388.

Wernicke, C. (1874). Der aphasische symptom-complex. In, Eine Psychologische Studie auf Anatomischer Basis. Breslau: Cohen & Weigert.

Wolff, P.H., Hurwitz, I., & Moss, H. (1977). Serial organization of motor skills in left- and right-handed adults. Neuropsychologia, 15, 539-546.

Yoshizaki, K., & Hatta, T. (1987). Shift of visual field advantage by learning experience of foreign words. Neuropsychologia, 25, 589-592.

Zaidel, D., & Sperry, R.W. (1973). Performance on the Raven's Coloured Progressive Matrices by subjects with cerebral commissurotomy. Cortex, 9, 34-39.

R. C. OLDFIELD

APPENDIX II

*Medical Research Council Speech & Communication Unit**EDINBURGH HANDEDNESS INVENTORY*

Surname..... Given Names.....

Date of Birth..... Sex.....

Please indicate your preferences in the use of hands in the following activities by putting + in the appropriate column. Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, put ++. If in any case you are really indifferent put + in both columns.

Some of the activities require both hands. In these cases the part of the task, or object, for which hand preference is wanted is indicated in brackets.

Please try to answer all the questions, and only leave a blank if you have no experience at all of the object or task.

		LEFT	RIGHT
1	Writing		
2	Drawing		
3	Throwing		
4	Scissors		
5	Toothbrush		
6	Knife (without fork)		
7	Spoon		
8	Broom (upper hand)		
9	Striking Match (match)		
10	Opening box (lid)		
i	Which foot do you prefer to kick with?		
ii	Which eye do you use when using only one?		

L.Q.

Leave these spaces blank

DECILE

MARCH 1970

END

22/1 2/92

FIN