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HEMISPHERIC INTERACTION IN UNIMANUAL AND BIMANUAL TARGET
LOCALIZATION

City University of New York

PH.D. 1984

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Hemispheric Interaction in Unimanual and
Bimanual Target Localization

BY

JUDITH CHALLOP LUHR

A dissertation submitted to the Graduate
Faculty in Psychology in partial fulfillment
of the requirements for the degree of Doctor
of Philosophy, The City University of New
York.

1984

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1984

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ABSTRACT

HEMISPHERIC INTERACTION IN UNIMANUAL AND
BIMANUAL TARGET LOCALIZATION

BY

JUDITH CHALLOP LUHR

Adviser: Professor Mitchell L. Kietzman

Fifty normal men and women were asked to manually locate a target or targets they had seen prior to being blindfolded. Their accuracy in localizing a target without visual guidance was measured for three movement conditions: Unimanual (U), where each hand moved to a target separately; Simultaneous Symmetrical (SS), where both hands aimed simultaneously for targets at corresponding locations, and Simultaneous Asymmetrical (SA), where both hands aimed simultaneously for targets at different locations. The asymmetrical condition task had been designed to represent a motor analogue of sensory tasks such as dichotic listening and dichhaptic stimulation in order to produce greater functional differences between the right and left hands in the SA condition as compared to the U condition.

Contrary to predictions, there was a trend for the right hand to be more accurate than the left hand in the U condition, but there were no differences between the hands in either the SS or SA conditions. What was revealed by the study was the extremely strong tendency toward symmetry in bilateral motor

performance, even among strongly right-handed, normal subjects. In addition the study revealed that a significant increase in error from unimanual performance occurred during bimanual simultaneous asymmetrical movement but not during bimanual simultaneous symmetrical activity. Another interesting, but unexpected finding was that the right-handed women were much more accurate than the right-handed men in every movement condition.

The study raises some issues about the tendency towards symmetry of movement in normal adults and the phylogenetic and ontogenetic significance of hemispheric symmetry and asymmetry. Additionally, the implications of hemispheric asymmetry research for developmental disorders, adult brain damage, and psychiatric disorders are discussed.

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CHAPTER I

Introduction

Upon gross inspection, the human brain appears to be a classic example of bilateral symmetry in nature. For each structure found in the right cerebral hemisphere there exists a mirror structure in the left cerebral hemisphere. Implicit in the concept of symmetry is the assumption that one side is the exact duplicate of the other, and should, in the case of the brain, be able to mediate the same types of functions. The emergence of evidence indicating that the apparent morphological symmetry of the brain belied rather striking functional differences in the respective abilities of each cerebral hemisphere began a new era in brain research.

However, until recently, the majority of information on hemispheric asymmetries of function had been collected from either unilaterally brain damaged patients (Critchley, 1972) or from epileptic patients who had had their cerebral commissures severed to control seizures (Bogen, Fisher, & Vogel, 1965; Gazzaniga, 1967; Sperry, 1974). While these discoveries have been monumental in the development of laterality research, the extent to which the results obtained on brain damaged subjects can be applied to normal subjects is limited.

Studying hemispheric asymmetries in the intact brain has proven to be difficult in light of the intricate communication system between the two cerebral hemispheres. Many techniques have been developed to study the relative abilities of each hemisphere in normal subjects, but the most interesting ones may be those which actually attempt to use the brain's complex communication system to bring about a greater functional separation between the hemispheres (Broadbent, 1954; Kershner, 1977; Kinsbourne, 1970; Witelson, 1974).

The main goal of most research on laterality has been to differentiate the abilities of the right hemisphere from those of the left hemisphere. However, in attempting to delineate the functional characteristics of each hemisphere, most experimenters have ignored one of the most interesting and unique aspects of the normal brain; namely, the incredibly complex integration of function between the two hemispheres.

Springer (1977) suggests:

Perhaps the next question to ask is how the brain exquisitely combines lateralized functions to produce behavior so well integrated that the experimenter has great difficulty isolating the components for study. (p. 333)

The present study will take a different approach to the investigation of hemispheric specialization and interaction. Rather than attempting to differentiate which abilities are better handled in one hemisphere or another, this study will

focus on the process of hemispheric interaction in mediating bilateral simultaneous competitive motor activity in normal adults.

Although a motor task will be employed, this is not a study of motor lateralization per se. The task involves the motor approximation of a visual memory trace of the location of a previously seen target.

Prior to a more detailed description of the theoretical framework and rationale for the specific study, it seems appropriate to place it in the more general perspective of the field of hemispheric specialization. This will include a discussion of several topics: a review of historical concepts, supporting evidence for lateralization of function, theories about the dichotomy of function between the left and right hemispheres, some of the approaches by which information about hemispheric specialization has been gathered, and some of the organismic factors which may interact with hemispheric specialization.

Emergence of the Cerebral Dominance Theory

Throughout most of history, the human brain was regarded as being a totally symmetrical structure with duplicative functions of the two hemispheres. Hippocrates wrote that "the human brain, as in the case of all other animals, is double" (Chadwick & Mann, 1950, p. 183). In the mid-nineteenth

century, however, the concept of two complete brains with the potential for independent thought began to emerge. On the basis of clinical evidence from patients possessed of only one cerebral hemisphere who still retained their personality and the ability to think, Dr. A. L. Wigan (1844) speculated that each hemisphere could be seen as "a distinct and perfect whole as an organ of thought" (p. 26). Wigan also claimed that different thought processes could be simultaneously carried out by each hemisphere. Ferrier (1886) elaborated on the duality of brain function: "The brain as an organ of motion and sensation, or presentative consciousness, is a single organ composed of two halves; the brain as an organ of ideation, or representative consciousness, is a dual organ, each hemisphere complete in itself" (p. 426).

While both Wigan and Ferrier recognized that separate thoughts could be simultaneously processed by each half of the brain, they did not specify specific functions that were consistently lateralized to one hemisphere or the other. The oldest source of evidence for the functional asymmetry of the hemispheres stems back to the mid-nineteenth century when it was observed that dysphasia was more commonly found among the symptoms of patients following damage to the left cerebral hemisphere than following damage to the homologous area of the right cerebral hemisphere (discussed in Critchley, 1972).

In 1874, Hughlings Jackson succinctly described the recognition of left hemisphere dominance for language:

Not long ago, few doubted the brain to be double in function as well as physically bilateral; but now that it is certain from the researches of Dax, Broca, and others, that damage to one lateral half can make a man entirely speechless, the former view is disputed. Thus, Broca and Moxon supposed that but one half of the brain--the left in the vast majority of people--is educated in words. (J. Taylor, 1958, p. 129)

While Jackson conceded that, in general, the left hemisphere was specialized for speech, he did not ignore the abilities of the right hemisphere. In describing the case of a patient with a right hemisphere tumor who did not know objects, persons, or places, Jackson labelled her deficit "imperception" and wrote:

I think... that the posterior lobes are the seat of most intellectual processes. This is in effect saying that they are the seat of visual ideation, for most of our mental operations are carried on in visual ideas. I think too that the right posterior lobe is the "leading" side, the left more automatic. This is analogous to the difference I make as regards use of words, the right is the automatic side for words and the left side for that use of words which is speech. (J. Taylor, 1958, p. 148)

Despite Jackson's recognition of different specialized abilities in each hemisphere, the abilities of the right hemisphere were largely ignored. This was due, perhaps, to the fact that left hemisphere damage resulted in deficits which seemed to strip a person of the behavioral indices of "unique

humanity"--language and reason--while comparable right hemisphere damage resulted in deficits of a much more subtle nature.

While the dominant hemisphere was defined as the one "which controls handedness, expression, and comprehension" (Grinker, Bucy, & Sahs, 1959, p. 621), it came to mean the hemisphere which had control over most cognitive processes. In 1943 Strong and Elwyn wrote that "the higher cortical functions are vested principally in one cerebral hemisphere, the left one in right-handed individuals... the dominant hemisphere... lesions of the other hemisphere producing as a rule no recognizable disturbances" (p. 374).

In the past century following the original reports of left hemisphere specialization for comprehension and expression of both written and spoken language, considerable evidence has been gathered in support of the left hemisphere's verbal abilities (Milner, 1974a; Prohovnik, 1978; Sperry, 1974). When the left hemisphere is removed or damaged, there is a paucity of voluntary propositional speech, and verbal comprehension and memory are impaired (Gott, 1973; Milner, 1974b; Sanders & Warrington, 1971; A. Smith, 1966; Smith & Burkland, 1966; Zaidel, 1973). When the isolated left hemisphere is tested in split-brain patients, it is better at mediating speech and verbal ability than is the isolated right hemisphere (Gazzaniga,

1967; Sperry, 1974). Studies with normal subjects also indicate a left hemisphere specialization for writing, speaking, reading, and syntactic and semantic discrimination (Carmon, Lavy, Gordon, & Portnoy, 1975; Ehrlichman & Weiner, 1979; Ornstein, Johnstone, Herron, & Swencionis, 1980), verbal analogies (Risberg, Halsey, Wills, & Wilson, 1975), letter and word recognition (McKeever, 1971; Rizzolatti, Umiltà, & Berlucchi, 1971), and speech and consonant memory (Shankweiler & Studdert-Kennedy, 1967; White, 1969b).

Although it has been called the "silent inhabitant of the right side of the cranium" (LeDoux, Wilson, & Gazzaniga, 1977), the right hemisphere is not word-blind or word-deaf as Geschwind (1965a, 1965b) has claimed. Searleman (1977) reviewed the studies on right hemisphere language function and found that, despite preliminary reports that the right hemisphere could only understand monomorphemic nouns and adjectives and distinguish between affirmative and negative sentences (Gazzaniga, 1970; Gazzaniga & Hillyard, 1971), the preponderance of evidence indicates that, even though speech production is difficult, there is significant verbal comprehension (French, Johnson, Brown, & Van Bergen, 1955; Hillier, 1954; A. Smith, 1966, 1974). Furthermore, the isolated right hemisphere of split-brain patients can follow verbal commands (Levy, 1970; Nebes & Sperry, 1971) and even spell simple words

by having the left hand manipulate a group of letters (Gazzaniga, 1970; Levy, Nebes & Sperry, 1971; Nebes & Sperry, 1971). The patients can sometimes write the words, using the left hand, even though they can not say them (Nebes, 1974). Levy (1974) demonstrated that the right hemisphere could verbally identify certain familiar objects but could not tell whether they rhymed or not. The rhyming property of words seems to be within the domain of left hemisphere function (Natale, 1977).

The right hemisphere also appears to be capable of simple syntactic constructions when short sentences are involved. Zaidel (1977) describes the performance of the right hemisphere on the Token Test, a test of language ability, to be similar to the performance of either an aphasic adult or a normal child. While the right hemisphere can understand more nouns and verbs than was first thought, it cannot distinguish active from passive, singular from plural, or present from future forms (Nebes, 1974).

Emergence of the Hemispheric Specialization Theory

Although the literature does appear to support the theory of a relative left hemisphere superiority in the mediation of language function, it has also shown that the right hemisphere appears to possess a relative superiority in the mediation of other functions, especially those that require spatial abilities.

In general, the functional domain of the right hemisphere appears to be in the field of visuo-spatial relations (Ornstein, Johnstone, Herron, & Swencionis, 1980; Prohovnik, 1978). One of the most extensively studied visuo-spatial abilities is face recognition. Patients with right hemisphere lesions tend to show impaired recognition of faces (De Renzi, Faglioni, & Spinnler, 1968; Hecaen & Angelergues, 1963; Milner, 1968; Teuber, 1962; Warrington & James, 1967; Yin, 1970). Left visual field advantages for recognition of faces have been found for split-brain patients (Levy, 1972; Levy & Trevarthen, 1976; Levy, Trevarthen, & Sperry, 1972) and in normal children and adults (Dumas & Morgan, 1975; Geffen, Bradshaw, & Wallace, 1971; Hilliard, 1973; Klein, Moscovitch, & Vigna, 1976; Leehey & Cahn, 1979; Marcel & Rajan, 1975; Rapaczynski & Ehrlichman, 1979; Rizzolatti, Umiltà, & Berlucchi, 1971; Schwartz & Smith, 1980; Young & Ellis, 1976).

Other visuo-spatial functions found to be subserved by the right hemisphere include: estimating the number of dots, recognition of nonsense patterns, visual maze learning (Milner, 1968), orientation in space (Umiltà, Rizzolatti, Marzi, Zamboni, Franzini, Camarda, & Berlucchi, 1974), picture completion (Bogen, DeZure, Ten Houten, & Marsh, 1972; De Renzi & Spinnler, 1966), and recognition of embedded or overlapping figures (Brooks, Wyper, & Lennox, 1975; Warrington & James, 1967).

Right hemisphere superiority has also been indicated in the performance of certain visuo-motor tasks such as playing video games (Rebert & Low, 1978) and visuo-motor matching of shapes (Nebes, 1974). Similar visuo-motor functions also appear to be important in the successful completion of certain WAIS performance subtests, primarily Block Design (Galin & Ellis, 1975; Warrington & Rabin, 1970).

The right parietal lobe seems to be crucial in normal somatosensory perception (Benton, Levin, & Varney, 1973; Carmon & Benton, 1969; Critchley, 1949; Denny-Brown, Meyer, & Horenstein, 1952; Fontenot & Benton, 1971; Luria, 1973), and especially in spatial perception (De Renzi, 1978; Hecaen & Angelergues, 1963; Joynt & Goldstein, 1975; Weinstein, 1978). Right parietal lobe damage is found in patients who exhibit somatoagnosias and apraxias (Hecaen, 1967) and impairments in localization of extrapersonal space (Battersby, Bender, Pollack, & Kahn, 1956).

It must be concluded that while the functional consequences of right hemisphere damage are indeed different from those of left hemisphere damage, it can no longer be said that right hemisphere damage produces "no recognizable defect" as Strong and Elwyn (1943) previously claimed, and as was widely believed.

The debate, therefore, about which hemisphere is "dominant" seems to be pointless, for as Dimond (1972) notes, "dominance can be attributed to one hemisphere in respect to one function, but may be attributed to another for another function" (p. 186). If one is discussing music, for example, the tonal aspect of music appears to be right hemisphere dominant as opposed to the notational aspect of music which appears to be left hemisphere dominant (Bogen, 1969/1974). Semmes (1968) writes:

Unfortunately, the concept of cerebral dominance is not helpful for it proposes nothing about mechanism, in fact it is little more than a label, a restatement of the finding that lesions of one hemisphere produce deficits that lesions of the other hemisphere do not. (p. 11)

Operational Basis for Cerebral Asymmetries

Prohovnik (1978) begins his literature review of cerebral lateralization of psychological processes with:

The classical idea of a dominant cerebral hemisphere and a minor hemisphere is no longer viable; it has been replaced by a view of two different hemispheres, each dominant for different stimulus types. Even this view seems to be changing now into a model of dominance that is not deterministically stimulus-bound. (pp. 161-162)

The most common dichotomy made between the hemispheres usually emphasizes whether the stimuli presented are of a verbal or spatial nature; assuming, of course, that whether the right or left hemisphere will be determined by the nature of the stimulus. This position is simplistic and, in

fact gives no indication of why one hemisphere is better at processing certain types of stimuli than the other. It may be that certain stimuli are handled better by one hemisphere due to the fact that the operations that are generally performed on that type of stimulus are more compatible with the way in which that hemisphere functions. Leiber (1976) points out that "the language processing capabilities of the major hemisphere are engaged by a verbal stimulus only when that verbal stimulus is being processed as a linguistic stimulus" (p. 444).

Supportive evidence for this stimulus-function compatibility position comes from studies where the subjects are required to deal with verbal or spatial material in nontraditional ways. Gibson, Dimond, and Gazzaniga (1972) found a left visual field/right hemisphere advantage in a word-matching task when the subject was required to use the configurational properties of the word rather than its semantic content. Under most conditions, it would be expected that a word would be better detected in the right visual field. In another study, Klatzky and Atkinson (1971) found a right visual field/left hemisphere advantage for pictures of common objects when the subject was required to determine the initial letter of the name of the object. Under most conditions, it would be expected that a picture would be better detected in the left visual field.

Other studies have found either right or left visual field advantages for the same stimuli depending upon the task

demands. When tachistoscopically presented visual material is matched by name, a right visual field advantage is obtained; when the same stimuli are matched by physical shape, a left visual field advantage is obtained (Geffen, Bradshaw, & Nettleton, 1972). Similar results have been found using single letters as stimuli (Niederbuhl & Springer, 1979; Springer, 1977).

When patients were required to arrange the same set of pictures in a task that relied on temporal sequences half of the time and configurational processes the other half of the time, patients with damage to the left hemisphere were more impaired on the sequential part of the task while the patients with damage to the right hemisphere were more impaired on the configurational part of the task (Veroff, 1978). It seems, therefore, that in any given situation, the crucial determinant of which hemisphere will be of principal importance depends more on what is done with the stimulus rather than on the exact nature of the stimulus.

Theories of Hemispheric Dichotomies in Function

Numerous investigators have advanced more general theories about the nature of the dichotomy in hemispheric operations, manifested in the general predisposition for the left hemisphere to respond better to task demands which involve verbal stimuli and for the right hemisphere to respond better

to task demands which involve spatial stimuli.

Analytic versus synthetic processing. A basic dichotomy drawn between the hemispheres refers to the analytic, computer-like processing of the left hemisphere and the synthetic, gestalt processing of the right hemisphere (G. Cohen, 1973; Levy-Agresti & Sperry, 1967, 1968). Nebes (1974) describes such a model:

The minor hemisphere [the right hemisphere] is seen to organize and treat data in terms of complex wholes, being in effect a synthesizer with a pre-disposition for viewing the total rather than the parts. The left hemisphere in this model sequentially analyzes input, abstracting out the relevant details, to which it associates verbal symbols in order to more efficiently manipulate and store the data. (p. 13)

In split-brain patients it has been found that each hemisphere was generally able to solve the same problems although often each seemed to use alternate kinds of solutions and, in the case of the right hemisphere, required use of a graphic or performance means of communication rather than the usual verbal channels (Nebes, 1974; Sperry, 1974). Although the logical mode of the left hemisphere is often prized in many fields of endeavor, one can see how the synthetic mode of the right hemisphere may be more appropriate for certain kinds of tasks. It seems that the right hemisphere:

Primarily uses a nonverbal mode of representation, presumably images; visual, tactile, kinesthetic, and auditory... reasons by a non-linear mode of

association rather than by syllogistic logic; its solutions to problems are based on multiple converging determinants rather than a single causal chain... is less involved with perception of time and sequence... deals more effectively with complex patterns taken as a whole than with the individual parts taken serially. (Galin, 1974, p. 574)

On the basis of their clinical observations of brain damaged patients, both Hecaen (1967) and Semmes (1968) suggested that the two cerebral hemispheres differ in their organization of functions with the left hemisphere characterized by focal, sharply defined localization of functions and the right hemisphere characterized by diffuse localization of functions. Semmes pointed out that discrete lesions of the left hemisphere produced specific sensorimotor deficits whereas similar deficits resulting from right hemisphere lesions depended less on specific locus. The focal or heterogeneous organization of the left hemisphere would favor integration of similar units of information while the more diffuse, homogeneous organization of the right hemisphere would favor integration of dissimilar units of information.

Semmes suggests that the focal organization of the left hemisphere may underlie "specialization for behaviors that demand fine sensorimotor controls, such as manual skills and speech" while the diffuse organization of the right hemisphere may underlie "specialization for behaviors requiring

multi-modal coordination, such as various spatial abilities" (p. 11).

Recent neuroanatomical evidence appears to provide a neural substrate for this theory (Gur, Packer, Hungerbuhler, Reivich, Obrist, Amarnek, & Sackeim, 1980). Although there appears to be an equality in the overall amount of neural tissue in the left and right hemispheres (von Bonin, 1962), Berger (1921/1969) had reported a greater density of cells in the left hemisphere. Corroboration of this finding has been found using a non-invasive inhalation method for measuring cerebral blood flow. Gur et al. (1980) found that there was a greater ratio of gray to white matter in the frontal and occipital lobes of the left hemisphere than right hemisphere. No differences were found between the parietal-central region and the frontal-temporal area around the Sylvian fissure. Gur et al. admit that while their detectors sampled fairly large and representative regions, the temporal and occipital lobes were not adequately sampled. However, other studies have reported a greater percentage of gray matter in the left than right temporal and occipital regions (Meyer, Ishihara, Deshmukh, Naritomi, Sakai, Hsu, & Pollack, 1978) as well as for the majority of the temporal lobe (McHenry, Memory, Bass, Stump, Williams, Witcofski, Howard, & Toole, 1978).

Gur et al. (1980) conclude that there is more gray matter, that is, nerve cells and unmyelinated fibers, in the

left hemisphere, and more white matter, or myelinated fibers, in the right hemisphere. The presence of more axons in the right hemisphere may imply a more integrated network of communication in the right hemisphere than in the left hemisphere. In attempting to explain the significance of these findings, Gur et al. write:

Thus our results suggest that verbal-analytic functions are subserved by an organization that emphasizes processing within regions [the left hemisphere] spatial-gestalt functions are subserved by an organization that optimizes transfer across regions [the right hemisphere]. (p. 1229)

Temporal versus spatial processing. An alternative dichotomy in hemispheric processing delineates a more parsimonious distinction in left and right hemisphere function. It suggests that the left hemisphere is better at processing stimuli separated by time whereas the right hemisphere is better at processing stimuli separated by space (Efron, 1963).

Although this theory is compatible with previous theories of the right hemisphere's superiority for various types of spatial relations, it points to the left hemisphere specialization for language as a specialized case of its more generalized superiority in processing temporally patterned stimulation (Efron, 1963; Halperin, Nachson, & Carmon, 1973; Papcun, Krashen, Terbeek, Remington & Harshman, 1974; Robinson & Solomon, 1974; Zatorre, 1979). Schwartz and Tallal (1980)

conclude that "the superiority of the left hemisphere for linguistic processing may reflect, at least in part, left-hemisphere dominance in processing rapidly changing acoustic events, which is critical for the processing of fluent speech" (p. 1381).

The temporal/spatial dichotomy makes it more difficult to classify stimuli because most stimuli contain both temporal and spatial components (Davis & Wada, 1978). Thus, both a flash and a click stimulus have temporal components (e.g. duration) that would be processed by the left hemisphere; but the flash also has a spatial component (the round circle) that would also be processed by the right hemisphere. Davis and Wada found that spectral analysis of evoked potentials produced larger amplitudes and coherences of the AEPs in the left hemisphere when a click (a predominantly temporal stimulus) was presented while the amplitudes and coherences of the VEPs to the flash (a combination of temporal and spatial components) were not as consistently lateralized to the right hemisphere.

Complex versus simple processing. An assumption that underlies most of the theories of hemispheric dichotomy is that the processes lateralized to one hemisphere or the other will generally result in a qualitative difference in the type of stimuli handled best by each hemisphere. However, the complexity theory maintains that more complex stimuli are processed by the left hemisphere, regardless of whether they are

verbal or spatial, while simple stimuli of either type are processed by the right hemisphere.

Simple linguistic tasks can be carried out by the right hemisphere as well as by the left hemisphere, but this is not true for more complex linguistic capabilities (Gazzaniga, 1970; Gazzaniga & Sperry, 1967). Mills and Rollman (1980) report that the right hemisphere was equivalent to the left hemisphere in processing temporal stimuli when the stimulus durations were above a critical value. Below that critical value, however, the left hemisphere was superior to the right hemisphere.

Even though music has generally been considered to be a right hemisphere function, Bever and Chiarello (1974) reported that, while musically naive subjects showed a right hemisphere advantage for recognition of simple melodies, musically sophisticated subjects showed a left hemisphere advantage. Bever and Chiarello interpreted the results as indicating that the two groups used different strategies for recognizing the melodic patterns--the naive group a holistic type of recognition process and the sophisticated group an analytic approach to the internal relation of the components of the melodic sequence. H. W. Gordon (1975), however, claims that these different modes of processing are not dependent upon musical training, but on level of performance. Support for this contention comes from the finding that poorer performers

in accuracy of perception of melodies had higher left ear scores whereas better performers had higher right ear scores. No such relationship was found for the perception of chords.

To test the theory of greater left hemisphere involvement in complex musical tasks, Shanon (1980) constructed three tasks of increasing difficulty, and found a greater degree of left hemisphere advantage, in terms of accuracy, for the more complex tasks. However, if one looks at the specific tasks Shanon employed, the easiest being a decision as to whether a pair of tones represented a match, and the most difficult being a decision as to the pairwise relations of a sequence of three tones, it appears that the tasks represent something more than just an increase in complexity; they seem to be different kinds of tasks, requiring different kinds of processing. It is possible that the sequence of three tones requires left hemisphere processing even though it utilizes musical stimuli.

It seems that the involvement of the left hemisphere in complex right hemisphere processes seems to arise from the introduction of a sequential element to the task rather than from the complexity of a single element (Ornstein et al., 1980). Thus, Umiltà, Bagnara, and Simion (1978) found a right visual field/left hemisphere advantage for easily named simple geometric figures such as triangles and squares, but a left visual field/right hemisphere advantage for complex geometric figures such as 10- and 11-sided regular polygons when only one geome-

tric figure was presented per trial rather than a sequence of stimuli.

The left hemisphere becomes involved in complex spatial tasks such as mental rotation (Benson & Barton, 1970; Butter & Barton, 1970; De Renzi & Faglioni, 1967), route finding (Semmes, 1968), and difficult levels of Kohs blocks (Galin, Johnstone, & Herron, 1978). De Renzi (1978) states that:

The more elementary the space ability tested, the more it appears to be confined to a focal area of the right hemisphere. Thus, the neural substrate subserving the processing of cues defining the orientation in space of a single element is exclusively represented in the right half of the brain and focally organized in its posterior region. No role is played in this case by the left hemisphere which, instead, becomes involved as soon as the integration of successive changes of orientation of space is required. (pp. 81-82).

Approaches to Studying Hemispheric Specialization

The vast and growing body of literature on hemispheric specialization is remarkable in its diversity. This diversity lies not only in the nature of the findings, but in the variety of ways in which the information has been gathered.

Many of the approaches used are dictated by the way in which the hemispheric abilities are defined and the population in which they are tested. For example, language ability can be defined in terms of speech comprehension, speech production, or visual recognition of verbal material. Even studies that

just concentrate on visual recognition can study reading comprehension, word recognition, nonsense syllable matching, letter recognition, etc. The exact nature of the task will also be determined by whether the subjects are brain-damaged, normal adults, or children.

The following discussion will present some of the approaches that have been used to create the growing body of literature on hemispheric specialization. In addition, it will provide a framework for the later discussion of the considerations which went into the design of the specific experiment which was used in this dissertation.

Unilateral disruption of function. Much of the information on the individual abilities of the two hemispheres has derived from the use of methods which have in common the unilateral disruption of function. The basic assumption behind these techniques is that the deficits subsequent to unilateral disruption of brain function indicate the function of that region in the intact brain.

A. Unilateral lesions. The specific nature of the deficits following a unilateral lesion appears to be largely determined by which side of the brain is damaged. While removal of either temporal lobe often results in memory impairment, removal of the left temporal lobe generally produces impaired retention of verbal material (Blakemore & Falconer,

1967; Meyer & Yates, 1955; Milner, 1958, 1967; Milner & Teuber, 1968), but does not affect memory for spatial material. Conversely, right temporal lobectomy does not generally affect verbal memory, but does impair the memory for items that are not easily verbally coded (Kimura, 1963a; Milner, 1962, 1967, 1968; Shankweiler, 1966). Corsi (1972) found that there was a rapid deterioration of memory for a group of three consonants after left temporal lobectomy and a concomitant deficit for the memory of the position of a 1/4 inch circle on an 8-inch line in other patients who had a right temporal lobectomy. It thus appears that there is a double dissociation between the effects of these two lesions in the area of memory (Teuber, 1955).

In much the same way, the general deficit in recency tasks associated with frontal lobe damage can be viewed in terms of the specific content of the test materials used. Patients with damage to the left frontal lobe have difficulty with a recency task involving verbal stimuli while patients with damage to the right frontal lobe show difficulty with the non-verbal form of the same recency task [Corsi (cited in Milner, 1971)].

Delineation of the control each hemisphere exerts over motor performance from the results of studies of patients with unilateral lesions reveals a rather complex pattern. Certain motor functions, regardless of the verbal or nonverbal content

of the task, tend to be controlled more by the left hemisphere (Heilman, Schwartz, & Geschwind, 1975; Kimura, 1977). According to Kimura and Archibald (1974), left hemisphere lesions produce impairment in the performance of complex motor sequences and may, therefore, account for the appearance of expressive aphasia. Speech production requires the sequencing of the muscles involved in articulation. Oral apraxia (impairment in whistling, yawning, etc.) is highly associated with Broca's aphasia, but not limb apraxia (De Renzi, Pieczuro, & Vignolo, 1966; Mateer & Kimura, 1977).

In right-handed patients, lesions of the right temporal lobe result in impaired learning of a stylus maze with either visual or proprioceptive feedback (Corkin, 1965, Milner, 1965). Since the degree of impairment on the task is related to the degree of hippocampal tissue removed with the temporal lobe, the deficit may reflect memory impairment for spatial relations. An alternative or supplementary explanation may be found in Levin's (1973) observation that defective utilization of proprioceptive feedback is so specific to right hemisphere damage that it has localizing significance. This may account for the impairment in reaching for visualized objects displayed by a patient with a right superior parietal lobe tumor (Levine, Kaufman, & Mohr, 1978).

B. Sodium amylobarbitone test. Some methods used to study hemispheric asymmetries mimic the unilateral lesion

studies in that they attempt to use the deficits produced by rendering one hemisphere inactive as clues to the function of that hemisphere. One of the most effective techniques for achieving this result is the intracarotid injection of sodium amylobarbitone (Serafitinades, Hoare, & Driver, 1965; Wada, 1949). Since sodium amylobarbitone temporarily depresses brain function, when injected into one carotid artery it interferes with the function of one hemisphere before being transferred through the circle of Willis. The right and left hemispheres can be tested on alternate sessions. If dysphasia occurs following the injection of one hemisphere but not the other, the hemisphere which produces dysphasia when inactivated is considered dominant for speech. Using this technique (often referred to as the Wada method), Milner, Branch, and Rasmussen (1964, 1966) estimated that 91% of right-handers have speech represented in the left hemisphere. Davis and Wada (1977) maintain that its range of accuracy in estimating speech dominance is 95-98%.

C. Unilateral electroconvulsive therapy. Another method by which the function of one hemisphere is temporarily disrupted is by the use of unilateral electroconvulsive therapy (ECT). Used primarily with severely depressed or psychotic patients, bilateral ECT has been shown to produce a temporary alteration in brain activity as evidenced by the confusion and amnesia which immediately follows treatment

(Breggin, 1979). While restricting ECT to one hemisphere greatly reduces the generalized effects, it requires more treatments to alter the same psychiatric symptoms and produces lateralized deficits. Pratt, Warrington, and Halliday (1971) and Pratt and Warrington (1972) found dysphasia to be more common following administration of ECT to the left hemisphere than to the right hemisphere.

Although the unilateral disruption methods have provided much of the evidence for hemispheric asymmetries, there are certain factors which limit the usefulness of the information gathered in this manner. Perhaps the most basic problem is inferring function from dysfunction. It is very tempting to assume that, when a behavior is disrupted subsequent to lesioning of or otherwise inactivating a brain region, the brain region was the "center" for that behavior. However, this is not necessarily the case. Hughlings Jackson is known for having recognized that dysfunction was not always the reciprocal of function. Although an area of the brain may be necessary for the performance of a certain behavior, and its removal disrupts the behavior, the area may have served as a relay station or an integral link in a chain of areas rather than being the control center in itself (Davis & Wada, 1978).

In addition, the unilateral disruption methods only provide information about subjects who have various pre-existing

forms of brain damage or psychiatric disorders. Even if one did not consider psychiatric disorders to be organic, the psychiatric patients who have received multiple ECT sessions appear to have signs of an organic mental syndrome (Abrams, 1974; Breggin, 1979; Elmore & Sugerman, 1975; Strain, 1972). There is some question as to how applicable the results are to a normal sample. The patterns of cerebral laterality found in patients with prior organic dysfunction may reflect compensatory activity in areas not generally used by people with intact brains (Geschwind, 1970).

Another problem inherent in the unilateral disruption of function method is a lack of control over the area of involvement. In sub-human animals, relatively discrete, well circumscribed lesions can be experimentally produced. If there is a question about the size or placement of the lesion, histological analysis can determine the exact boundaries of the lesion. Such experimentation is, of course, not feasible with humans. The lesions studied in humans are generally produced by unplanned accidents--cerebrovascular or traumatic head wounds--or as the unavoidable by-product of certain therapeutic interventions. Thus, a group of patients with so-called "rightsided" lesions may, in fact, be quite heterogeneous with respect to the size, location and etiology of the lesion.

Recent advances in technology such as computerized tomography (CT scans), positron emission transaxial tomography (PET

scans), nuclear magnetic resonance, and angiograms contribute a great deal to the detection and description of brain lesions in living patients; however, much of the evidence collected on patients with unilateral lesions had been amassed prior to the advent or availability of these diagnostic tools. Even with their current usage, angiograms, CT, and PET scans do not always provide the definitive information required. Their usefulness depends on the quality of the scans' resolution and the state of knowledge about their interpretation.

In many of the earlier studies, there was little attempt to carefully control for the size and location of the damaged brain area. Thus, patients with small, discrete, lesions of one hemisphere may be grouped with patients who have far more extensive areas of involvement. Additionally, many of the patients who have been classified as having unilateral damage on the basis of very obvious localizing clinical findings such as hemiparesis may, in fact, have undetected bilateral involvement. Even lesions of one side can cause bilateral disruption of function or even result in what may appear to be unilateral deficits produced by the opposite hemisphere. One example of this may be a mass-producing lesion of the right hemisphere which produces very few right hemisphere signs but, as a result of the pressure produced by a midline shift, causes greater left hemisphere dysfunction.

The criticisms of the unilateral lesion method are also applicable to the sodium amylobarbitone and unilateral electro-convulsive methods in that there is very little control over the area that is affected. Although sodium amylobarbitone is injected into one internal carotid artery, the possibility that both hemispheres may be affected cannot be ruled out. It is not unknown for there to be small branches of the anterior or middle cerebral arteries which can feed the opposite hemisphere. Therefore, some of the sodium amylobarbitone can be diffused to both hemispheres without going through the circle of Willis.

In unilateral ECT, electrical impulses are administered to one hemisphere. The subsequent deficits are assumed to be the result of disruption of function in that hemisphere due to the introduction of the electric current. However, when a gross electrical current is introduced to an area, it cannot always be assumed that the electrical current only affects the area to which it is applied. Since the skull has a great resistance to the passage of electricity, the outside of the skull collects the charge and then pours it through the area of the skull which is the thinnest and least resistant (Hayes, 1950). There appears to be a very diffuse flow of current through the brain; the current does not travel in a straight line between the two electrodes, as some ECT proponents suggest (Alexander & Lowenbach, 1944). Although in unilateral

ECT the electricity is only applied to one hemisphere, the convulsion produced is generalized. Therefore, the electrical energy must be transferred to the opposite side of the brain. Since the behavioral and cognitive deficits reported following ECT are reported postictally, they represent the results of bilateral dysfunction.

Split-brain studies. A relatively recent source of evidence concerning hemispheric asymmetries has been provided by those patients who have either been born with agenesis of the corpus callosum or have had their midline cerebral commissures surgically severed in order to control severe, intractable epilepsy (Bogen, Fisher, & Vogel, 1965). In both cases, each hemisphere functions independently since there is no direct communication between them at the cortical level.

Despite the lack of communication between the hemispheres, carefully lateralized testing procedures are required to detect the deficits resulting from commissurotomy (Sperry, 1974). Without this special testing, the deficits can be easily concealed by, for example, shifting an unseen object from one hand to another or by exploratory eye movements since each eye projects visual information to both hemispheres.

It has been demonstrated that each of the separated hemisphere is capable of problem-solving, but tends to employ a

different strategy (Sperry, 1974). Whereas the left hemisphere does well on the verbal aspects of intelligence tests, the scores for the split-brain patients's left hands are far superior to those of the right hands on the Raven's Colored Progressive Matrices, a nonverbal intelligence test that requires perceptual abilities and spatial reasoning (Zaidel & Sperry, 1973).

As in the case of the unilateral disruption methods, the split-brain procedure has greatly enhanced our knowledge of hemisphere asymmetries, but has very serious limitations. For example, sectioning the corpus callosum eliminates most direct transfer of information between the hemispheres; however, some interhemispheric communication may occur below the level of the callosum, particularly in regard to emotional material (Gazzaniga, 1967). Thus, callosal sectioning does not totally isolate the hemispheres.

Another limitation of the split-brain method is its questionable applicability to normals. Since the split-brain procedure has only been performed on patients with severe epilepsy who have been unresponsive to other forms of treatment, there is some question as to whether they can be considered to have had "normal" brains even before the surgical procedure. While the etiologies for epilepsy are diverse, including traumatic head injuries, brain tumors, metabolic and nutritional deficiencies, the common factor is the aberrant

electrical activity produced by certain cells. This points to the fact that the brains of patients with severe, long-term epilepsy may initially have a structural or biochemical deficit that is repeatedly compounded by the effects of recurrent seizure activity. It would seem, therefore, that the brains of epileptics may function differently from those of people without epilepsy.

Secondly, the number of patients that have had the split-brain procedure is relatively small, and can not be considered to be a representative sample of normal adults. The basic rules of inferential statistics warn against generalizing the results obtained from such a sample. There is some indication that the epileptic seizures may be controlled by only sectioning the anterior commissures, leaving the majority of inter-hemispheric connections intact (Sperry, 1974).

A final problem with the applicability of the data collected on split-brain patients is related to the assumptions of the procedure itself. Ornstein et al. (1980) caution that the disconnection itself requires that the brain function differently from normals. The relative isolation of the two hemispheres eliminates one of the most characteristic aspects of cerebral functioning in the normal situation--namely the way in which the two hemispheres interact. Data derived from studies of split-brain patients does not explain how the hemispheres alternate control or combine their abilities. The

procedure may produce an exaggerated picture of lateralized function in the two hemispheres due to the fact that they are disconnected.

Electrical stimulation. During brain surgery on conscious patients, Penfield and Roberts (1959) reported that mild electrical stimulation of the right temporal area resulted in visual illusions or detailed recall of memories. These results were not found after stimulation of the homologous area in the left hemisphere.

Recording techniques. Recording techniques involve much less danger to the subject than the unilateral dysfunction, split-brain, or electrical stimulation methods in that they do not interfere with or disrupt function, but attempt to measure it as it occurs. The general assumption is that the hemisphere which shows the greatest level of activity during a particular task is most involved in the mediation of that task. The recording techniques provide essential supplementary information about hemispheric activity that cannot be obtained via behavioral techniques. They are particularly valuable for measuring brain activity in the absence of overt behavior.

A. Electrophysiology. One method of studying hemispheric asymmetries is to compare the electrical activity of the two sides of the brain. The two primary techniques

used, electro-encephalograms (EEGs), and evoked responses (ERs) both measure gross electrical activity of the cortex via scalp electrodes.

While there are some contradictory findings about the usefulness of the EEG for studying hemispheric differences (Butler & Glass, 1974), there appears to be evidence that the best electrophysiological indicator of hemispheric asymmetries is obtained with the alpha suppression method (Dumas & Morgan, 1975; Galin & Ellis, 1975; Prohovnik, 1978). In addition to being less restrictive than many of the other methods used in studying hemispheric asymmetries, the alpha suppression method provides a fairly direct measure of hemispheric activation which allows inferences to be made about how the two hemispheres are relatively engaged during cognitive activity (Ornstein et al., 1980). It has also been shown to have high test-retest reliability (Ehrlichman & Wiener, 1979; Salamy & Amochaev, 1979).

Since alpha is associated with a state of relaxation, suppression of alpha, or alpha blocking, is associated with increased attention and activation in that brain region. Thus, alpha power is relatively reduced in the hemisphere that is primarily engaged in the task being performed. In general, greater alpha suppression occurs in the left hemisphere during language-related tasks such as reading, writing, speaking, listening to verbal material, syntactic and semantic discrimi-

nations, and arithmetic, whereas greater alpha suppression occurs in the right hemisphere during more spatial or musically-related tasks such as block design, clock rotation, mirror tracking, manipulating forms, playing or watching Pong (T.V. tennis), tonal memory, and singing (Davidson, Schwartz, Pugash, & Bromfield, 1976; Doyle, Ornstein, & Galin, 1974; Ehrlichman & Weiner, 1979; Galin & Ellis, 1975; Galin & Ornstein, 1972; Herron, Galin, Johnstone, & Ornstein, 1979; Osbourne & Gale, 1976; Rebert & Lowe, 1978; Salamy & Amochaev, 1979).

One difficulty with concluding that these tasks differentially engage the hemispheres on a cognitive basis is that they entail rather different perceptual and motor activities which could also affect alpha power. Ornstein et al. (1980) has found task-dependent EEG alpha asymmetries on cognitive tasks that have been selected to reduce afferent and efferent contamination.

In contrast to the continuous EEG, the evoked response (ER) or event related potential (ERP), is a much more discrete electrophysiological event which is in response to the presentation of a specific, discrete stimulus. In contrast to the complex cognitive tasks used in the continuous EEG, the ER studies generally employ simpler stimuli such as flashes, clicks, or words.

Larger visual evoked responses (VERs) have been reported in the right hemisphere than in the left hemisphere (Beck &

Dustman, Note 1) while larger auditory evoked responses (AERs) have been reported in the left hemisphere than in the right & Bromfield, 1976; Doyle, Ornstein, & Galin, 1974; Ehrlichman & Weiner, 1979; Galin & Ellis, 1975; Galin & Ornstein, 1972; Herron, Galin, Johnstone, & Ornstein, 1979; Osbourne & Gale, 1976; Rebert & Lowe, 1978; Salamy & Amochaev, 1979).

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hemisphere (Morrell & Salamy, 1971). These findings may be related to the hemispheric asymmetries in ERs found to non-verbal and verbal stimuli (Buchsbaum & Fedio, 1969, 1970; Marsh, Poon, & Thompson, 1976; Marsh & Thompson, 1973; Thatcher, Roemer, Harrison, & Thompson, 1977). Davis and Wada (1978) maintain that they are 90% accurate in classifying patient's language-dominant hemisphere (as assessed by the Wada technique) on the basis of the comparative AER and VER magnitudes and coherences. A larger AER coherence to a click stimulus in one hemisphere increases the probability of language being lateralized to that hemisphere. Conversely, a larger VER coherence to a flash stimulus in one hemisphere increases the probability that language is lateralized to the opposite hemisphere.

B. Cerebral blood flow. An increase in cerebral blood flow to a particular region of the brain has been shown to be a reliable indicator of the metabolic demand of the neurons in that area (Raichle, Grubb, Gado, Eichling, & Ter-Pogossian, 1976). Thus, the area that receives more blood is assumed to be more active or involved in the functions being performed by the cerebral cortex. Different methods have been developed to study cerebral blood flow patterns, although not all of them are appropriate for studying normal subjects. Probably the least appropriate and least popular of these is the hydrogen clearance polarographic method which requires implantation of 102 electrodes throughout the frontal, temporal,

parietal, and occipital lobes of each hemisphere (Shakhnovich, Serbinenko, Razumovsky, Rodionov, & Oskolok, 1980).

The more common methods for mapping regional cerebral blood flow patterns (rCBF) involve the detection of a radioactive isotope tracer that is introduced into the cerebral blood system and carried through the cerebral arteries. The original procedure for studying rCBF requires the intra-carotid injection of radioactive ^{135} -Xenon (Hoedt-Rasmussen, Sveinsdottir, & Lassen, 1966; Lassen, Hoedt-Rasmussen, Sorensen, Skinhoj, Cronqvist, Bodforss, & Ingvar, 1963). Clearance of the xenon from brain tissue is measured by sodium iodide crystal detectors placed across the subject's head. Hemispheric asymmetries in rCBF have been reported during problem solving and memorization (Ingvar & Risberg, 1967; Risberg & Ingvar, 1973), during speech and reading (Ingvar & Schwartz, 1974), and during sensorimotor activation (Olesen, 1971).

The carotid injection of xenon has a major experimental limitation in that only one carotid artery can be injected at a time, making bilateral simultaneous rCBF measurements of both hemispheres impossible (Carmon, Lavy, Gordon, & Portnoy, 1975). The development of the ^{133} -Xenon inhalation method (Obrist, Thompson, Wang, & Wilkinson, 1975; Risberg, Ali, Wilson, Wills, & Halsey, 1975) allowed bilateral rCBF

studies to be performed which were non-traumatic and non-invasive. A comprehensive review of the method and its applications is presented by Risberg (1980).

Most reports indicate that the resting levels of blood flow in the two hemispheres are almost identical (Prohovnik, Hakansson, & Risberg, 1980; Risberg, Halsey, Wills, & Wilson, 1975), although there are small, but statistically significant, indications of greater mean blood flow in the right hemisphere of strongly right-handed subjects (Brooks, Wypner, & Lennox, 1975; Carmon, Harishanu, Lowinger, & Lavy, 1972; Prohovnik et al., 1980). Prohovnik et al. (1980) also report that the left frontal premotor area differs from the right frontal premotor area in that the left shows much more asymmetry of variance in cerebral blood flow.

More often, differences in rCBF have been used to study hemispheric asymmetries in "activation" while the subject performs a task. This technique has been used to study various sensori-motor and speech functions (Gustafson, Hagberg, & Ingvar, 1978; Halsey, Blauenstein, Wilson, Wills, & Greenspon, 1977; Ingvar & Philipson, 1977; Ingvar & Schwartz, 1974; Larsen, Skinhoj, Soh, Endo, & Lassen, 1977; Olesen, 1971; Roland & Larsen, 1976), verbal and spatial reasoning (Hagberg & Ingvar, 1976; Ingvar & Risberg, 1967; Risberg, Halsey, Wills, & Wilson, 1975; Risberg & Ingvar, 1973; Risberg,

Maximillian, & Prohovnik, 1977), and memory and learning (Hagberg, 1978; Maximillian, Prohovnik, Risberg, & Hakansson, 1978).

Prohovnik et al. (1980) maintain that the rCBF procedure provides more accurate localization of function than the traditional electrophysiological measures. The data obtained with the rCBF methods has been found to be reliable, as shown by the consistency of results across experiments, laboratories, and investigators (Blauenstein, Halsey, Wilson, Wills & Risberg, 1977; Ingvar, 1976; Maximillian et al., 1978; Meyer, Sakai, Naritomi, & Grant, 1978; Prohovnik et al., 1980; Wilkinson, Bull, DuBelay, Marshall, Ross-Russel, & Symon, 1969).

C. Positron-emission tomography. The use of computerized tomography in conjunction with detection of gamma rays emitted by a radioactive tracer, referred to as positron-emission tomography (PET), can create a color-coded visual reconstruction of the metabolic activity of living brain tissue (Ter-Pogossian, Raichle, & Sobel, 1980). Since the radioactive tracers can be inhaled or injected intravenously in the peripheral blood system, the PET scans provide the first method to study internal metabolism and blood flow via relatively non-invasive means (Phelps, Kuhl, & Mazziotta, 1981).

Depending upon the half life of the labeled tracer substances used and the speed of the PET system, different brain

functions can be assessed. Ranging from Oxygen 15 with a half life of two minutes, to Fluorine 18 with a half life of 110 minutes, the various tracers have been used to assess cerebral blood flow, blood volume, tissue permeability, drug levels, and glucose metabolism.

PET scans are not widely available, but preliminary PET scan data on human subjects, supports the concept of metabolic hemispheric asymmetries in the human brain, primarily in the frontal and temporal lobes (Landis, 1980; Farkas, Note 2).

A point that must be raised in relation to the recording techniques is the assumption that activity in the brain, whether measured electrically or metabolically, is equatable with excitatory transmissions. It is generally assumed that if there is an increase in the activity of an area, that area is directly responsible for "producing" the behavior. It is also possible that the activity in that area is of an inhibitory nature, and that the behavioral outcome may result from a decrease in activity of another brain region. Thus, the area labelled as the "center" for a behavior may not be that at all.

Lateralized stimulus presentation. The goal of the lateralized stimulus presentation method is to channel the incoming information to only one half of the brain. In this

way, the two halves of the brain can be compared in their relative ability to perceive and process a particular kind of stimulus or to perform a particular task. It is not easy, however, to project information to only one half of the intact brain since sensory systems are designed to facilitate the wide diffusion of afferent activity. Each eye and ear has both contralateral and ipsilateral projections, requiring the use of special techniques to bring about the initial lateralization of incoming stimuli.

Springer (1977) presents the basic rationale behind the interpretation of performance differences on two of the most commonly used lateralized stimulus procedures, dichotic listening and visual field testing, as reflecting hemisphereic information processing asymmetries:

Both tachistoscopic and dichotic listening experiments assume that visual field and ear effects exist because of an advantage that occurs when the stimulus to be processed and the processor meet directly, i.e., when the stimulus is initially presented to the hemisphere that will be responsible for its processing. A stimulus initially presented to the unspecialized hemisphere is presumed to be at a disadvantage since it is either handled in that hemisphere less efficiently, or must be transferred interhemispherically to the other side. It is easy to envision how less efficient processing might produce a performance decrement, and only slightly more difficult to imagine how information loss associated with interhemispheric transfer could be translated into poorer performance. (pp. 328-329)

A. Visual lateralization: Tachistoscopic paradigm.

The tachistoscope (T-scope) has been used to produce an initial

lateralization of visual input in both split-brain and normal subjects (Geffen, Bradshaw, & Nettleton, 1972; Levy, Trevarthen, & Sperry, 1972; Rizzolatti, Umiltà, & Berlucchi, 1971; Sperry, 1974). Information presented in the right visual field (RVF), falls on the left hemi-retina of each eye. For the left eye it is the temporal retina; for the right eye it is the nasal retina. Since the optic fibers from the temporal retina project to the ipsilateral visual cortex while the optic fibers from the nasal retina cross at the optic chiasm and project to the contralateral visual cortex, the RVF of each eye projects its information to the left hemisphere (Gross & Mishkin, 1977). The same pattern applies to the left visual field (LVF), so that the LVF of each eye projects its information to the right hemisphere. If the stimulus is presented for less than 200 milliseconds, so that saccadic eye movements do not occur, the T-scope paradigm can bring about an initial lateralization of visual information by restricting the input to the visual half-fields of each eye (Springer, 1977).

It is expected that verbal material would be more easily recognized in the right visual field because of the RVF's direct anatomical access to the left hemisphere, if the left hemisphere is specialized for verbal material (Kimura, 1961). In general, material of a verbal nature, such as words, letters, and nonsense syllables, are recognized more accurately

or faster when presented in the RVF rather than the LVF (Barton, Goodglass, & Shai, 1965; Bryden, 1965; Hilliard, 1973; Hines, 1975; Kimura, 1966; Marcel, Katz, & Smith, 1974; McKeever & Huling, 1971). Material of a spatial nature, however, such as geometric shapes (especially ones that are not easily named), dots, line slopes, faces (especially unfamiliar ones), are recognized more accurately or faster when presented in the LVF rather than the RVF (Bryden, 1960; Hilliard, 1973; Hines, 1975; Leehey & Cahn, 1979; Marcel & Rajan, 1975; Rizzolatti et al., 1971; Schwartz & Smith, 1980; Terrace, 1959; Umilta, Bagnara, & Simion, 1978).

White (1972) maintains that much of the experimental evidence from T-scope studies is inconclusive and ambiguous because many of the experiments have been poorly designed, poorly executed, and poorly analyzed. He recommends that there be a:

"Separation of analysis-coding indicators from response output indicators. Until we can be sure that observed tachistoscopic laterality differences do not reflect hemispheric differences in efficiency of response initiation, we shall not be able to meaningfully discuss functional differences in information analysis. To this end, laterality research must employ response measures which are not left-hemisphere dependent. (p. 506)

It seems apparent that while the laterality differences in visual perception obtained with the T-scope can reflect basic hemispheric asymmetries, the results are influenced by

a wide variety of factors. Among these factors White (1970) includes: the type of presentation (unilateral or bilateral); amount, nature, and spacing of the stimulus information elements: intensity of stimulus presentation; the order in which it is reported; the viewing condition employed; and the lateral dominance of the subject (e.g., handedness, eyedness).

Springer (1977) notes that the kind of stimuli used in T-scope experiments--brief, non-foveally presented elements--severely limits the complexity of the stimuli used. Springer views the differences between the hemispheres as being quantitative; thus, stimuli which are easy enough to be handled by either hemisphere will not bring out performance asymmetries. Only when the difficulty of the task is increased may asymmetries appear. Bryden (1965) found no RVF superiority for a 25 millisecond presentation of single capital letters; however, a RVF superiority was obtained when the task was made more difficult by reducing the duration of presentation to 20 milliseconds.

B. Auditory lateralization: Dichotic listening paradigm. In the auditory modality, lateralization of auditory input is basically achieved via the use of the dichotic listening task, first described by Broadbent (1954) and elaborated by Kimura (1961). While some studies report performance

asymmetries for monaurally presented verbal material (Belmore, 1980; Frankfurter & Honeck, 1973), it is difficult to interpret these results in terms of hemispheric asymmetries since each ear projects 60% of its fibers to the contralateral hemisphere and 40% of its fibers to the ipsilateral hemisphere from the level of the superior olivary complex upward (Berlin, 1977). In the dichotic listening paradigm, a different message is simultaneously presented to each ear. There is evidence that, in this competitive situation, there is suppression of information from the ipsilateral fibers (Heilman & Watson, 1977; Milner, Taylor, & Sperry, 1968). Thus, information presented to each ear will primarily be lateralized to the contralateral hemispheres.

When simultaneous, but different, sequences of verbal material are presented to the two ears, there is more accurate reporting of the material presented to the right ear (D. Ingram, 1975a, Kimura, 1961, 1963b, 1967; Knox & Kimura, 1970; McGlone, 1972; Studdert-Kennedy & Shankweiler, 1970). In the same subjects who showed a right ear advantage (REA) for verbal material, a left ear advantage (LEA) has been found for the recognition of music and environmental sounds such as yawning, coughing, and telephone dialing (Kimura, 1964; Knox & Kimura, 1970).

It appears that the dichotic procedure facilitates recognition of material presented to the ear contralateral to

each hemisphere via suppression of ipsilateral fibers (Kimura, 1961); however, there is evidence that the suppression of ipsilateral messages is not complete. Split-brain patients are able to report some of the left ear verbal material that is dichotically presented, although it is a small amount (Gazzaniga, Risse, Springer, Clark, & Wilson, 1975; Milner, Taylor, & Sperry, 1968; Sparks & Geschwind, 1968). The dichotic procedure may not, therefore, satisfy the requirements of purely lateralized input.

The results obtained with the dichotic procedure may be affected by intensity, spectral composition, and temporal variables of the stimulus elements (Berlin, 1977), by perceptual, memory, and attentional factors in the subject (Donnenfeld, Rosen, MacKavey, & Curcio, 1976), and by the response mode (Springer, 1977). While RT is extensively used in T-scope experiments (Geffen et al., 1971; Gross, 1972; Moscovitch, 1972), it is rarely used as a response measure in dichotic listening experiments (Kallman & Corballis, 1975; Springer, 1971a, 1971b, 1973, Note 3). Springer (1977) maintains that hemispheric differences in auditory processing may only be revealed by the dichotic procedure if the task is sufficiently difficult to exceed the "disadvantaged" hemisphere's upper limit of abilities, or the response measure is sensitive enough to detect subtle differences between the hemispheres. The first point is illustrated by the work of

Weiss and House (1973) who demonstrated that, while there are no ear asymmetries for dichotically presented vowels under a favorable signal-to-noise ratio, a REA appears with a lower signal-to-noise ratio. The second point is illustrated by the experiments which report no ear asymmetries for CV vowels dichotically paired with a burst of white noise when percent correct identification is used as the dependent measure (Corsi, 1967; Darwin, Note 4); however, when RT is used as the dependent measure, a 14 millisecond advantage is obtained for the right ear (Springer, 1973).

C. Somesthetic lateralization: Dichhaptic paradigm.

When each hand of a normal adult is tested in the detection of brief tactile stimulation, the left hand is more accurate (Benton, Levin, & Varney, 1973). This left hand superiority is also true of tactual-tactual matching (Milner & Taylor, 1972).

In certain tasks, no difference in accuracy is found when one hand is tested at a time (Carmon & Benton, 1969; De Renzi & Scotti, 1969). Believing that the absence of lateralized hand differences on such tasks was due to the unilateral testing procedures, Witelson (1974, 1976b) attempted to apply the rationale behind the dichotic listening task to somesthesia. Dubbing it a "dichhaptic" procedure, a child had to simultaneously palpate different nonsense shapes with the index and middle fingers of both hands. The child was not allowed to

see the shapes during the 10-second palpation period, but was required to select the two shapes from among a visual display containing the two test stimuli along with four additional shapes that were similar to the ones used.

The rationale behind the use of simultaneous competitive somesthetic input was to "highlight hemispheric asymmetry... by simultaneously activating homologous cortical areas and thus hindering interhemispheric transmission which would be of greater significance for the hemisphere less competent for the task" (Witelson, 1974, p. 13). As in the dichotic listening paradigm where greater ear differences are obtained under competitive stimulation, Witelson predicted greater hand differences in her dichhaptic procedure. The task required haptic, spatial abilities, and a left hand superiority was obtained for a small sample of boys (Witelson, 1974). When both males and females between the ages of 6 and 13 years were tested on the dichhaptic procedure, only the males demonstrated a left hand advantage (Witelson, 1976b).

Subsequent studies of both normal and deaf children do not provide support for Witelson's findings since non-significant right hand superiorities have been reported for these groups (Cranney & Ashton, 1980; LaBreche, Manning, Goble, & Markman, 1977). However, there were some procedural diffe-

rences among these studies which may account for the discrepancy in the results.

Motor lateralization. Since motor responses are generally used as indicators of hemispheric asymmetries, some investigators have directed their attention to the motor responses themselves. Some of the motor responses that have been used to assess hemispheric asymmetries are:

A. Gestural activities. Kimura (1973a) suggests that the right hand may control certain skilled motor functions which happen to easily lend themselves to communication. In her study of people's "free" manual movements during speech, Kimura (1973a, 1973b) reports that people who are left hemisphere dominant for speech, regardless of whether they are right-or left-handed, use their right hand significantly more than their left hand. Kimura concludes that the asymmetry of free movements during speech reflects the asymmetry of cerebral control of language.

B. Lateral eye movements. It has been fairly well established that people tend to look at a person who is speaking to them, but look away when it is their turn to speak (Kendon, 1967). Clinical and experimental evidence from studies of unilateral electrical stimulation of Brodman's area 8, the frontal eye fields, indicate that there is a shift in gaze away from the side of stimulation (Mott & Shafer, 1890;

Penfield & Roberts, 1959; Robinson, 1968). This has led to the postulation that lateral eye movements (LEMs) may be used as an indicator of asymmetrical hemispheric activation. Bakan (1969) writes that:

It may be that the left or right movement associated with the reflective process is symptomatic of easier triggering of activities, in the hemisphere contralateral to the direction of eye movement. (p. 790)

If there is indeed a relationship between the direction of eye movements and hemispheric activation, then LEMs can be used to evaluate which hemisphere is being activated while solving a particular type of problem (Kinsbourne, 1972, 1974a; Kocel, Galin, Ornstein, & Merrin, 1972). Thus, if the eyes move to the right while solving a verbal problem, it is assumed that the left hemisphere is primarily involved, and if the eyes move to the left while solving a spatial problem, it is assumed that the right hemisphere is primarily involved.

While this expected pattern has been found, Ehrlichman and Weinberger (1978), in their comprehensive review of LEMs, report that, of the 19 experiments which have compared LEMs for "left" and "right" hemisphere questions, only nine found significantly greater numbers of right LEMs for left hemisphere questions. One study (Ehrlichman, Weiner, & Baker, 1974) found a significantly greater number of right LEMs for right hemisphere questions, and nine studies found no diffe-

rences in LEMs according to question type. Because more than half of the experiments failed to demonstrate the expected LEM pattern, Ehrlichman and Weinberger question whether LEMs are a reliable indicator of hemispheric asymmetries for cognitive processing. At least, the relationship is more complex than originally assumed.

There are a number of factors which may have contributed to the lack of consensus among the LEM studies. These factors include differences in the kinds of questions used to selectively activate the hemispheres, the scoring procedures used to record eye movements, the recognition of staring as a response, and the position of the experimenter with respect to the subjects.

Manual Interference studies. Interference studies are based on the assumption that simultaneously performed behaviors which interfere with one another do so as a result of intra-hemispheric competition for limited neural space. Kinsbourne and Cook (1971) reported that the ability of subjects to balance a dowel rod was adversely affected by concurrent repetition of the alphabet only when the right hand was used for balancing. Since the verbal cognitive task is assumed to selectively engage the left hemisphere, it would interfere with the left hemisphere's mediation of right hand performance. The right hemisphere would be relatively unencumbered by the task.

Numerous studies have used the basic paradigm of evaluating functional cerebral lateralization via the degree of manual interference produced by concurrent cognitive activity (Dimond & Beaumont, 1971, 1972; Hicks, 1975; Hicks, Provenzano, & Rybstein, 1975; Hiscock & Kinsbourne, 1980; Johnson & Kozma, 1977; Kinsbourne & McMurray, 1975; Lomas, 1980; Lomas & Kimura, 1976; McFarland & Ashton, 1975a, 1975b, 1978a, 1978b; Piazza, 1977). In most cases, the manual activity of the right hand was adversely affected by concurrent verbal activity. This would indicate that both of these activities require voluntary motor performance initiated by the primary and associative motor areas of the left frontal lobe.

Selective disruption of the performance of the left hand during non-verbal cognitive activity has proved to be more difficult. If disruption of left hand performance occurs during these tasks, it is usually accompanied by disruption of right hand performance as well (Bowers, Heilman, Satz, & Altman, Note 5; McFarland and Ashton, 1978a). Lomas (1980) writes:

It is suggested, therefore, that lateralized intra-hemispheric competition is not simply attributable to competition between two activities controlled by the same hemisphere.... Rather, the inability to obtain lateralized interference with right hemisphere tasks suggests it is a phenomenon restricted to the left hemisphere. (p. 147)

One example of left hand interference was reported by Smith, Chu, and Edmonston (1977) who found that the accuracy of the left hand in the haptic identification of Braille letters was reduced by playing music to the left ear, while the accuracy of the right hand was not reduced by playing music to the right ear. Since each hand was tested separately, it is difficult to tell if both hands would have been affected by music played to the left ear. However, in the condition in which the right hand was tested alone during music presentation to the left ear, right hand performance was enhanced. Smith et al. concluded that detectable interference by the auditory stimulus of tactual perception occurred only in the situation where the dominant perceptual mechanisms associated with each stimulus resided in the same hemisphere.

In light of findings that not all right hand activities are disrupted by concurrent verbal activity, it appears that interference between two tasks is not produced solely by being processed by the same hemisphere," but rather that it results from the degree of functional similarity of the competing systems within the hemisphere" (Lomas, 1980, p. 141). Kinsbourne and Hicks (1978) refer to a concept of cerebral geography where different tasks can be simultaneously mediated within the same hemisphere as long as they each occupy their own functional cerebral space. It is when two tasks attempt

to occupy proximal functional space within a hemisphere that interference occurs.

Lomas and Kimura (1976) and Lomas (1980) propose that competition between verbal systems and manual activity occurs when the manual activity involves position changes in the absence of visual guidance. This competition may occur because speech also requires a fast sequence of changes in the position of the articulator muscles without visual guidance.

The interference studies are plagued by a common problem in research on laterality, and that is in the definitions of what are right and left hemisphere tasks. It is difficult to predict the occurrence of interference between two tasks on the basis of the functional cerebral space they occupy when it is not really known which areas of the brain are responsible for which tasks. Thus, even if two tasks interfere with one another, it does not necessarily localize functions within the brain. If two tasks such as music perception and tactile perception of Braille [as used in the Smith et al. (1977) study] are selected to interfere, it can be argued that elements of music perception involve both hemispheres, as does interpretation of Braille letters.

Neuroanatomical asymmetries. One approach to studying hemispheric asymmetries has been to look for structural and

biochemical differences between the hemispheres and attempt to relate them to the behavioral differences that have been observed. The attempt to find physiological differences between the two cerebral hemispheres has been something akin to a function in search of a structure. If there had not been so much interest in the functional differences between them, the apparent morphological symmetry of the hemispheres would probably have been accepted as such.

A. Magnitude differences. Since there is no known structure which is present on only one side of the brain, attention has been paid to the relative size of homologous brain regions of the two hemispheres in an attempt to correlate anatomical and functional asymmetries.

1. Planum temporale. The area in the auditory region of the left hemisphere referred to as the planum temporale is thought to be of prime importance in language function (Geschwind, 1967; Ingvar & Schwartz, 1974; Penfield & Roberts, 1959; Wernicke, 1874). It has been reported that, in the majority of adults and infants, the planum temorale is larger in the left hemisphere than in the right hemisphere (Chi, Dooling, & Gilles, 1977; Geschwind & Levitsky, 1968; Teszner, Tzavaras, Gruner, & Hecaen, 1972; von Economo & Horn, 1930; Wada, 1969; Wada, Clarke, & Hamm, 1975; Witelson & Pallie, 1973).

Recent investigations of anatomical asymmetries in the human brain at post-mortem have re-emphasized the differences found in the left and right Sylvian fissures, as first noted by Cunningham in 1892. Rubens, Mahowald, and Hutton (1976) found that, in the adult brain, at least 69% had a more pronounced and more anteriorly placed upward angulation of the right Sylvian fissure. The pattern is concomitant with a reduction in the length of the planum temporale and frontal operculum of the right hemisphere. Thus, the Sylvian fissure angle may be related to the larger language areas of the left hemisphere.

Galaburda, Sanides, and Geschwind (1978) raise the possibility that the extent of the planum temporale, which is a surface measure, may not accurately reflect the size of the cytoarchitectonic area, since much of the cortex may be buried in sulci. It is possible that the left and right areas are of equal size but, due to the folding pattern of the cortex, create a smaller or larger surface area. Galaburda et al. conclude, however, that there are true size differences between the left and right planum temporale.

2. Posterior bulk. In 1907, G. E. Smith first noted that the bulk of the left occipital pole was larger than the bulk of the right occipital pole. This observation was supported by the finding that the impression made by the left occipital lobe on the cranial vault is larger than the

impression made by the right occipital lobe 2-4 times more frequently (Gundara & Zivanovic, 1968). The occipital horn of the lateral ventricle also tends to be significantly longer in the left hemisphere (McRae, Branch, & Milner, 1968).

The size of the left occipital lobe is reflected by the position of the distal superior sagittal sinus. Inglessis (1925) reported that the superior sagittal sinus was pulled to the right in 60% of the brains he studied, indicating greater left-sided bulk. This off-centered position was also noted in a 20 mm embryo (Streeter, 1915). The transverse sinus was also higher on the right, again indicating greater bulk of the posterior portion of the left hemisphere (Hochberg & LeMay, 1975; LeMay, 1976).

In contrast to post-mortem autopsy studies, Hier, LeMay, Rosenberger, and Perlo (1978) report that the use of computerized tomography (CT scans) can help establish the relative sizes of the two parieto-occipital regions in patients on whom behavioral evidence can be collected. Chui and DaMasio (1980) maintain that human cerebral asymmetries as assessed by CT scan provide an index of language lateralization that is more direct and accurate than handedness. Right-handed global aphasics with a CT pattern of "reverse asymmetry" (larger right than left parieto-occipital regions) show greater improvement than those who show a regular left-hemisphere

predominance (Pieniadz, Naeser, Koff, & Levine, Note 6). Hier et al. (1978) conclude that a reversal of the normal pattern of a wider left than right parieto-occipital region on the CT scan is associated with impaired verbal performance in dyslexic patients.

3. Parietal region. The asymmetries in the Sylvian fissures discussed by Rubens, Mahowald, and Hutton (1976) also have significance for the size of the parietal lobes. The more anteriorly placed right Sylvian fissure is significant in that it is related to a comparative increase in the anterior-posterior extent of the right parietal area posterior to the fissure. It is this area that is known to be involved in many visuo-spatial abilities (Ornstein et al., 1980).

The positioning of the Sylvian fissures also seems to be of significance for the distribution of the middle cerebral arteries. In dextral subjects there appears to be a consistent difference in the magnitude of the angle formed by the middle cerebral arteries as they leave the posterior end of the right and left Sylvian fissures. On the average, the right Sylvian point angle is 23.5 degrees larger than the left angle (Hochberg & LeMay, 1975; LeMay & Culebras, 1972). Carmon, Harishanu, Lowinger, and Lavy (1972) maintain that the greater diffusion of cerebral blood flow over the right

hemisphere is indicative of the right hemisphere being more physiologically developed than the left.

Organismic Variables and Hemispheric Organization

The preceding discussion concerning the patterns of hemispheric lateralization has assumed that there is one clear pattern of hemispheric specialization present in all people. However, it appears that the general pattern of left hemisphere specialization for verbal/analytic/sequential/complex abilities and right hemisphere specialization for spatial/holistic/synthetic/simple abilities is not universal (Milner, 1974a; Milner, Branch, & Rasmussen, 1964, 1966). Certain organismic variables have been found to be correlated with distinctive cerebral organization patterns. These include: handedness, writing position, family sinistrality, and gender.

Handedness. Hand preference is a fairly accurate indicator of language lateralization in the majority of dextral individuals, who comprise about 86 to 92% of the general population (Briggs & Nebes, 1975; Durost, 1934; H. Gordon, 1920; Haefner, 1929; Hardyck & Petrinovitch, 1977; Hardyck, Petrinovitch, & Goldman, 1976; Hildreth, 1949a, 1949b; Jasper & Raney, 1937; Newcombe & Radcliffe, 1973; Ojemann, 1930a, 1930b; Oldfield, 1971; Quinan, 1930; Updergraff, 1932). When the data was combined from six studies using various methods, 700 of the 737 dextral patients (95%) demonstrated left hemi-

sphere language specialization (Davis & Wada, 1978). Most studies agree that the vast majority of right-handers appear to have language function subserved primarily by the left hemisphere (Butler, 1971; Levy, 1974; Penfield & Roberts, 1959; Pratt & Warrington, 1972; Wada & Rasmussen, 1960; Zangwill, 1960, 1967), although the exact estimates vary from about 90 to 99%.

The relationship between handedness and cerebral organization is generally more complex in sinistrals than in dextrals (Carter, Hohenegger, & Satz, 1980; Kimura & Vanderwolf, 1970). Hughlings Jackson (cited in Critchley, 1972) was one of the earliest writers to draw an association between dysphasia and left hemiparesis in patients who had been left-handed prior to right hemisphere damage.

The majority of left-handers, however, do not show right hemisphere specialization for language. It is generally estimated that approximately two-thirds of left-handers show left hemisphere language specialization (Goodglass & Quadfasel, 1954; Hecaen & Sauguet, 1971; Piercy, 1964; Prohovnik, 1978; Roberts, 1969; Russell & Espir, 1961; Wada & Rasmussen, 1960; Warrington & Pratt, 1973; Zangwill, 1967). The remaining third is either right hemisphere language specialized or has bilateral language representation (Beaumont, 1974; Benton,

1962; Branch, Milner, & Rasmussen, 1964; Jones, 1966; Levy, 1969, 1972; Levy & Sperry, 1968; Milner, Branch & Rasmussen, 1964, 1966; Rossi & Rosadini, 1967; Subirana, 1969; Zangwill, 1967; Zurif & Bryden, 1969).

Much of the evidence concerning bilateral representation of language in left-handers has derived from clinical reports of aphasia being more common after unilateral lesions of either hemisphere, as opposed to its occurrence in right-handers who generally only show dysphasia when the left hemisphere is damaged (Annett, 1970b; Botez & Crighel, 1971; Brown & Jaffe, 1975; Chesher, 1936; Gloning, Gloning, Haub & Quatember, 1969; Gloning & Quatember, 1966; Goodglass & Quadfasel, 1954; Hecaen & Piercy, 1956; Luria, 1947). In a comprehensive review of the major studies in the area, Satz (1979) reported that the incidence of aphasia in adults following a unilateral brain injury was 58% for the left-handed patients, but only 33% for the right-handed patients. Satz generated a model of speech representation in left-handers on the basis of the expected likelihood of aphasia (given a lesion of the language hemisphere) which predicted, in essence, that 15% of left-handers would have left hemisphere representation, 15% would have right hemisphere representation, and 70% would have bilateral representation. Carter, Hohenegger, and Satz (1980) have reviewed Satz's (1979) study and suggest that,

while right-handers appear to show unilateral speech specialization in the proportions of 95% left and 5% right hemisphere representation, the left-handers appear to show 24% left hemisphere representation and 74% bilateral.

While bilateral speech representation in left-handed patients may make them more susceptible to aphasic difficulties since language problems could result from damage to either hemisphere; its advantage is that, for such individuals, the symptoms are generally found to be milder and more transient (Hecaen & de Ajuriaguerra, 1964; Luria, 1947; Subirana, 1958). Carter et al. (1980) discuss the combined data from Luria and Subirana's studies which demonstrated that residual aphasia following left hemisphere damage was found in 95% of the right-handed patients and in only 32% of the left-handed patients. The authors suggest that the higher percentage of remissions among left-handers is due to the large group of left-handers with bilateral speech representation. Carter et al.'s predictive model would conclude that 24% of left-handers and 95% of right-handers who show aphasia following left hemisphere damage would recover slowly. These predicted values are fairly close the reported values of 32% and 95%, respectively.

A variety of studies have provided evidence of less hemispheric asymmetry in left-handers than in right-handers. In regard to morphological asymmetries observed on angiograms,

Hochberg and LeMay (1975) reported that, in 67% of their right-handed sample, the angle formed by the vessels leaving the posterior end of the Sylvian fissure was at least 10 degrees greater in the right hemisphere than in the left hemisphere, with a mean difference in Sylvian point angles being 23.5 degrees. In the left-handed sample, however, only 21.4% had greater right than left Sylvian point angles of more than 10 degrees and the mean difference in Sylvian point angles was 6.6 degrees. While the exact significance of this asymmetry is unknown, it is possible that it reflects differences in the distribution of the middle cerebral arteries and in the diffusion of blood across the areas they supply. The important point is that the left-handed sample had evidence of less asymmetry on this measure.

Behavioral evidence from tests of lateralized presentation of stimuli such as in the tachistoscopic and dichotic listening paradigms indicate that there are smaller right and left visual field and ear differences, respectively, for left-handed subjects than for right-handed subjects (Bryden, 1965; Zurif & Bryden, 1969). While the verbal intelligence scores of left-handers are nearly identical to those of right-handers (Berman, 1971; Gilbert, 1973; Levy, 1969; Miller, 1971), they do not do as well on certain visuo-spatial tasks (James, Mefferd, & Wieland, 1967; Mefferd, & Wieland, 1965;

Nebes, 1971; Silverman, Adevai, & McGough, 1966). One explanation offered for this relatively poorer visuo-spatial performance in left-handers relies on the concept of "interference." If language is represented in both hemispheres, it may interfere with the visuo-spatial functions of the right hemisphere by occupying neural space that may have been used for spatial functions had language been more strongly localized to the other hemisphere (Levy, 1969, 1972; Levy & Sperry, 1968).

Electrophysiological recordings indicate that there is a greater degree of asymmetry between the EEG recordings from the right and left hemispheres of right-handed than from those of left-handed individuals (Butler & Glass, 1974; Herron, Galin, Johnstone, & Ornstein, 1979; Hynek, Tosovsky, & Susova, 1975). Cernacek and Podivinsky (1971) report that, while the somatosensory evoked response (SER) of right-handed children was reliably higher in the left-hemisphere, the SERs of left-handed children produced a much more variable pattern.

The slow cortical potentials that precede voluntary movement are consistently larger over the hemisphere contralateral to the hand being used in right-handed subjects (Kutas & Donchin, 1974). However, while left-handed subjects have a slightly larger contralateral than ipsilateral wave form when they use their left hand, bilaterally symmetrical wave forms are produced when they use their right hand. Kutas and Donchin

maintain that their results provide evidence for less cerebral asymmetry in left-handed individuals.

A. Methodological issues in handedness. There are certain methodological problems in the use of handedness as a measure of cerebral organization. Two of the most basic problems are, first, the consistency of handedness classifications from one study to the next, and secondly, the criteria used for assigning subjects to these handedness categories. It is difficult to compare the performance of left-handers across studies in which left-handedness has been defined differently.

Handedness has traditionally been viewed as a dichotomous variable; that is, a person is either right- or left-handed. Many studies, especially earlier ones, assessed handedness by merely asking subjects whether they were right or left-handed. It was assumed, of course, that individuals could accurately answer such a question. This is true for the person who consistently does everything with the same hand. Difficulty arises in classifying people who alternate in their hand preference for a particular task or who use one hand consistently for certain tasks and the other hand consistently for other tasks.

Critchley (1972) recognized that, in a large sample of normal subjects, one would find that most people possess a

varying degree of motor dominance and cerebral laterality. This implies that there is a continuum from strongly right-handed to strongly left-handed. However, the distribution would probably be skewed in that there would be a preponderance of strongly right-handed subjects and relatively few left-handers at each point along the distribution. Certainly, when a relatively small sample of people are studied, there may appear to be discontinuous handedness groups since few people will be found in many of the intermediate left-handedness measures. In reality, it is often more practical to use such discrete handedness groups since, unless a very large sample is used, there would not be a sufficient range of scores for a continuous variable.

If discontinuous handedness groups are employed to subdivide the sample, some general agreement should be reached about the number of categories that should be included and about the criteria for inclusion in each category. In addition to the usual distinction between right- and left-handers, Flowers (1975) suggests a third group of ambilaterals who, despite the fact that they claim to be equally "good" with each hand, cannot perform as well with either hand as the average right or left hander can with the dominant hand. This indicates that people who use both hands are not necessarily "ambidextrous" in the sense that they have two dominant hands.

Todor and Doane (1977) maintain that ambilaterals can be subdivided into ambisinistrals (who show poor performance with either hand on adaptive motor tasks) and ambidextrals (who show performance with either hand that is equal to the dominant hand of lateralized subjects). Herron (1976) proposes that, in addition to hand-variables and bimanuals (the respective equivalents of ambisinistrals and ambidextrals), there exist hand-specific people who consistently prefer one hand for some tasks and the other hand for other tasks.

Many of the handedness inventories available take the form of a questionnaire that asks the subject to report which hand is generally used to perform each of a number of simple, commonplace tasks such as writing one's name or throwing a ball (Annett, 1970b; Benton, Meyers, & Polder, 1962; Briggs & Nebes, 1975; Crovitz & Ziner, 1962; Hildreth, 1949a, 1949b; Oldfield, 1971; Satz, Achenbach, Pattishall, & Fennel, 1965). The performance inventories require that the subject actually perform the same type of basic tasks that are only asked about in the questionnaires (Roudinesco & Thyss, 1948; Subirana, 1961; Zazzo, 1960).

It appears that questionnaires concerning hand preference do not always accurately reflect actual proficiency on performance measures (Barnsley & Rabinovitch, 1970; Benton et al., 1962; Provins & Cunliffe, 1972; Raczkowski, Kalat, & Nebes,

1974; Satz, Achenbach, & Fennell, 1967; Todor & Doane, 1977). In those studies that use questionnaires alone, the errors tend to be more frequent in mis-classifying left-handers than right-handers (Benton et al., 1962; Satz et al., 1967). Estimates of left-handedness in the general population vary between 1 and 30%, depending on the specific method used (Hardyck & Petrinovitch, 1977). When performance measures are used, the estimates are more stable, ranging between 8 and 10% (Durost, 1934; H. Gordon, 1920; Haefner, 1929; Hardyck, Petrinovitch, & Goldman, 1976; Hildreth, 1949a, 1949b; Jasper & Raney, 1937; Newcombe & Radcliffe, 1973; Ojemann, 1930a, 1930b, Oldfield, 1971; Quinan, 1930; Updergraff, 1932).

A simple performance measure suggested by Syed (1979) requires that the subjects spread their fingers so that there are two pairs of fingers on each hand. One pair is formed by joining the second and third fingers and the other pair by joining the fourth and fifth fingers. The subjects must stretch the two pairs as far away from each other as possible. Syed reports that, when the measurements of maximum spread between the paired fingers are compared, the right-handed person stretches the paired fingers of the left hand farther than the paired fingers of the right hand. People who show no difference in spread are generally classified as right-handed, but they tend to be people who use both hands in

their work and who have good coordination (such as pianists and typists). Larger spread between the paired fingers of the right hand than the left hand is indicative of left-handedness, as is the inability to pair the fingers of the right hand. Further testing is required to determine the validity of this measure.

B. Writing position. Levy and Reid (1976) suggest that writing position, in addition to handedness, provides important information about the hemisphere predominant for language and that predominant for spatial abilities. There are two basic writing positions described: the noninverted position (N) in which the hand is held below the line of writing and the point of the pen is directed towards the top of the page, and the inverted position (I) in which the hand is held above the line of writing and the point of the pen is directed towards the bottom of the page. Levy and Reid postulate that the hemisphere specialized for language is contralateral to the writing hand of noninverted writers and ipsilateral to the writing hand of inverted writers. This hypothesis is supported by the finding that a right visual field superiority for verbal stimuli and a left visual field superiority for spatial stimuli is found in right-handed noninverters (RN) and left-handed inverters (LI) (Levy & Gur, 1980; Levy & Reid, 1976; Moscovitch & Smith, 1979).

Levy and Reid (1976) also report that left-handers with the inverted writing position show smaller degrees of lateral differentiation on verbal and spatial tachistoscopic tests than either right- or left-handers with the noninverted writing position. The actual significance of the inverted writing position is not known, although it has been reported that, among left-handers, LI writers show a mild decrement in performance on certain cognitive and neuropsychological tests (Gregory & Paul, 1980), and an elevated probability of familial psychiatric problems (D. B. Cohen, 1978) as compared to LN or RN writers. Gregory and Paul (1980, p. 234) conclude that "apparently, left-inverted hand writing style is a marker for less than optimal adjustment in both the psychological and neuropsychological realms." However, evidence reported after the data were collected for the present study indicates that the relationship between writing position and cerebral laterality may be more complex than originally proposed (Parlow & Kinsbourne, 1981; Tapley & Bryden, 1983), if a relationship exists at all (Bashore, McCarthy, Heffley, Clapman, & Donchin, 1982; Bradshaw, Nettleton, & Spehr, 1982; Herron, Galin, Johnstone, & Ornstein, 1979; Smith & Moscovitch, 1979; Weber & Bradshaw, 1981).

C. Family sinistrality (FS). Any attempt to define the relationship between handedness and cerebral organization is further complicated by the fact that the two basic handedness groups (if handedness is treated as a dichotomous variable) may be further sub-divided on the basis of familial history of sinistrality, and that the sub-groups with FS appear to demonstrate different patterns of performance on tasks used to assess hemispheric specialization than the sub-groups without FS (Bryden, 1965; Zurif & Bryden, 1969). Family history of dextrality does not appear to correlate with performance on such tasks.

Inherent in the study of family sinistrality is the assumption that handedness is largely genetically determined (Annett, 1964, 1967, 1975). In a large study of familial handedness among college students and faculty, Leiber and Axelrod (1981) conclude that:

Incidental intra-familial modeling or adaptation has only a miniscule effect on manifest handedness and that intentional reversals of handedness result in decreased strength and consistency of hand usage, regardless of the direction of change... there are definite limits--set, we assume, by biological determinants--to the influence which training can exert on human handedness. (p. 286)

A corollary to the theory that handedness is inherited is that hemispheric patterns for language lateralization are also inherited. Levy and Nagylaki (1972) have devised a genetic

model for handedness which involves two genes and four alleles. One gene determines the hemisphere for language dominance while the other determines whether hand preference will be contralateral or ipsilateral to the language hemisphere. There are, therefore, nine possible alternative genotypes for hemisphere specialization and handedness that one can inherit.

Many of the studies on family sinistrality provide contradictory evidence about its relationship to handedness and cerebral organization. However, one basic problem in many of the FS studies is that even though great care may be taken in assessing the handedness of the respondent, information about familial handedness is generally obtained by the verbal report of the subject. In addition, the studies differ in what defines the presence of FS. Although it generally refers to the presence of sinistrality in either parents or siblings, some studies include aunts, uncles, grandparents, etc..

Leiber & Axelrod (1981) report that, in comparison with respondents who had only dextral relatives, the incidence of self-declared sinistrality was significantly higher when there were non-dextral siblings in the family, even higher when either parent was non-dextral, and highest when there were both non-dextral siblings and parents. Familial sinistrality was also related to the degree of handedness (as assessed by a questionnaire combining the Annett and Edinburgh scales and

defined in terms of strength and consistency). Degree of right-handedness was reduced more by a non-dextral parent than by a non-dextral sibling, and most reduced when there were several non-dextrals in the family. The degree of left-handedness also decreased with increasing numbers of non-dextrals in the family, a rather surprising result.

Studies that have sub-divided right- and left-handers on the basis of family sinistrality when looking at performance on measures of hemispheric specialization such as dichotic listening and tachistoscope tasks indicate that the presence of family sinistrality is a more significant factor in the brain organization of left-handers than in that of right-handers. For example, right-handed subjects, regardless of familial history of sinistrality, are more accurate and have faster reaction times to verbal stimuli in the right visual field on tachistoscopic tasks (G. Cohen, 1972; Dimond & Beaumont, 1974; Hines & Satz, 1971; McKeever, Gill, & Van Deventer, 1975; McKeever, Van Deventer, & Suberi, 1973). However, the relationship between FS and brain organization in left-handers is much less clear. There is evidence which suggests that left-handers with FS tend to be less dependent upon the left hemisphere for language function than non-familial left-handers (Annett, 1973; Bryden, 1970; Dee, 1971; Hines & Satz, 1971; McKeever et al. 1973). This is not to

say that the FS left-handers do not have any left hemisphere language ability, but that language may be more bilaterally mediated (Piazza, 1980).

Evidence from studies of patients with unilateral brain lesions indicate that aphasic difficulties occur following damage to either hemisphere in FS left-handers, whereas in left-handers with no family history of sinistrality, aphasic difficulties occur more frequently following lesions of the left than of the right hemisphere (Hecaen & Sauguet, 1971). Luria (1970) suggests that the presence of FS is a positive predictor of speech recovery following left hemisphere lesions in both right- and left-handers. Subirana (1969) maintains that:

The cases seen in the last years authorize me to write that the aphasics with a left-handed sibling are nearly always the champions of the language rehabilitation division. (p. 268)

There appears to be a tendency towards a reversed pattern of lateral asymmetries in left-handers with FS as compared to the usual pattern found in dextrals and in left-handers without a family history of sinistrality. It has been reported that there is superior recognition of verbal material presented in the left visual field (Bryden, 1965; Zurif & Bryden, 1969), to the left ear on dichotic listening tasks (Dee, 1971; Zurif & Bryden, 1969), and of tactile direction with the right

hand (Benton, Levin, & Varney, 1973) in FS left-handers. These findings would indicate that in familial left-handers the right hemisphere may be more involved in language mediation than the left hemisphere.

In a summary of 15 studies which have employed family sinistrality as a category variable, Hardyck and Petrinovitch (1977) report that, for FS left-handers, 10 studies showed smaller between-hemisphere differences and five studies showed no between-hemisphere differences. Hardyck and Petrinovitch suggest that:

Bilaterality of cerebral organization is not a characteristic of the non familial left-handed and that, as a group, they are organized for cerebral specialization exactly as are the right-handed. Such individuals may be left-handed owing to some early brain insult. (p. 396)

Bakan (1975) maintains that all left-handedness is pathological in origin and is the result of birth trauma. The tendency for left-handedness to run in families is explained by a genetic predisposition towards birth trauma in such families (Bakan, Dibb, & Reed, 1973). A more moderate view is presented by Satz (1972) who argues that while pathological factors can account for the high incidence of left-handedness in clinical populations (Bakan, 1973; Hecaen & Piercy, 1956; Hicks & Barton, 1975; Lonton, 1976), as well as some of the left-handers in the general population, there is a group of

"normal" left-handers who are genotypically as well as phenotypically left-handed.

Using family sinistrality and writing position as criteria for classifying subjects into handedness groups may help eliminate some of the heterogeneity found among left-handers. In their study of inverted writing position, Gregory and Paul (1980) report that the presence or absence of FS had no relation to the neuropsychological test performance of the left-handers with a noninverted writing position. However, those inverted left-handers with no history of FS scored considerably poorer than those with a positive history of FS. Gregory and Paul conclude that:

Lack of family history for left-handedness and inverted writing style, when combined as marker traits, appear to have a synergistic effect in the prediction of relative inferior performance on [neuropsychological] tests.
(p. 234)

Gender. It has long been noted that men and women differ in their ability to perform certain types of tasks. Women often excel in verbal and memory tasks while men often excel in visuo-spatial and arithmetical reasoning tasks (Guilford, 1967; Kimura, 1973c; Maccoby & Jacklin, 1974). In a task in which subjects are required to mentally count the number of letters in the alphabet that, when pronounced, contain the sound "ee", women are more accurate and faster, however,

when the same subjects are required to mentally count the number of letters in the alphabet that, when printed as capitals, contain curves, men are more accurate and faster (Coltheart, Hull, & Slater, 1975).

The differential performance of men and women on verbal and spatial tasks may be related to sexual dimorphism of the brain in regard to lateralization of function. There is little agreement, however, on the exact nature of these differences.

Levy (1972) maintains that women possess bilateral representation of language function which interferes with visuospatial functions. This would explain the less proficient performance of women on many measures of spatial abilities when compared to men (Porteus, 1965; I.M. Smith, 1967; Wechsler, 1958).

Evidence from unilateral brain lesion, anatomical, electrophysiological, and behavioral studies indicate that language function may be more bilaterally controlled in women (Bradshaw, Gates, & Nettleton, 1977; Davidson, Schwartz, Pugash, & Bromfield, 1976; Edwards, Ellams, & Thompson, 1976; Hannay & Malone, 1976; Harshman, Remington, & Krashen, 1976; Lake & Bryden, 1976; Landsdell, 1961, 1973; Levy & Reid, 1976; Marshall & Holmes, 1974; McGlone, 1977; Ray, Morell, Frediani, & Tucker, 1976; Wada, Clarke, & Hamm, 1975).

In addition to the work on lateral differences in verbal abilities, numerous investigators have found that visuo-spatial abilities are more consistently lateralized in males than in females (Kimura, 1969; Lansdell, 1962, 1968; McGlone & Davidson, 1973; McGlone & Kertesz, 1973). Men with right hemisphere damage perform more poorly on visuo-constructional tasks such as the block design subtest of the WAIS than non-asphasic men with left hemisphere damage (Inglis & Lawson, 1981; McGlone, 1977). Women perform equally well with either left or right hemisphere damage.

de Lacoste-Utamsing and Holloway (1982) report that the splenium of the corpus callosum is larger and more bulbous in women than in men. When a discriminant analysis was performed using total callosal area, maximum splenial width, and surface areas of the posterior fifth and third of the corpus callosum as variables, male and female callosa were correctly identified in each of the 14 cases. Citing evidence that the splenium is important in the interhemispheric transfer of visual information, de Lacoste-Utamsing and Holloway speculate that:

If we are to believe that a larger splenium implies a larger number of fibers interconnecting cortical areas and that the number of fibers correlates inversely with lateralization of function, then our results are congruent with a recent neuropsychological hypothesis that the female brain is less well lateralized--that is, manifests less hemispheric specialization--than the male brain for visuospatial functions. (p. 1432)

A contrary view to the Levy hypothesis is presented by Buffery and Gray (1972), who maintain that the female brain is more clearly lateralized than the male brain and has language exclusively localized in the left hemisphere and spatial skills in the right hemisphere. The male brain is seen as having bilateral representation of spatial skills which can compromise language function. Buffery and Gray suggest that the organization of the female brain is most efficient for linguistic skills which demand quick associations and serial ordering whereas the male brain's bilateral spatial representation is more appropriate for handling spatial skills in a three-dimensional world.

There is little direct evidence to support the notion of greater lateralization in the adult female brain. Witelson and Pallie's (1973) report of reduced left-right planum temporale differences in males as compared to females was based on post-mortem analysis of 14 neonatal brains. The report of greater hemispheric competition on a facial recognition task in males than females was based on a study of children between the ages of 5-11 (Young & Ellis, 1976).

An indirect line of evidence for greater bilateral representation of function in males stems from reports of a higher incidence of left-handedness in males (Annett, 1967; Oldfield, 1971). Since left-handedness has been associated

with both bilateral representation of function and being male, bilateral representation of brain function has been associated with being male. However, guilt by association does not constitute proof and represents fallacious reasoning. First, left-handers are a rather heterogeneous group, and it has not been definitively shown that the left-handers with bilateral representation of function are predominantly male. Secondly, most of the studies on left-handers have discussed bilateral representation of language function, which does not necessarily mean that visuo-spatial abilities are also bilaterally represented (Marcel & Rajan, 1975). Lastly, not all reports concur with the higher incidence of left-handedness in males (Briggs & Nebes, 1975; Falek, 1959).

Rationale for the Present Study

The underlying question in this study is whether the pattern of cerebral hemispheric interaction and the degree of hemispheric input to the right and left hands can be altered via different patterns of hand movement. More specifically, can bimanual simultaneous asymmetrical movement result in reduced ipsilateral hemispheric input to each hand; and if the task requires abilities considered to be primarily the province of the right hemisphere, will that reduction in ipsilateral input more adversely affect the performance of the right hand than of the left hand?

The task employed required that blindfolded subjects attempt to locate a target they had seen prior to being blindfolded by making a simple, ballistic, abductive hand/arm movement. Each subject was tested under three movement conditions: unimanual, simultaneous symmetrical, and simultaneous asymmetrical. In the unimanual condition, each hand was tested separately; in the simultaneous symmetrical condition, both hands aimed for targets at corresponding locations; and in the simultaneous asymmetrical condition, both hands aimed for targets at different locations.

Certain assumptions underlie the development of the experimental task. These assumptions derive from a review of the literature on motor activity and from studies involving simultaneous competitive stimulation in various sensory modalities. The first assumption is that during unimanual activity, there is both contralateral and ipsilateral hemisphere input to the moving hand. The second is that, during simultaneous asymmetrical movement, ipsilateral hemisphere input is reduced both through uncrossed fibers and transcallosal connections. The third is that the task selected--target localization without visual guidance--maximizes right hemisphere/left hand abilities and minimizes left hemisphere/right hand abilities.

In the motor system, approximately 80% of the pyramidal fibers arise from the contralateral hemisphere (Thompson,

1967). However, electrical stimulation of the precentral motor cortex produces increased firing in ipsilateral as well as contralateral pyramidal tract fibers (Goldring & Ratcheson, 1972; Pieper, Goldring, Jenny, & McMahon, 1980). In addition, there are callosal projections between the motor areas of the two cerebral hemispheres, including the hand area (Jenny, 1979; Pandya & Vignolo, 1971). Thus, it is possible for both hemispheres to participate in directing any unilateral motor act.

Although the actual innervation for a smooth, goal-directed movement of the right hand will occur maximally in the left hemisphere (Grunewald, Grunewald-Zuberbier, Homberg, & Netz, 1979), it is reasonable to assume that the spatial abilities of the right hemisphere are involved in the trajectory of the movement. Gazzaniga (1967) reports that some split-brain patients could draw better with their left hands after surgery even though they had been able to draw better with their right hands prior to surgery. This is also true of performance on other constructive tasks such as block design (Bogen & Gazzaniga, 1965; Gazzaniga, Bogen & Sperry, 1962, 1967). Le Doux, Wilson, and Gazzaniga (1978) maintain:

That the right hand loses much (though not all) of its capacity to perform on the block design task in free vision immediately after brain bisection suggests that the efficient performance of the right hand in normal subjects is highly dependent on commissural connections. (p. 508)

In the normal situation, then, even unilateral movements probably involve the participation of both hemispheres. It is, in fact, difficult to prevent bilateral involvement in motor activity. Voluntary contraction of muscles in one limb is accompanied by electro-myographic activity in the symmetrical muscles of the opposite limb, indicating transcallosal irradiation of unilateral movements (Cernacek & Podivinsky, 1966; Podivinsky, 1964). In order to perform a unilateral motor movement, it appears to be necessary to inhibit motor activity on the other side.

If normal unilateral motor activity requires inhibition of contralateral activity, the performance of simultaneous asymmetrical motor acts should be even more difficult since mutual inhibition of motor overflow (transference of motor activity from one hemisphere to the other) must occur in order to avoid interference via transcallosal irradiation of activity from both hemispheres. An extreme example of elimination of interference is in the case of the split-brain patient who can simultaneously perform different tasks with each hand as fast as performing each task alone (Gazzaniga, 1967). Gazzaniga and Hillyard (1973) suggest that "the overall information processing capacity" of the hemispheres is increased by severing the corpus callosum and eliminating most of the interference and competition between the hemispheres.

It seems that simultaneous asymmetrical activity of homologous body parts would produce a greater functional separation of the hemispheres' response initiation abilities via increased mutual inhibition of interhemispheric communication mediated, at least partially, through the corpus callosum (Kinsbourne, 1974b). Kelso, Southard, and Goodman (1979) found that reaction times of unimanual movements to an easy target or bimanual simultaneous movements to two easy targets were faster than reaction times of simultaneous bimanual movements to either two difficult targets or to one difficult target and one easy target. They maintain that, for these latter conditions, increased time is needed to program the required muscle linkages when either two difficult targets or two different targets are involved. It would seem that difficult simultaneous asymmetrical movements require a different functional pattern of cerebral organization than those that involve unilateral or simple bilaterally symmetrical movements. It would have been of interest and relevant to the present study if Kelso et al. had measured the comparative accuracy of each hand in actually executing the programmed muscle linkages.

The notion of reduced ipsilateral hemispheric input to each hand during simultaneous asymmetrical activity represents a motor analogue to the bilateral simultaneous stimulation paradigms in the auditory, visual, and somatosensory systems.

In addition, the right ear advantage for the processing of verbal stimuli obtained under conditions of dichotic simultaneous stimulation represents, at least in part, suppression of the ipsilateral afferent pathways (Kimura, 1961).

Rosenzweig (1951) demonstrated that in cats, the amplitude of the evoked responses to a click stimulus was greater in the hemisphere contralateral to the ear stimulated singly than in the hemisphere ipsilateral to that ear; this may be explained by the greater proportion of auditory fibers which project to the opposite hemisphere. However, the amplitude of the evoked response is even larger in the contralateral hemisphere when both ears are stimulated simultaneously. This would indicate that perception of the contralateral input is enhanced by competitive stimulation.

In vision, even though hemispheric advantages have been found for unilateral presentation, other studies have shown greater right visual field advantages for verbal material when using bilateral presentation than when using unilateral presentation (Hines, 1975; Kershner, 1977; McKeever, 1971). Mackavey, Curcio, and Rosen (1975) report that the more robust right visual field advantage they found for bilateral presentation occurred irrespective of whether the stimuli were arranged horizontally or vertically. These studies indicate that the usual left to right scanning habits do not sufficiently explain the lateral differences obtained in the

tachistoscopic experiments, and contradict White's (1970) finding of a left visual field advantage for recall of digits using bilateral presentation due to a learned tendency to scan to the left of the fixation point.

In the somatosensory system, the rationale behind Witelson's (1974, 1976b) dichhaptic procedure again relies on the concept of simultaneous competitive input that produces greater lateral differences than unilateral testing.

The present study attempts to demonstrate a left hand superiority in right-handed subjects. The importance of such a finding would be that it might represent an example of contralateral hemispheric control of the left hand. It is therefore important that the task maximize those abilities associated with the right hemisphere. If one were to use a verbal task (associated with the left hemisphere) and a right hand advantage was obtained in right-handed subjects, it would not be a terribly surprising result. There are many reasons why a right-hander may perform better with the right hand that need not implicate central asymmetries. A left hand superiority in people who generally use the right hand may indicate that something has been added to the left hand performance or subtracted from the right hand performance. In the simultaneous asymmetrical situation, the reduction of right hemisphere input to the right hand may be more damaging to the

performance of a spatial task than the reduction of left hemisphere input to the left hand, due to the right hemisphere's relative superiority for spatial tasks.

An example of a study where a left hand advantage was found for right-handed subjects during asymmetrical movement is one done by Buffery (1970, 1971). He used a Conflict Drawing Test in which children, with their eyes closed, had to simultaneously draw a square with one hand and a circle with the other hand. Buffery found that there was a left hand superiority on the task and that the degree of left hand superiority increased as a function of the child's degree of right-handedness. Thus, the more strongly right-handed the child was, the better the left hand was at drawing in a simultaneous asymmetrical condition.

One way in which the analogy between the bilateral simultaneous stimulation procedures and the bilateral asymmetrical movement paradigms fails appears to be in the primary modes by which ipsilateral input is suppressed. In most of the sensory studies it appears that ipsilateral suppression is produced by pre-cortical inhibition of uncrossed fibers (Berlin, 1977). In the motor system, ipsilateral suppression appears to be mediated by transcallosal inhibition of homologous motor areas (Kinsbourne, 1974c).

The type of movement employed in the present experiment --a ballistic, abductive hand/arm movement performed without visual guidance--meets Kelso's (1977) definition of a "pre-selected movement" whose terminal location is, most probably, centrally determined. Hongo, Nakamura, Narabayashi, & Oshima (1976) maintain that most of the left-right differences found in finger, hand, and elbow motor responses reflect central and not peripheral control. In addition, abductive arm movements (those movements away from the body axis) have been shown to be contralaterally controlled (Van Der Staak, 1975). Therefore, differential upper limb performance on this task is being used as an indicator of contralateral hemispheric involvement.

In a series of tasks in which subjects had to alternately tap two targets as quickly as possible with a stylus, Todor and Doane (1978) reported that the left hand of right-handed subjects was more accurate in the condition in which there was a greater demand for preprogrammed motor plans--the condition with the larger target and a longer amplitude of hand movement. The equally difficult condition of a smaller target and a shorter amplitude of hand movement required, according to Todor and Doane, a greater amount of visual feedback control and sequential motor movements. There was a slight right hand advantage on this task.

Both Roy and McKenzie (1978) and Guiard, Diaz, and Beaubaton (1983) report that the left hand of right-handers

is more accurate than the right in terms of calculating limb displacement in visual space in the absence of visual feedback. Guiard et al. conclude that, since, irrespective of the hand used, movements were programmed with better accuracy when the target was placed on the left side of the device, that the right hemisphere was largely responsible for programming whatever the side of output. They conclude:

along these lines, the left limb superiority will be explained by its better linkage with the neural circuits of this (right) hemisphere and the relative performance inefficiency of the right limb either by weakness of ipsilateral control or by, some obligatory interhemispheric exchange of information. (p. 113)

Although the right hand has been shown to be better at localization under visual guidance--especially when using a tool (Anan'ev, 1965; Heap & Wyke, 1972; Reitan, 1971; Zurif & Carson, 1970), the left hand is better at many spatial tasks when vision is excluded (Critchley, 1953; Gardener, 1942; Hermelin & O'Connor, 1971; Rudel, Denckla, & Spalten, 1974; J. M. Smith, 1929). Experienced touch typists are more accurate with their left hands, while novice typists, who rely on vision to a greater extent, are more accurate with their right hands (Provins & Glencross, 1968). D. Ingram (1975b) found that right-handed children and adults were better at placing a mapping pin under a spot marked on the top of an opaque table when their left hands were used. Benton, Levin, and Varney

(1973) reported that right-handed subjects demonstrated a significant left-hand superiority in perception of tactile direction without visual cues.

The left hand generally shows a superiority in the isolated flexion of a single finger or pairs of fingers (Kimura & Vanderwolf, 1970) as well as hand posturing and finger spacing tasks (D. Ingram, 1975b). These abilities, in combination with greater sensitivity to tactile pressure (Semmes, Weinstein, Ghent, & Teuber, 1960), may help explain how the left hand of right-handed violinists does the complex fingering on the frets (Ojemann, 1930a, 1930b).

It would seem then, that, in the present experiment, a target localization task performed without visual guidance and accomplished via a simple ballistic hand/arm movement would reflect those abilities that have been associated with the right hemisphere and left hand. The movement required is also well within the motor ability of the left hand. If the task requires speed, dexterity, or strength, the right hand may have a mechanical advantage (Denckla, 1973; Wyke, 1967). However, none of these skills are required.

Predictions

Certain predictions can be made concerning differences in accuracy between the two hands under the three movement condi-

tions. Some of the predictions refer to all subjects tested; other predictions refer to strongly right-handed, weakly right-handed, and left-handed subjects.

All Subjects.

A. Unimanual conditions. It was predicted that there would be no significant difference between the absolute accuracy of the right and left hands during unimanual movement to the targets. As discussed earlier, both cerebral hemispheres can contribute to unimanual movement; therefore, each hand is expected to adequately handle the task when tested alone.

B. Simultaneous conditions. When each subject's unimanual performance was used as a baseline indicator and the change in their performance during simultaneous movement used as the measure of bimanual motor performance, all subjects were expected to show a decrease in accuracy of target localization from their unimanual performance. Although simultaneous movements were expected to bring about a functional separation of the hemispheres, this separation was not expected to be complete. Some interference and competition between the hemispheres will still occur. Therefore, two tasks done simultaneously will not be performed as accurately as each separately.

Although there would be an expected reduction in accuracy for both simultaneous conditions, the greatest reduction in accuracy from the unimanual performance level was expected to occur in the simultaneous asymmetrical condition. It should be easier to program and carry out two identical tasks simultaneously with each hand than two different tasks. The competition between two different tasks should result in a significant reduction in the accuracy of performance on each task.

Strongly right-handed subjects. Although both hands are expected to be less accurate in the simultaneous asymmetrical condition than when each is tested alone, it was not expected that the accuracy of both hands would be equally reduced. In strongly right-handed subjects, it was predicted that the right hand would show a greater reduction in accuracy from its unimanual performance level in the simultaneous asymmetrical condition than would be shown by the left hand.

As pointed out above, the change from unimanual to simultaneous asymmetrical movement should result in a relative reduction in ipsilateral hemispheric input to each hand. It was predicted, therefore, that in the simultaneous asymmetrical movement condition the relative reduction in left hemisphere input to the left hand would be less detrimental to its performance on a target localization task done without visual

guidance than the relative reduction in right hemisphere input would be to the performance of the right hand.

The prediction of differential reduction in accuracy for the two hands for the strongly right-handed subjects is based on the assumption that strong right-handers should possess a clearer pattern of lateralized function with spatial abilities more localized in the right hemisphere and verbal abilities more localized in the left hemisphere. This is in contrast to weakly right-handed and left-handed subjects who may possess more bilateral representation of both functions.

Weakly-right-handed and left-handed subjects. It was predicted that for weakly right-handed and left-handed subjects, both hands would show comparable decreases in accuracy from the unimanual to the simultaneous asymmetrical movement condition. This prediction is based upon the hypothesis that these two groups have bilateral representation of function, thereby allowing each hand to perform equally well in the simultaneous asymmetrical condition.

CHAPTER II

Method

Subjects

Fifty normal adults (25 men and 25 women) between the ages of 17 and 27 (mean = 18.7 years) were the subjects. All of the subjects, either undergraduate college students or medical residents, volunteered to participate. All of the subjects were selected without knowledge of their handedness. Prior to testing, the subjects were informed of the nature and purpose of the experiment. After the testing session, there was a brief discussion of their performance and its significance in terms of the experimental goals. All testing was done on an individual basis in a quiet room in Queens College in New York.

Materials

Questionnaire. A questionnaire was orally administered to each subject in order to obtain information on certain variables that might be related to cerebral laterality patterns. The questionnaire, shown in Appendix A, called for information about the subject's age, gender, background history in regard to neurological damage, early training to reverse handedness, incidence of family sinistrality in natural parents and in full brothers and sisters, whether they possessed asymmetrical motor ability in their daily life (as

indicated by being able to play a musical instrument or to touch type), and writing position according to Levy and Reid's (1976) categories. One subject was eliminated from the data analysis on the basis of reporting extensive neurological damage sustained in a car accident. The remaining 50 subjects included in the final sample were, according to their self-reports, neurologically intact.

Motor overflow tasks. The subjects were tested to ascertain whether they demonstrated any evidence of motor overflow. Motor overflow was defined as the presence of mirror movements in the hands or of an inability to wink either eye without the other eye simultaneously closing. The subjects' performance on these tasks were recorded on the questionnaire form. Motor overflow was measured as a possible factor which may have been related to a subject's difficulty in performing the target localization task which required inhibition of motor overflow in the asymmetrical condition.

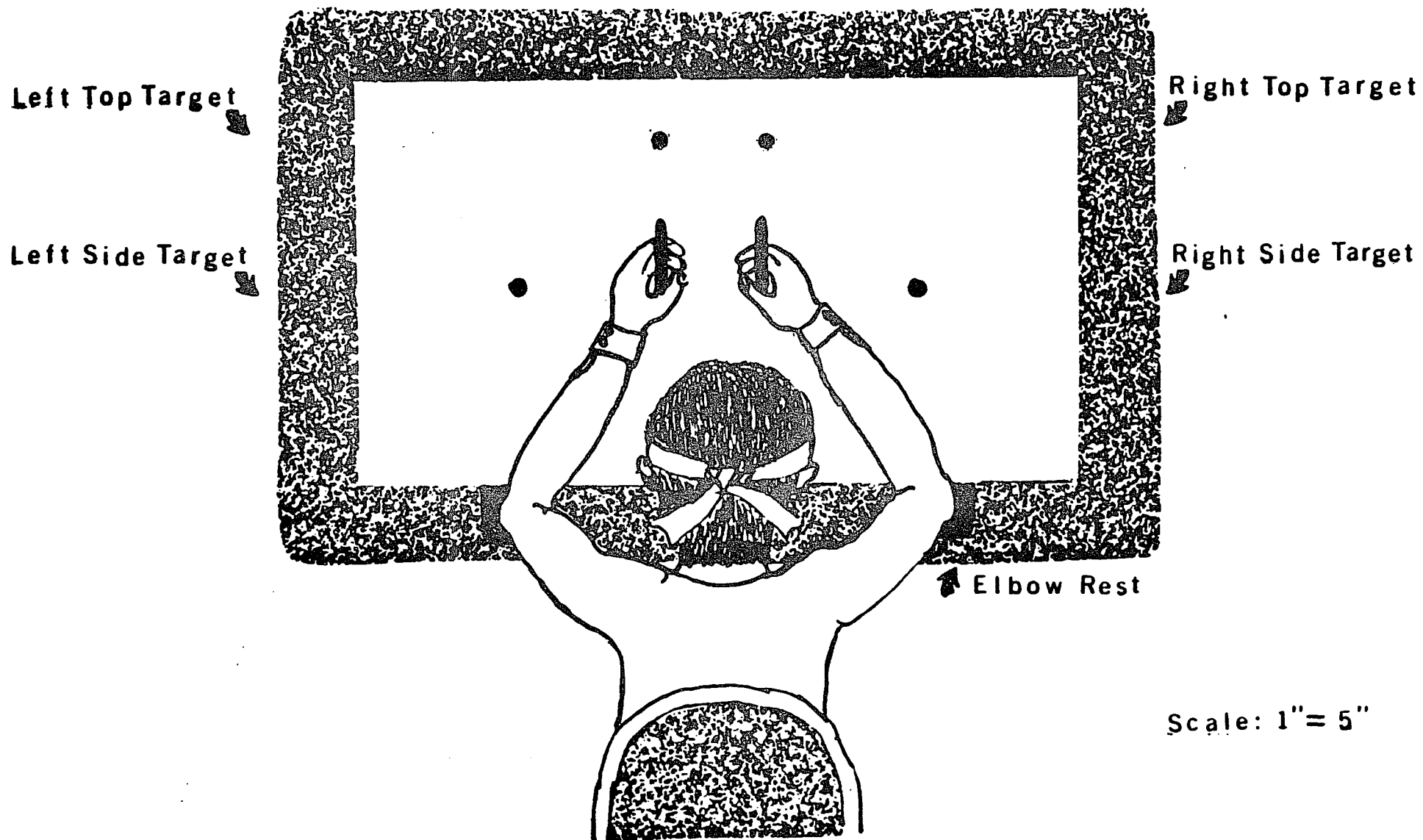
Handedness inventory. Each subject was required to perform a series of 13 simple, everyday tasks. The hand used to perform each of the tasks was recorded (see Appendix B for a list of the specific tasks used). The majority of the tasks used were those that Briggs and Nebes (1975) found to be the most reliable items in Annett's (1967) handedness inventory. A performance inventory of handedness was used since the

self-report method has been shown to be an unreliable measure of handedness, particularly in determining left-handedness (Hardyck & Petrinovich, 1977; Todor & Doane, 1977).

Target localization apparatus. The apparatus (see Figure 1) consisted of a rectangular lucite board (25" in length, 14" in height, and 1/4" thick) on which two penholders had been mounted in such a way as to support two pens perpendicular to the surface of the board. The holders were 1/2" in diameter and were inset 5 1/2" from the right and left sides of the board along a horizontal plane parallel to, but 6 1/2" above, the bottom edge. For each subject tested, a new sheet of large white paper was placed flush against the surface of the board, covering it completely except for the penholders. There were four black circular 1/8" targets printed on each sheet of paper. The targets were positioned so that there was one target 5" directly above each of the penholders (the top targets) and one target 5" to the left side of the left penholder and one target 5" to the right side of the right penholder (the side targets). Thus, there was a total of four targets (two top and two side).

The board was placed on a tabletop which had two elbow rests attached to it. In this way, when the subject as seated in front of the apparatus with his or her hands on the pens and their elbows on the stationary rests, there was a

Figure 1. Subject positioned in front of the target localization apparatus.



consistency in the starting position over trials. The pens used were 12 different shades of Marvey Markers. They were thin-cased, medium point, felt-tipped pens that fit, point down, in the penholders. The pens were set up in a small rack so that the experimenter could easily change pens for each trial. The points of the pens rested in a shallow tray of alcohol so that the felt tips remained clean and retained their original colors throughout testing.

Procedure

Questionnaire. In all cases the subjects were given the questionnaire first to establish the demographic and background information.

Motor Overflow. The tests for motor overflow were always given following the questionnaire:

A. Mirror movements. The subject was asked to hold both arms straight out in front of him or her at shoulder level, hands open, palms up, and eyes closed. The subject was then asked to make a fist with only the right hand, open it, and then make a fist with the left hand. The second trial required that the subject make a fist only with the left hand. If synergistic movements occurred in the hand that was supposed to be held open while the other hand closed in a fist, the trial was repeated. When synergistic movements

were present on two consecutive trials, it was recorded as a mirror movement.

B. Winking deficit. The subject was asked to wink the right eye, open it, and wink the left eye. If there was difficulty in closing only one eye, the trial was repeated. If there was inability to wink one or both eyes on two consecutive trials, it was recorded as a winking deficit, another example of motor overflow.

Handedness inventory. Tasks on the handedness inventory that required the use of certain props, such as a pen or a toothbrush, were presented to the subject at a midline position on the table top. This was done to avoid biasing the use of one hand or the other.

Each of the 13 tasks was given equal weight in scoring except for the first one, "signing your name," which accounted for one third of the entire handedness score. The decision to give the hand used in writing a larger share of the score arose from preliminary categories of handedness that were based on equal representation of all 13 tasks. If subjects were classified as dextral when seven or more of the tasks were performed with the right hand and as sinistral when seven or more of the tasks were performed with the left hand, 98% (49/50) could be classified as dextral or sinistral by

using the writing hand task alone. Since signing one's name seemed to be the best predictor of handedness classification, as measured by performance on the entire inventory of tasks, it was given greater representation than those tasks that were less discriminative.

Allotting the writing hand a third of the handedness score made it an important factor in the assignation of handedness but, by no means, the sole one. If a subject wrote with the left hand but did most of the other tasks with the right hand, the subject was classified as a dextral, but a weaker one than the subject who used the right hand for all of the tasks. The same distinctions applied to a subject who wrote with the right hand but used the left hand to do most of the other tasks.

In calculating the handedness score for each subject, the hand that was used for writing received six points, and one additional point for each of the other 12 tasks that hand performed. All of the handedness scores were converted into a percentage of right hand usage. This was done by summing the total number of points accumulated by the right hand and dividing it by 18--the maximum number of points possible. Thus a score of 100% (18/18) meant that all tasks were performed by the right hand, while 0% (0/18) meant that all tasks were performed by the left hand.

A handedness score above 50% classified a subject as right-handed while a score below 50% classified a subject as left-handed. A score of exactly 50% meant that a subject was not given a handedness determination. Within each classification, a distinction was made between strongly and weakly handed subjects. For the right-handed subjects, any score above 85% was considered to be strongly right handed. Any score between 51-85% was considered to be weakly right-handed. In the left-handed group, 15-49% was considered to be weakly left-handed while below 15% was strongly left-handed. Briggs and Nebes (1975) also used weighted scores to arrive at their handedness classifications, but their procedure differed from that used in the present study.

Target localization task. Once the subject was seated at the target localization apparatus, he or she assumed the "Ready" position by wrapping each hand around one of the pens in a dagger-like fashion. Each subject was read a standard set of instructions (see Appendix C) that explained which targets were the top and which were the side targets for each hand. During the reading of the instructions, the subjects were allowed to see the board. The subject was also told of the possible combinations of moves that would be required-- either each hand moving to a specified target alone, both hands simultaneously moving to symmetrical targets, or both hands simultaneously moving to asymmetrical targets. Table 1

presents the abbreviations used to represent each of the movement conditions, and Figure 2 illustrates each of these movements.

When the subjects claimed to understand the requirements of the task, they were blindfolded. No feedback or correction was given to the subjects during the testing session. The subjects were given eight "passive" practice trials with the experimenter moving the subject's hands in each of the possible movement conditions. The subjects were then given eight more "active" practice trials in each of the movement conditions with the subjects initiating the movements by themselves. The experimenter watched the subjects' performance during these "active" practice trials to determine that the subject followed directions correctly, that the hand movements were smooth, ballistic movements, and that, in the bilateral conditions, the hand movements were initiated and terminated as simultaneously as could be determined by the naked eye.

Following the practice trials, each of the eight movement conditions was repeated five times for a total of 40 test trials. The order of presentation was quasi-random in that the order was randomly determined unless there were more than two of the same kind of trials in a row. In that case, another random selection was made until a different trial was selected. In this way, a subject would not be told to go, for example, to the right side target on three successive trials. Since

Table 1

Abbreviations Used for Right and Left
Hand Movements to the Side and Top Targets

Hand	Movement		
	Unimanual	Simultaneous Symmetrical	Simultaneous Asymmetrical
Right			
Side	RU-S	RSS-S	RSA-S
Top	RU-T	RSS-T	RSA-T
Left			
Side	LU-S	LSS-S	LSA-S
Top	LU-T	LSS-T	LSA-T

Figure 2. Possible movement combinations in the target localization task.

UNIMANUAL			
RU-S	RU-T	LU-S	LU-T
SIMULTANEOUS SYMMETRICAL		SIMULTANEOUS ASYMMETRICAL	
LSS-S, RSS-S	LSS-T, RSS-T	LSA-T, RSA-S	LSA-S, RSA-T

there were only five presentations of each condition, having too many of them consecutively might have produced certain stereotyped movements towards that target or targets. The same order of trials was given to each subject. On trials which involved instructions for the left and right hands, there were an equal number which began with the left hand instruction as with the right hand instruction. This was done to avoid the pattern of always leading with one hand during simultaneous movements.

The testing session consisted of 4 blocks of 10 trials each for a total of 40 trials. There were 30 seconds between trials to allow the subject to resume the starting position and for the experimenter to select the appropriate pens and place them in the penholders for the next trial. There were 3 minute rest periods between the blocks of trials. A complete session of 40 trials took about 45 minutes.

A different colored marking pen represented each of the 12 different kinds of marks that could be made by the subject. Obviously, on the four simultaneous trials, two marks were made for each trial. On the unimanual trials where only one pen had to be used, two pens were still placed in the holders so that the starting positions were uniform with the simultaneous trials. When there were two of the same movement

conditions in succession, the pens were still removed and replaced between trials. In this way, possible clues were eliminated as to the nature of the next trial. The actual sequence of trials and the color representations for each of the marks are presented in Appendix D.

Following the subject's movement on each trial the experimenter said "good" to indicate that the task was carried out properly, but no differential feedback or knowledge of results was given in relation to the accuracy of the subject's aim. On trials in which the subject mistakenly went to the wrong target or did not either lift or bring the pens down simultaneously, the experimenter informed the subject of his or her error, put an "X" through the mark on the test sheet, and went on to the next trial. The trial that had been missed was then added on at the end of the block.

The quasi-random presentation of trials and the lack of feedback was thought to help equalize the effects of practice, fatigue, and possible fading of the visual memory trace for the targets on the movement conditions. There would be no reason to assume that any of these factors would differentially affect any of the movement conditions since the movements were randomly scattered throughout the testing situation.

A clean sheet of white paper with the four targets was placed on the testing board for each subject. Thus, at the

end of testing there was one large sheet of paper with 60 different-colored dots on it. There were 15 dots made around each of the four targets. The 15 dots were then separated, on the basis of color, into the five trials made during each of the unimanual (U), the simultaneous symmetrical (SS), and the simultaneous asymmetrical (SA) movement conditions.

Figure 3 presents a typical dot pattern for a subject's hand moving to the side target under the three movement conditions. The difference in the performance of the right hand in localizing the target under the three movement conditions reflects the comparative accuracy of the hand moving alone and that same hand under the influence of symmetrical or asymmetrical activity of the contralateral hand.

The target localization task was scored in terms of the absolute accuracy of each trial (raw scores). Each raw score consisted of the linear distance, in millimeters, between the center of the mark made by the subject and the perimeter of the intended target. The arithmetic mean was obtained for the five trials in each of the three movement conditions around a target. Thus, the absolute distance of each mark from its target was used, regardless of whether the mark represented an over or undershooting of the target.

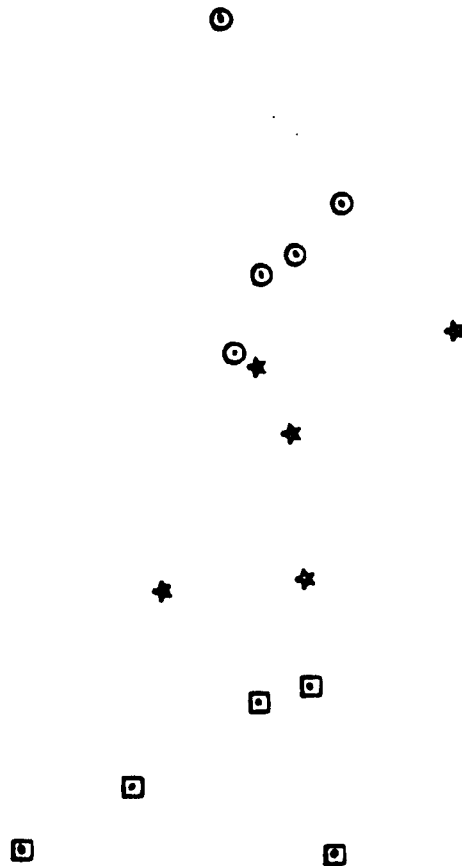
Figure 3. Typical dot pattern around right side target for an individual subject.

⊙=Unimanual

★=Simultaneous Symmetrical

◻=Simultaneous Asymmetrical

Right Side
Target → ●



Statistical Analysis

A split-plot analysis of variance was initially used (Kirk, 1968 pp. 294-298) with the following four factors: Gender (Men, Women), Movement (Unimanual, Simultaneous Symmetrical, and Simultaneous Asymmetrical), Hand (Right, Left), and Target (Side, Top). However, since no significant main effects or interactions were found for the Target factor, the observations from the side and top targets were combined and a three-factor analysis of variance was performed (Kirk's type SPF-p.qr design, pp. 298-302).

An analysis of variance (ANOVA) was performed separately for each of the three handedness groups (the left-handed group was not divided into strongly and weakly left-handed due to the small sample size and the confounding of strength of handedness and gender in that group). For each ANOVA, the same three factors were used: Gender (G), Movement (M), and Hand (H). There were two levels of factor G [men (M) and women (W)], three levels of factor M representing the type of movement used in the localization attempt [unimanual (U), simultaneous symmetrical (SS), and simultaneous asymmetrical (SA)], and two levels of factor H representing the hand used to localize the target [right (R) and left (L)].

CHAPTER III

Results

The data on handedness will be presented first since the experimental findings are examined in light of their relationship to hand preference.

Handedness. The sample of subjects proved to be predominantly right-handed, with a mean handedness score of 87.4% for all 50 subjects. Ninety two per cent of the sample (46/50) was classified as right-handed on the basis of their performance on the handedness inventory. Of the 46 right-handed subjects, 38 were classified as strongly right-handed and only 8 were weakly right-handed. In each of the two right handed groups, there was an equal representation of men and women.

The remaining four subjects (8% of the sample) were classified as left-handed. Although two of them were strongly left-handed and two of them were weakly left-handed, there was not an equal sex distribution in each category. Both of the women were strongly left-handed and both of the men were weakly left-handed. Since gender was to be considered as a main factor in the analysis of the data, differences between the female and male left-handers could have been due either to gender or to the magnitude of handedness. Because of this

problem, and the fact that the sample was so small, magnitude of handedness was not considered for left-handed subjects.

Taken as a whole, the sample consisted of 76% (38/50) strongly right-handed subjects, 16% (8/50) weakly right-handed subjects, and 8% (4/50) left-handed subjects. The low incidence of left-handedness in the present study is within the range reported for the general population (Hardyck & Petrinovitch, 1977).

Writing position. All of the 46 right-handed subjects signed their name with the right hand in a non-inverted writing position. The left-handed subjects were more diversified in that one weakly left-handed male signed his name with the right hand in a noninverted position, the other weakly left-handed male signed his name with the left hand in the hooked, inverted position, and the two strongly left-handed females signed their names with the left hand in the non-inverted position. Since there were no inverted right-handers and any consideration of the inverted and non-inverted positions in the left-handed group would be confounded by sex differences, writing position was not included in the subsequent analysis.

Family Sinistrality. In the overall sample, 24% of the subjects reported having either a sinistral parent or full sibling (see Table 2). There was no significant difference, however,

in the incidence of family sinistrality among the three main handedness groups [$\chi^2(2)=2.58$, $p > .05$]. Furthermore, there was no significant difference in the incidence of family sinistrality among the three handedness groups when gender was considered as a factor [$\chi^2(5)=9.23$, $p > .05$].

Since there were only four left-handed subjects, examination of the relationship between hand preference and family sinistrality is difficult in the present study. The lack of significant differences among the three handedness groups is consistent with the findings that family sinistrality is not relevant to right-handed individuals (G. Cohen, 1972; Dimond & Beaumont, 1974; Hines & Satz, 1971; McKeever, Gill, & Van Deventer, 1975).

Asymmetrical ability. On the question of whether subjects either play a musical instrument or can touch type, 82% (41/50) of the subjects reported having one or both of these asymmetrical abilities (see Table 2). There was a significant difference in the incidence of asymmetrical ability among the three handedness groups [$\chi^2(2)=10.96$, $p < .05$]. The strongly right-handed subjects were the ones who reported the highest incidence of asymmetrical ability, with 92% reporting these abilities while only 50% of the weakly right-handed and 50% of the left-handed reported this ability.

TABLE 2

Incidence of Subject Variables in Each of
the Handedness Categories

Handedness	n	Subject Variables		
		Family sinistrality	Motor overflow	Asymmetrical ability
Strongly right	38	7	21	35
Weakly right	8	3	6	4
Weakly left	2	0	1	0
Strongly left	2	2	0	2
Total	50	12	28	41

Motor overflow. Ten percent (5/50) of the sample demonstrated mirror movements, 30% (15/50) demonstrated a unilateral winking deficit, and 22% (11/50) demonstrated a bilateral winking deficit. Thus, 56% of the sample (28 subjects; see Table 2) demonstrated some evidence of motor overflow as defined by having either mirror movements or a winking deficit, or both. However, the incidence of motor overflow was not significantly different among the three handedness groups [$\chi^2(2)=2.74$, $p > .05$]. Significance was not reached by considering gender as a variable [$\chi^2(5)=3.86$, $p > .05$]. Therefore, motor overflow was not considered in the subsequent analysis of the data.

Target Localization Task

Reliability. The Spearman-Brown formula for split-halves reliability (Cronbach, 1970, p. 161) was used to assess the internal consistency of the 3,000 target localization scores collected on all 50 subjects (50 x 60 measurements per subject). Combining the scores from the side and top targets, the odd and even trials within each of the movement conditions were paired for each subject. The reliability coefficient, corrected for the actual number of scores in the sample, was .90. This coefficient indicates that, within a subject, repeated trials within the same movement conditions yielded consistent performance.

The fact that performance was reliable within each movement condition lends support to the conclusion that any differences in performance found among the movement conditions represent differential performance related to the task demands of the movement conditions rather than to within subject inconsistency.

Raw scores. The raw scores were comprised of the distance, in millimeters, of each localization attempt (as evidenced by a colored pen mark) from the perimeter of the intended target, regardless of direction. The higher the score, the greater the amount of error made in localizing the target; conversely, the lower the score, the smaller the amount of error.

In order to facilitate the description and comprehension of the results, the discussion of the ANOVA has been interspersed with a descriptive account of means, standard deviations and Tukey's a posteriori tests.

A. Strongly right-handed subjects (n=38). Table 3 presents the mean distance from the intended target in each of the three movement conditions. The smallest amount of error made was in the unimanual condition (41.2 mm). Error increased slightly in the simultaneous symmetrical condition (by 1.2 mm). The largest increase in error was in the simultaneous asymmetrical condition, where the mean error was 6.4 mm higher than in the unimanual condition.

The ANOVA performed on the raw scores of the strongly right-handed subjects (Table 4) revealed that Movement Condition was a significant main effect. A posteriori comparisons of totals via Tukey's method (Winer, 1962, pp. 87-89) confirm that even though the amount of error was greater during SS movement than during U movement, the difference was not statistically significant whereas the amount of error during SA movement was significantly greater than the amount of error during both U and SS movement (see Table 5, Section A). It appears, then, that bimanual simultaneous movement as such was not sufficient to produce a significant impairment in accuracy from the unimanual condition. An increase in the amount of error did occur, however, when the bilateral simultaneous movement was asymmetrical. When each hand was moving to a different target, the subjects' localizations were significantly further away from the actual targets than when one hand alone aimed for the targets or two hands aimed for two equivalent targets.

Table 3 also shows the mean distances from the intended target for the right and left hands in each of the movement conditions. The only difference between the hands occurred in the U condition, with the right hand mean error being 4.9 mm closer to the intended target than the left hand. The difference between the right and left hands was reduced to .5 mm in the SS condition, and .1 mm in the SA condition.

Although the ANOVA did not show Hand to be a significant main effect (Table 4), the interaction between Movement Condition and Hand was statistically significant. This significant interaction resulted from the fact that although the right hand demonstrated a statistically significant increase in the amount of error between the U and SA movement conditions, the left hand demonstrated no statistically significant change between any of the movement conditions (see Table 5, Section C).

Figure 4 illustrates the interaction between Movement Condition and Hand. Inspection of this figure reveals an interesting trend in the data: The introduction of simultaneous hand movement, either symmetrical or asymmetrical, brought about an equalization of performance between the right and left hands. This equalization did not, however, result from equivalent changes in the accuracy of the two hands.

Comparison of the mean errors for each hand across the movement conditions indicates that for the equalization of performance to occur in the SS condition, the accuracy of the right hand decreased by 3.4 mm from the U condition while the accuracy of the left hand increased by 1.0 mm from the U condition. The equalization of performance that occurred in the bimanual simultaneous conditions resulted primarily from a reduction in the accuracy of the right hand to the approximate level of the left hand.

As can be seen from Table 6 and Figure 5, the women were more accurate than the men in each of the three movement conditions, with the overall differences between them being 11.6 mm. Gender was a significant main effect (Table 4). The greater accuracy of the women was statistically significant for each of the three conditions. (see Table 5, Section B). The significant interaction between Gender and Movement (Table 4) indicates that there were movement pattern differences between the men and women. It can be seen from Table 3 (Section B), that although there were no significant differences between the U and SS conditions for either the men or the women, the men showed a nonsignificant increase in error from the U to the SS condition whereas the women showed a nonsignificant decrease in error from the U to SS condition. The cumulative effect of these nonsignificant differences was that, for the men, while there was no significant increase in error from the SS to SA conditions, there was a significant increase from the U to SA conditions. In contrast, the women showed a significant increase in errors from the SS to the SA conditions.

Even though Gender x Hand did not interact significantly (see Table 3), Table 7 demonstrates an interesting pattern. Although the performances of the right and left hands were virtually identical for the men, the performance of the

right hand was more accurate than the left hand for the women (Table 9).

The three-way interaction of Gender x Movement x Hand was not statistically significant. Figure 6 presents the patterns found at this level of analysis. While the right hand of the women was more accurate than the left hand in all of the movement conditions, the men demonstrated a crossover trend. That is, although the right hand was more accurate than the left hand by 2.9 mm in the U condition, the left hand was more accurate than the right hand by .6 mm in the SS condition, and by 3.2 mm in the SA conditions. This trend in the data is quite interesting because it suggests that the SA condition may, in fact, adversely affect the right hand of men on a spatial task.

TABLE 3

Mean Distance from Target (in millimeters) for the
 Right and Left Hands in Each Movement
 Condition: Strongly Right-Handed Subjects (n=38)

Hand n=38	Movement Condition			
	U	SS	SA	Total
Right $\bar{X}$ (S.D.)	38.8 (19.8)	42.2 (18.6)	47.5 (21.7)	42.8 (19.3)
Left $\bar{X}$ (S.D.)	43.7 (14.8)	42.7 (12.0)	47.6 (14.7)	44.7 (12.6)
Total $\bar{X}$ (S.D.)	41.2 (16.2)	42.4 (14.5)	47.6 (16.9)	43.8 (15.0)

TABLE 4

ANOVA: F Summary Table: Raw Scores
 Gender x Movement Condition x Hand
 (Strongly Right-Handed Subjects)

	Sum of Squares	df	Mean Squares	F
Between subjects	5114110.25	37	138219.20	
Gender	736901.07	1	736901.07	6.06*
Subjects	4377209.18	36	121589.14	
Within subjects	1867750.33	190	98409.21	
Movement	175887.34	2	87943.67	11.80**
Gender x Movement	15635.43	2	78117.72	10.48*
Movement x subjects	536821.56	72	7455.86	
Hand	17368.86	1	17368.86	.70
Gender x Hand	36216.76	1	36216.76	1.45
Hand x subjects	897937.38	36	24942.71	
Movement x Hand	31363.70	2	15681.85	7.37**
Gender x Movement x Hand	3398.47	2	1699.24	.80
Movement x Hand x subjects	153213.83	72	2127.97	
Total	6981860.58	227		

* $p < .05$

** $p < .01$

TABLE 5

Tukey's A Posteriori Tests on Raw Score Totals:
Strongly Right-Handed Subjects

Factors		Differences Between Totals					
Section A							
Movement		U	SS	SA			
U		0	601	4748*			
SS			0	4147*			
SA				0			
Section B		Females	Females	Females	Males	Males	Males
Gender X Movement		SS	U	SA	U	SS	SA
Females	SS	0	462	2357*	3955*	5018*	6808*
Females	U		0	1895	3493*	4556*	6346*
Females	SA			0	1598	2661*	4451*
Males	U				0	1063	2853*
Males	SS					0	1790
Males	SA						0
Section C		Right	Right	Left	Left	Left	Right
Movement X Hand		U	SS	SS	U	SA	SA
Right	U	0	1151	1359	1909	3265*	3392*
Right	SS		0	208	758	2114	2241*
Left	SS			0	530	1906	2033
Left	U				0	1356	1483
Left	SS					0	127
Right	SA						0

(a) critical value (p.05)=2551.85.

(b) critical value (p.05)=2208.96.

* p < .05.

Figure 4. Mean error as a function of movement condition and hand: Strongly right-handed subjects.

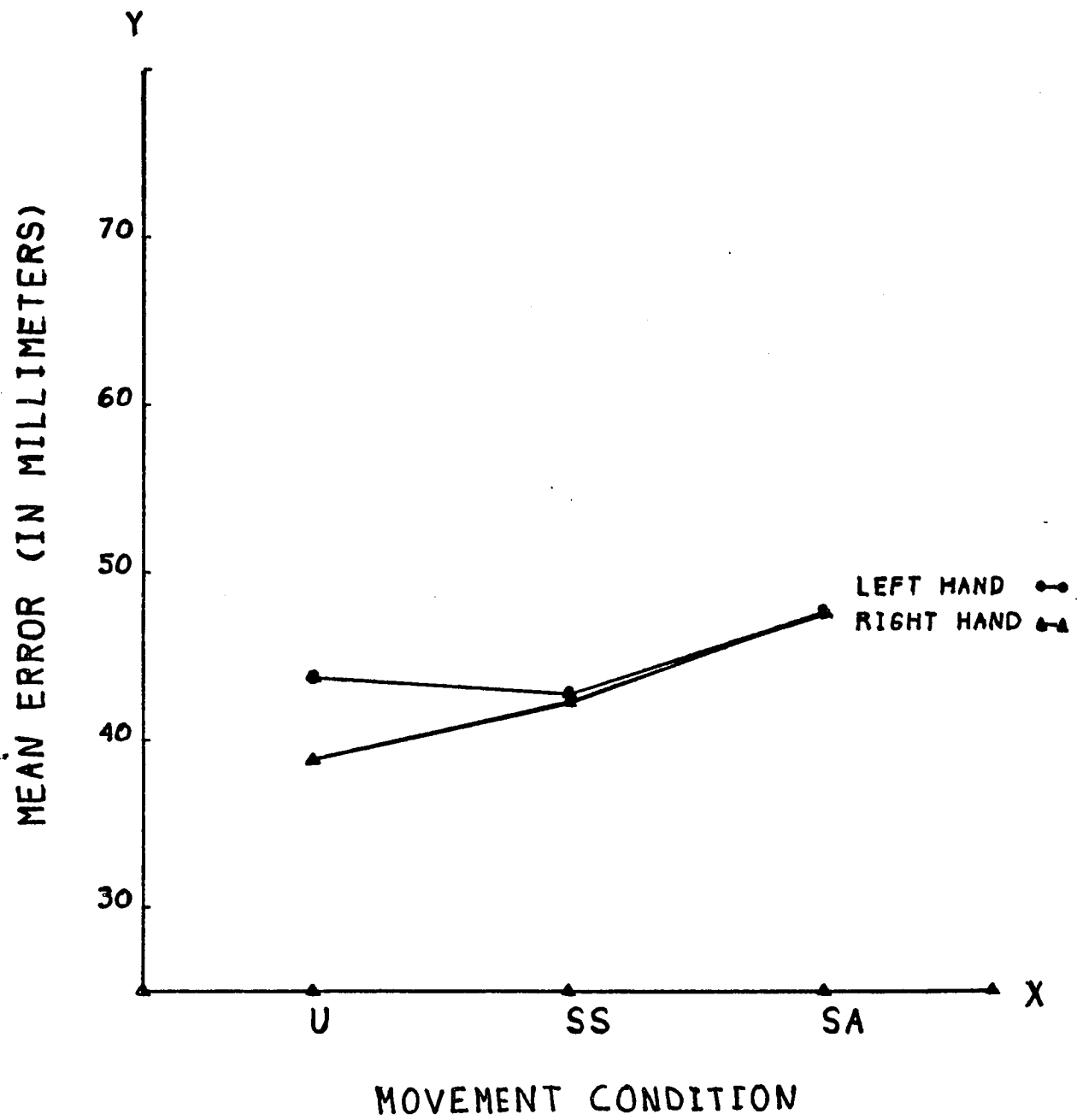


TABLE 6

Mean Distance from Target (in millimeters) for
Men and Women in Each Movement
Condition: Strongly Right-Handed Subjects

Gender	Movement Condition			
	U	SS	SA	Total
Men n=19 $\bar{X}$ (S.D.)	46.0 (18.0)	49.1 (16.0)	53.5 (18.0)	49.5 (16.9)
Women n=19 $\bar{X}$ (S.D.)	36.4 (12.2)	35.7 (8.5)	41.6 (13.7)	37.9 (10.2)

Figure 5. Mean error as a function of Gender and Movement condition: Strongly right-handed subjects.

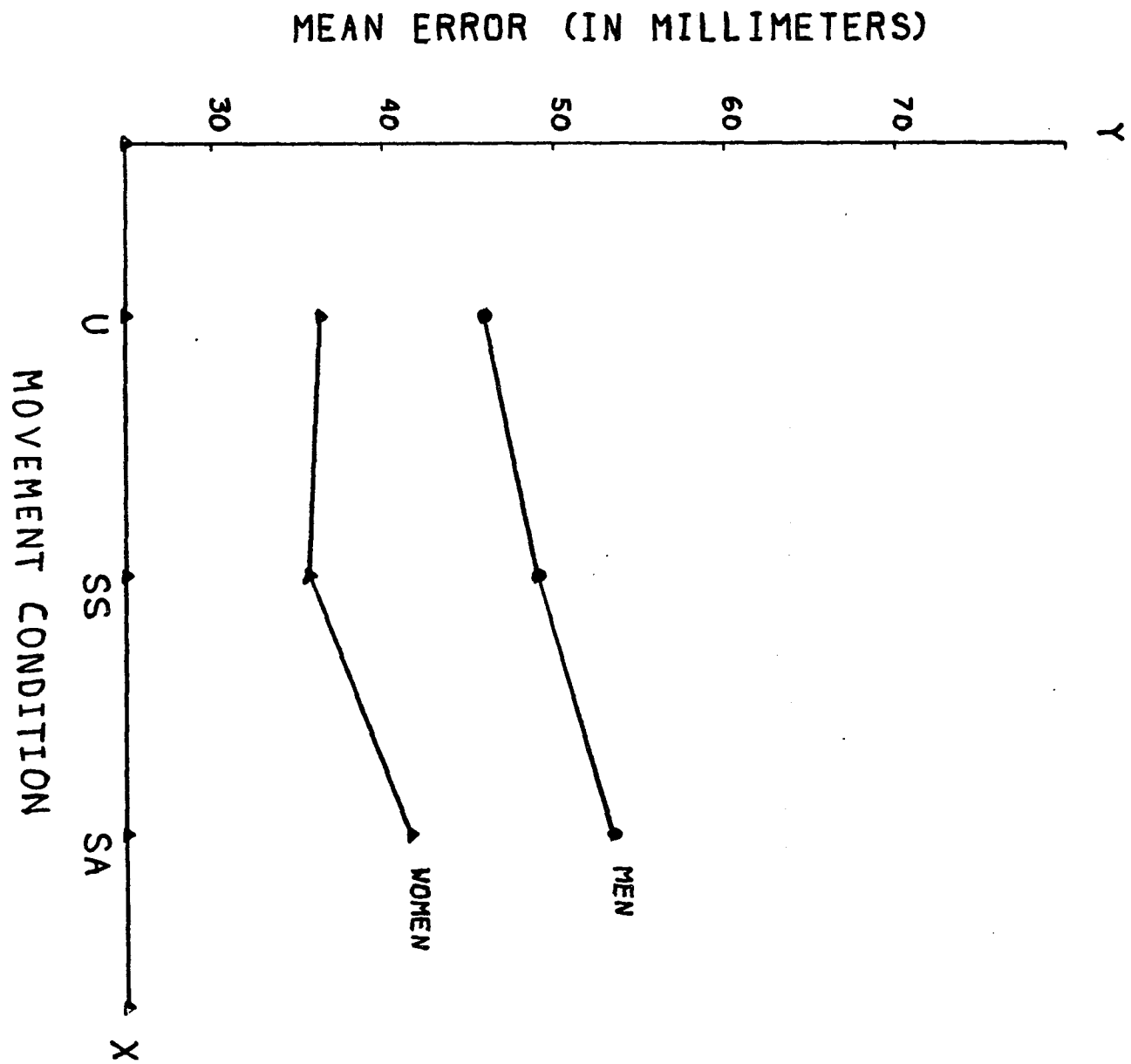
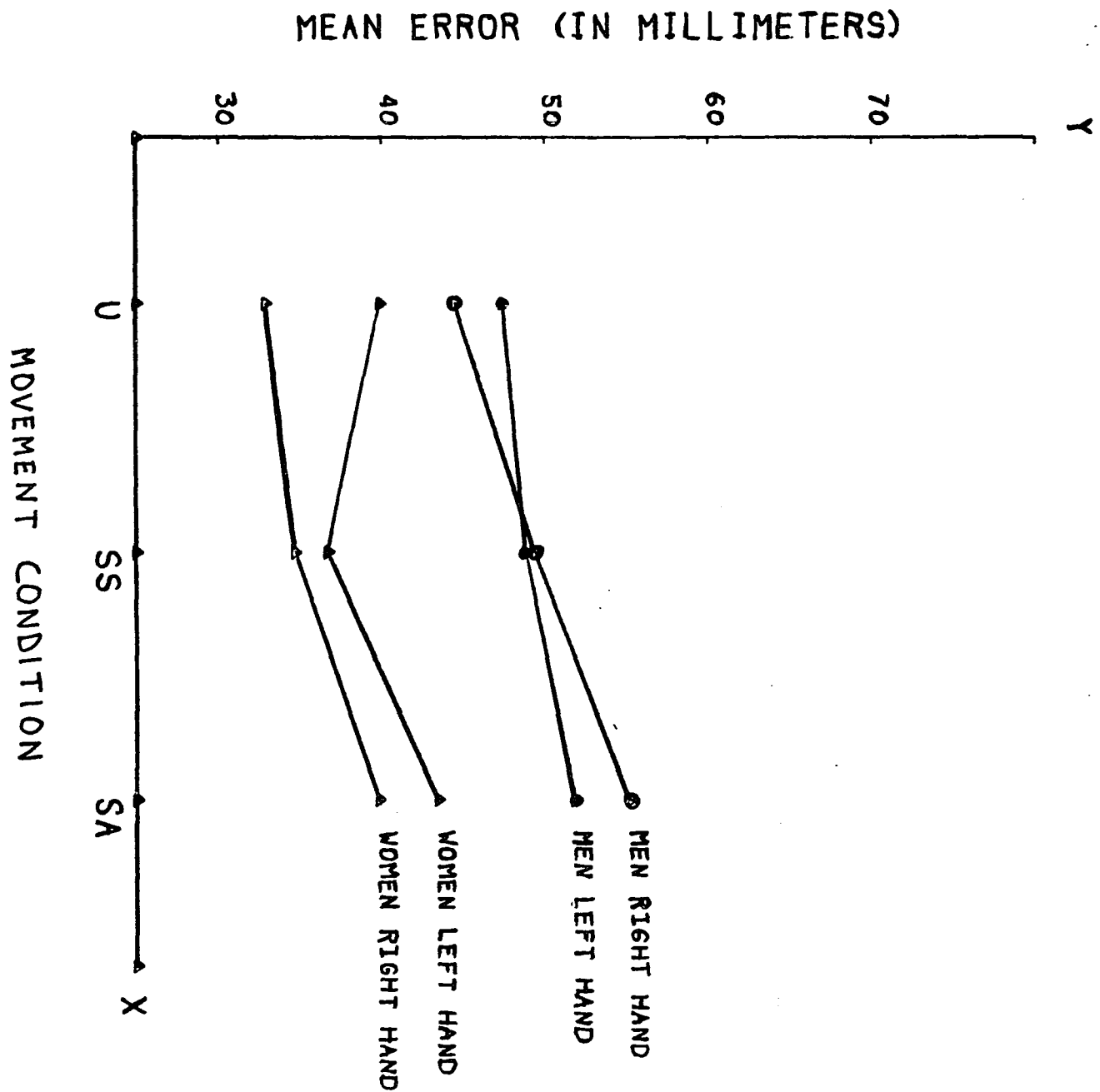


TABLE 7

Mean Distance from Target (in millimeters) for the
 Right and Left Hands of Men and Women:
 Strongly Right-Handed Subjects

	Right Hand	Left Hand
Men n=19 $\bar{X}$ (S.D.)	49.8 (22.6)	49.3 (13.1)
Women n=19 $\bar{X}$ (S.D.)	35.8 (11.3)	40.0 (10.3)

Figure 6. Mean error as a function of Gender, Movement condition, and Hand: Strongly right-handed subjects.



B. Weakly right-handed subjects (n=8). As can be seen from Table 8, the weakly right-handed subjects showed no significant main effects or interactions among Gender, Movement, and Hand. This was not surprising due to the smallness of the sample. Figure 7 illustrates pattern of performance for the weakly right-handed subjects.

Table 9 presents the mean distance from the intended target for each hand in each of the three movement conditions. In contrast to what was found in the strongly right-handed subjects, the U condition was not the one with the least error; the SS condition was the most accurate. The SA condition was, however, still the least accurate.

As was the case in the strongly right-handed group, the women were more accurate than the men in each of the movement conditions (see Table 10). However, this greater accuracy of women over men was not significant (Table 8). The Gender difference found is consistent for both hands (see Table 11); the women are more accurate than the men with both the right and the left hands. As can be seen from Figure 7, the men showed a crossover trend similar to the one shown by strongly right-handed men where the right hand was slightly more accurate than the left hand in the U condition, but then switched over to where the left hand was more accurate than the right hand in the SS and SA conditions. This pattern was

TABLE 8

ANOVA: F Summary Table: Raw Scores
 Gender x Movement Condition x Hand
 (Weakly Right-Handed Subjects)

	Sum of Squares	df	Mean Squares	F
Between subjects	885471.34	7	126495.91	
Gender	188752.09	1	188752.09	1.63
Subjects	696719.25	6	116119.88	
Within subjects	747750.33	40	18693.76	
Movement	38865.17	2	19432.59	1.99
Gender x Movement	15448.66	2	7724.33	.79
Movement x subjects	117151.50	12	9762.63	
Hand	24480.34	1	24480.34	.32
Gender x Hand	36.74	1	36.74	.00
Hand x subjects	454223.92	6	75703.99	
Movement x Hand	11980.66	2	5990.33	1.09
Gender x Movement x Hand	19360.51	2	9680.26	1.75
Movement x Hand x subjects	66202.83	12	5516.90	
Total	1633221.67	47		

* $p < .05$

** $p < .01$

Figure 7. Mean error as a function of Gender, Movement condition, and Hand: Weakly right-handed subjects.

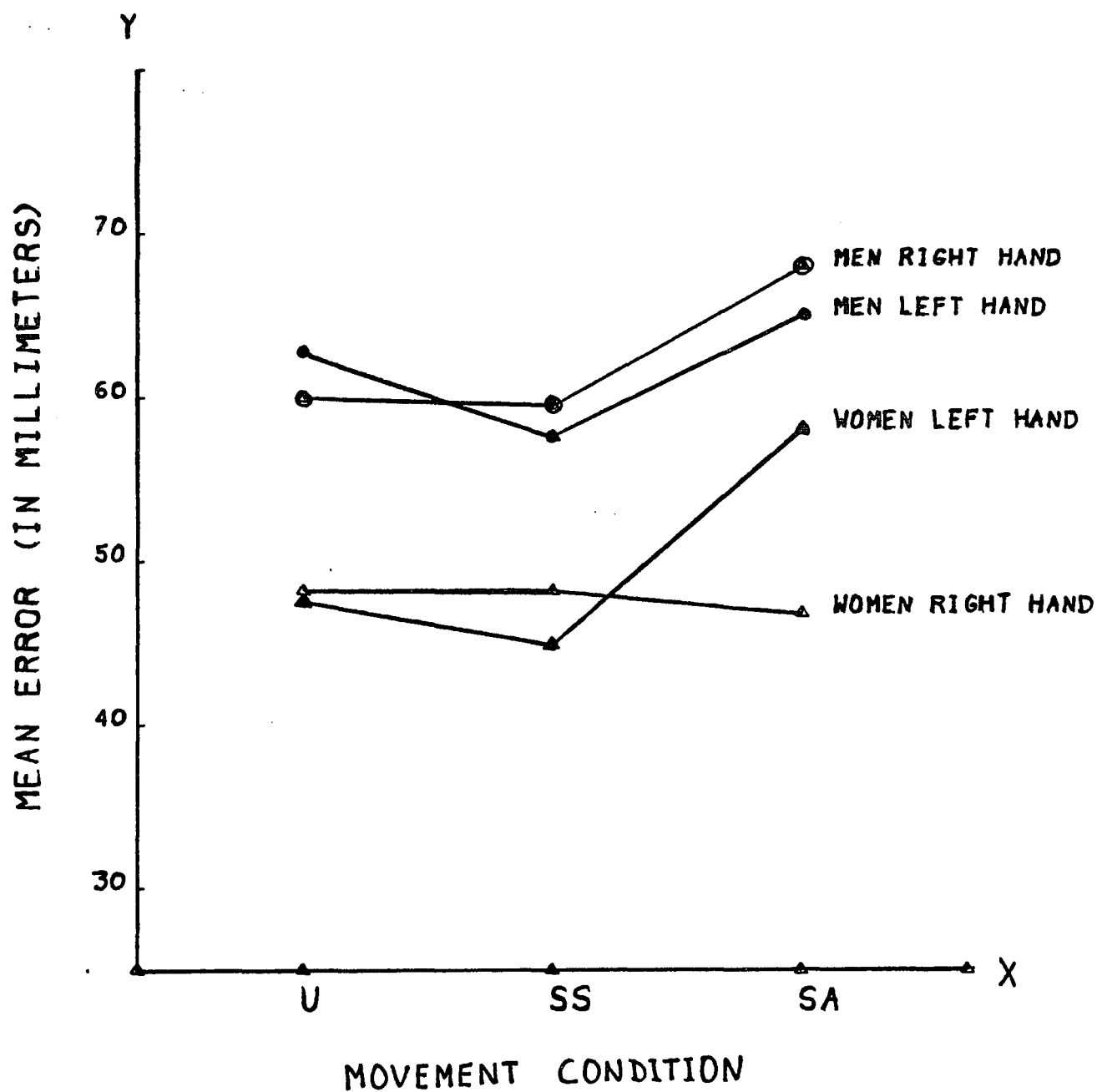


TABLE 9

Mean Distance from Target (in millimeters) for the
 Right and Left Hands in Each Movement
 Condition: Weakly Right-Handed Subjects (n=8)

Hand	Movement Condition			
	U	SS	SA	Total
Right				
$\bar{X}$ (S.D.)	54.1 (14.7)	53.9 (15.8)	57.4 (20.1)	55.1 (16.3)
Left				
$\bar{X}$ (S.D.)	55.2 (18.0)	51.2 (19.5)	61.6 (21.2)	56.0 (16.6)
Total				
$\bar{X}$ (S.D.)	54.7 (16.5)	52.6 (17.7)	59.4 (20.8)	55.6 (16.5)

TABLE 10

Mean Distance from Target (in millimeters) for
Men and Women in Each Movement
Condition: Weakly Right-Handed Subjects

Gender	Movement Condition			
	U	SS	SA	Total
Men n=4 $\bar{X}$ (S.D.)	61.4 (1.5)	58.6 (7.8)	66.5 (4.7)	62.2 (4.4)
Women n=4 $\bar{X}$ (S.D.)	47.9 (16.2)	46.6 (18.0)	52.4 (19.8)	49.0 (17.8)

TABLE 11

Mean Distance from Target (in millimeters) for the
 Right and Left Hands of Men and Women:
 Weakly Right-Handed Subjects

	Right Hand	Left Hand
Men n=4 $\bar{X}$ (S.D.)	62.5 (16.0)	61.8 (9.4)
Women n=4 $\bar{X}$ (S.D.)	47.7 (12.7)	50.2 (19.9)

not shown by the women who demonstrated a sharp decrease in the accuracy of the left hand in the SA condition.

C. Left-handed subjects (n=4). As can be seen from Table 12, the ANOVA on the raw scores of the left-handed subjects showed no significant main effects or interactions among Gender, Movement, and Hand. Figure 8 illustrates the pattern of performance for the left-handed subjects. For the first time there is the suggestion of the men being more accurate than the women.

Although there are no statistically significant differences among the movement conditions, the same trend found in the two right-handedness groups exists for there to be the least accuracy in the SA condition (see Table 13) exists in the left-handed group. The left-handed men were more accurate than the left-handed women in all of the movement conditions (see Table 14). This gender difference was also found for the right and left hands (see Table 15). Again, the results obtained on the left-handed group have been cautiously interpreted due to the fact that there are only 4 subjects in this group.

TABLE 12

ANOVA: F Summary Table: Raw Scores
 Gender x Movement Condition x Hand
 (Left-Handed Subjects)

	Sum of Squares	df	Mean Squares	F
Between subjects	875753.33	3	291917.78	
Gender	62016.66	1	62016.66	.15
Subjects	813737.00	2	406868.50	
Within subjects	86132.00	20	4306.60	
Movement	14121.58	2	7060.79	1.61
Gender x Movement	8358.09	2	4179.05	.95
Movement x subjects	17518.33	4	4379.58	
Hand	96.00	1	96.00	.00
Gender x Hand	1232.67	1	1232.67	.07
Hand x subjects	36840.66	2	18420.33	
Movement x Hand	1777.75	2	888.88	.65
Gender x Movement x Hand	683.58	2	341.79	.25
Movement x Hand x subjects	5503.34	4	1375.84	
Total	961885.33	23		

* $\underline{p} < .05$

** $\underline{p} < .01$

Figure 8. Mean error as a function of Gender, Movement condition, and Hand: Left-handed subjects.

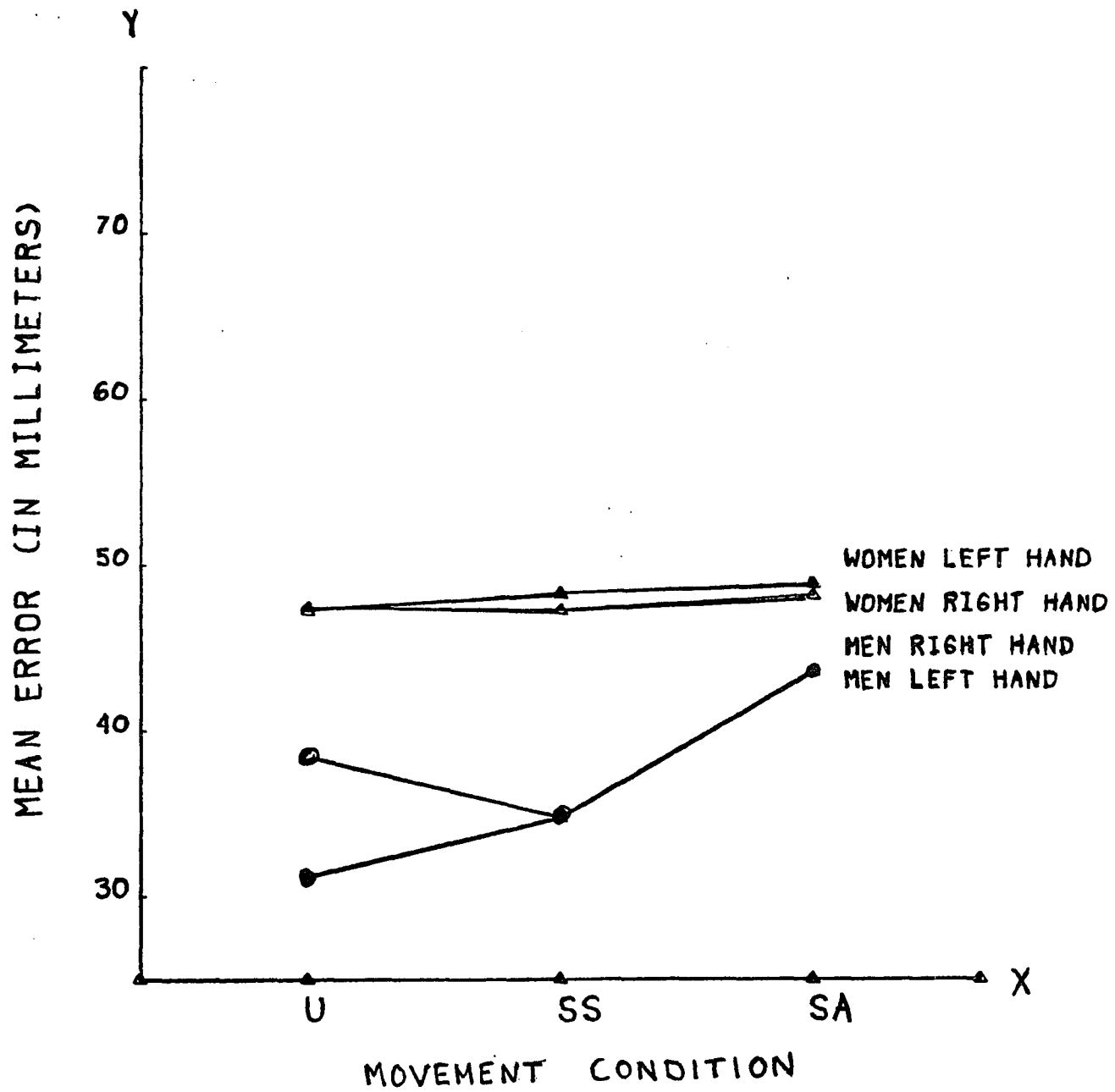


TABLE 13

Mean Distance from Target (in millimeters) for the
 Right and Left Hands in Each Movement
 Condition: Left-Handed Subjects (n=4)

Hand	Movement Condition			
	U	SS	SA	Total
Right				
$\bar{X}$ (S.D.)	42.9 (19.1)	41.0 (18.9)	45.8 (19.0)	43.2 (18.6)
Left				
$\bar{X}$ (S.D.)	39.2 (21.3)	41.4 (19.2)	46.2 (21.0)	42.3 (20.2)
Total				
$\bar{X}$ (S.D.)	41.1 (20.3)	41.2 (19.1)	46.0 (20.1)	42.8 (19.4)

TABLE 14

Mean Distance from Target (in millimeters) for Men and Women
in Each Movement Condition: Left-Handed Subjects

Gender	Movement Condition			
	U	SS	SA	Total
Men n=2 $\bar{X}$ (S.D.)	34.8 (9.2)	34.7 (5.0)	43.5 (8.2)	37.7 (6.0)
Women N=2 $\bar{X}$ (S.D.)	47.3 (25.8)	47.7 (24.8)	48.4 (26.9)	47.8 (25.8)

TABLE 15

Mean Distance from Target (in millimeters) for the
Right and Left Hands of Men and Women:
Left-Handed Subjects

	Right Hand	Left Hand
Men n=2 $\bar{X}$ (S.D.)	38.9 (4.9)	36.5 (6.6)
Women n=2 $\bar{X}$ (S.D.)	47.6 (25.0)	48.1 (26.6)

D. Comparisons among handedness groups. Table 16 shows the mean distance from the intended target in each of the movement conditions and for each of the handedness groups. A general trend seen among all three groups was for the most accurate condition to be the U condition (with the exception of the weakly right-handed group, where the SS condition was slightly, but not significantly, more accurate) and the least accurate condition to be the SA condition.

Comparisons among the three handedness groups indicated that the weakly right-handed group was the least accurate. The difference between the weakly right-handed group and the strongly right-handed was statistically significant for the U movement condition and for the overall total (see Table 17). In addition, the overall total for the left-handed group was significantly more accurate than the weakly right-handed group, but no different than the strongly right-handed group.

TABLE 16

Mean Distance from Target (in millimeters) for the
Handedness Group in Each Movement Condition

Handedness Group	Movement Condition			Total
	U	SS	SA	
Strongly-Right Handed $\bar{X}$ (S.D.) n=38	41.2 (16.2)	42.4 (14.5)	47.6 (16.9)	43.8 (15.0)
Weakly-Right Handed $\bar{X}$ (S.D.) n=8	54.7 (18.0)	52.6 (19.5)	59.4 (21.2)	55.6 (16.6)
Left-Handed $\bar{X}$ (S.D.) n=4	41.1 (20.3)	41.2 (19.1)	46.0 (20.1)	42.8 (19.4)

TABLE 17

Calculated t-values for Comparison of the Performance
of the Handedness Groups in Each of the Movement Conditions

	Weakly Right Handed				Left-Handed			
	WRH-U	WRH-SS	WRH-SA	WRH-T	LH-U	LH-SS	LH-SA	LH-T
SRH-U	2.10				.01			
SRH-SS		1.86				.17		
SRH-SA			1.98				.21	
SRH-T				3.58**				.24
WRH-U					1.24			
WRH-SS						1.19		
WRH-SA							1.28	
WRH-T								2.27*

* $p < .05$

** $p < .01$.

CHAPTER IV

Discussion

It seems appropriate, at this time, to evaluate the results of the study with reference to the predictions set forth in Chapter I. Overall, the basic goal of the study was to demonstrate, for strongly right handed subjects, a greater performance difference between the right and left hands in a simultaneous asymmetrical task than in a unimanual task. The underlying assumption was that the simultaneous asymmetrical activity would maximize the functional differences between the cerebral hemispheres, and in this way, right and left hand performance would better represent the respective abilities of the left and right cerebral hemispheres. The particular spatial motor task used was expected to be mediated better by the right hemisphere, thereby conferring an advantage on the left hand, especially during asymmetrical movement.

Since it was recognized that the right hand of strongly right-handed subjects might have some motor advantage over the left hand, it was not expected that the left hand would necessarily be more accurate than the right hand. However, when the changes in performance from the unimanual to the bimanual asymmetrical movement conditions were considered for each hand, it was expected that the change would be greater for the right hand than for the left hand. Thus, it was anti-

cipated that the performance of the right hand would be more adversely affected by the reduced contribution of the right hemisphere than the performance of the left hand would be adversely affected by the reduced contribution of the left hemisphere.

Summary of Results

Movement condition. The strongly right-handed subjects (n=38) were most accurate in localizing a previously seen target in the unimanual condition. There was no significant change in performance by the introduction of simultaneous symmetrical movement. However, there was a statistically significant decrease in the accuracy of localizing the target when simultaneous asymmetrical activity was required. This pattern was found for both the right and left hands.

Although there were no significant differences between the movement conditions for the weakly right-handed or left-handed groups, there was a trend for the largest amount of error to be in the simultaneous asymmetrical condition. The lack of statistical significance between conditions for these groups was probably due to their small sample size (weakly right-handed, n=8; left-handed, n=4).

The significant increase in error in the simultaneous asymmetrical but not the simultaneous symmetrical movement

condition parallels the findings of Kelso et al.'s (1979) study on reaction time (RT). There was no increase in RT when a subject aimed for either one target or two targets simultaneously, as long as both targets were the same, that is, they were both "easy" or both "difficult" targets. However, there was a significant increase in RT when simultaneous asymmetrical movement was required, that is, aiming for a "difficult" target with one hand and an "easy" target with the other hand. Kelso et al. regarded the longer RT's in the latter case as representing an increased preparatory period for programming muscle linkages. The results of the present study indicate that not only may simultaneous asymmetrical movement of the hands and arms require more planning time, but that the end result may also be less accurate.

Hand differences. It was predicted that there would be no differences between the accuracy of the right and left hands in the unimanual condition. This was true in terms of statistically significant differences. However, for the strongly right-handed subject, there was a trend for the right hand to be more accurate than the left hand. This hand difference, however, was eliminated in both the simultaneous symmetrical and simultaneous asymmetrical conditions. Thus, the introduction of bimanual activity, whether symmetrical or asymmetrical, produced an equalization of performance between the two hands.

The prediction that there would be a greater performance difference between the right and left hands in the simultaneous asymmetrical condition than in the unimanual condition was also not supported.

The equalization of performance which occurred in the bimanual simultaneous conditions did so at the expense of the right hand which was brought down to the less accurate level of the left hand. It is not unusual to find bilateral simultaneous movement performed at the level of the less able side. Belmont, Karp, and Birch (1971) report that when hemiplegic patients are required to move both legs simultaneously, the level of activity of the good side is reduced by the addition of simultaneous movement on the impaired side. Similar results have been obtained by Hausmanowa-Petrusewicz (1959) and Cohn (1951) who concluded:

The primary major effect of bilateral simultaneous supination-promotion action was to decrease the ability of the intact side to perform with the facility that was evident when the intact side alone was set into operation. (p. 472)

The tendency towards symmetry in bilateral simultaneous movement also seems to be a strong tendency in normal subjects (Hausmanowa-Petrusewicz, 1959; Nathanson, 1974). In describing his normal control subjects, Cohn (1951) wrote:

In my observation, synchronization, or at least a strong attempt at synchronization, resulted whenever the upper extremities were set into simultaneous motion. In such instances the normal subjects exerted great effort, and experienced

much difficulty, in maintaining asynchronous alternating movements. As observed in the sample control recording, synchronization was accomplished by the assumption of the movement of the slower acting part. (p. 475)

Using "The Imaginary Piano-Finger test", Nathanson (1969) reported that 91% of the normal subjects had their hands in symmetrical positions when they were stopped at random intervals as they were rapidly striking notes on an imaginary keyboard. Symmetry in motor performance appears to be a basic preference. Most individuals find it rather difficult to carry out two different motor tasks simultaneously (Broadbent, 1974; Nathanson, 1974).

Although the relative changes in performance from the unimanual to simultaneous asymmetrical conditions between the right and left hands had been expected to shed light on the effect of reduced right hemisphere input to the right hand during simultaneous asymmetrical movement to a target, the results are not at all clear. While it is indeed true that the performance of the right hand showed a greater impairment in accuracy than the left hand between the unimanual and simultaneous asymmetrical conditions, it cannot be interpreted as a clear demonstration of relative reduction in right hemisphere spatial abilities to the right hand. Rather, it appears to represent the initial superiority of the right hand in the unimanual condition and the strong tendency toward symmetry in

bilateral motor performance at the lowest shared level of skill between the two sides.

Gender differences. An important finding that had not been predicted was the impressive and statistically significant difference in the accuracy of localizing a previously seen target between the men and women. For both the strongly and weakly right-handed subjects, the women were significantly more accurate than the men in all three movement conditions. Only the two left-handed women were less accurate than the two left-handed men, although the difference was not significant.

The gender difference found was surprising in light of the majority of evidence indicating that men tend to excel in many spatial tasks (Harris, 1977; Witelson, 1976b). However, most of the studies which have reported better male than female spatial performance have used visuo-spatial tasks (Inglis & Lawson, 1981; McGlone & Davidson, 1973). The task in this study did not require visuo-spatial abilities per se. Since it was performed blindfolded and the subjects received both active and passive practice trials, it may be regarded as requiring kinesthetic reproduction as well as approximation of a visual memory trace. Clear sex differences have not been reported for kinesthetic reproduction (Cochran, Note 7). In addition, since the task did involve the transfer of a visual memory trace, the increased number of fibers found in the splenium of the corpus callosum of women as compared to men

[an area involved in the interhemispheric transfer of visual information (de Lacoste-Utamsing & Holloway, 1982)] may have provided an advantage for women in this situation. These arguments are, of course, purely speculative, and more work remains to be done on sex differences in non-visually guided spatial tasks.

Another interesting gender-related trend emerged from the study. Although the overall prediction of there being a greater impairment in the accuracy of the right hand in the asymmetrical condition was not found, there was a trend in that direction for the right-handed men. The men demonstrated a slight right hand superiority in the U condition but then showed a left hand superiority in the SS and SA conditions. This trend, although not statistically significant, is similar to that reported by Witelson (1974, 1976b) in her dichhaptic procedure where only the right-handed boys showed a left hand superiority on the recognition of nonsense figures that had been simultaneously palpated by both hands. The implication for such a trend is that the SA condition may in fact bring about a greater functional separation of the hemispheres and--since men have been reported to be more clearly lateralized for spatial abilities (McGlone & Davidson, 1973)--thereby produce a greater impairment in the right hand of men when right hemisphere input is relatively reduced. It is possible that if this trend were to still be present in a larger sample of men, statistical significance may be obtained.

Handedness groups. The accuracy of the strongly right-handed group was virtually identical to that of the left-handed group, and both of these groups were more accurate than the weakly right-handed group by approximately 12 mm. These total differences were statistically significant and are congruent with prevailing notions of so-called "ambidextrous" individuals who, rather than perform as though they have two dominant hands, perform as though they have two non-dominant hands (Flowers, 1975).

One exception to the poor performance of weakly-handed individuals were the two left-handed men (both were weakly left-handed) whose accuracy was extremely close to that of the strongly right-handed women. It is difficult to make assumptions based on the performance of two subjects, especially when they are both the only weakly left-handed subjects and the only left-handed men; however, there may be something about the cerebral organization of left-handed men or weakly left-handed subjects (or being a weakly left-handed man) which is conducive to accurate performance on localizing a previously seen target.

Conclusions

Even if the results on the target localization task in this study can be attributed to a tendency toward symmetry of both hands during simultaneous movement, this conclusion does

not preclude hemispheric asymmetry in spatial abilities. The presence of bilateral symmetrical movement does not necessarily indicate that the controlling cerebral hemispheres are symmetrical. One hemisphere may be responsible for the initiation and cessation of the motor program for bilaterally symmetrical movements (Peters, 1976). In this particular study, the right hemisphere may have been responsible for the motor program provided to both hemispheres and, therefore, both hands (although the present investigation cannot assess this).

A basic assumption underlying the design of the task was that interhemispheric communication would be reduced during simultaneous asymmetrical movement. This may have indeed occurred since each hand was able to move in a different direction. What the study did not take into account was the preparatory period before movement was initiated. During this period information about the visuo-spatial memory trace and estimation of trajectory may have been communicated transcallosally. Even if a relative restriction of information existed between the hemispheres as the movement was occurring, it does not mean that the necessary information about the terminal location of the hand would not be stored in each hemisphere regardless of the hemisphere of origin.

Slow cortical potentials have been shown to precede voluntary movements (Deecke, Schied, & Kornhuber, 1969; Gerbrandt, Goff, & Smith, 1973; Gilden, Vaughan, & Costa, 1966;

Vaughan, Costa, & Ritter, 1968). The complex of four potentials has been referred to as the "motor potential" (Gilden et al., 1966; Vaughan et al., 1968), and one component, N, has been referred to as the "readiness potential" (Deecke et al., 1969). The N potential always precedes movement by several hundred milliseconds. It is quite similar to the contingent negative variation (CNV) that was originally described by Walter, Cooper, Aldridge, McCallum, and Winter (1964) and measured during preparatory periods in reaction time experiments. The CNVs can be elicited in the absence of a motor response (Donchin, Gerbrandt, Leifer, & Tucker, 1972), as can an increase in regional cerebral blood flow in the supplementary motor areas during internal programming of ballistic hand movements without executing the movements (Roland, Skinhoj, Larsen, & Lassen, 1977).

Grunewald, Grunewald-Zuberbier, Homberg, & Netz (1979) describe the cerebral potentials that precede voluntary ballistic movement as:

A slow negative shift about 0.1-0.8 s prior to movement... having initially about the same amplitude on both sides, and becoming larger contralaterally than ipsilaterally over precentral regions in the 1st 400 or 300 ms prior to movement. (p. 39)

Kutas and Donchin (1974) also describe a bilateral negative potential that becomes larger over the sensorimotor location contralateral to the hand that will be used as early as 500

milliseconds before the initiation of movement. In both cases, unilateral movements were studied. Since the preparatory potentials preceding voluntary unimanual movements show bilateral components, both hemispheres would certainly be expected to participate in preparation for bimanual movements.

Kelso, Southard, and Goodman (1979) report that the reaction times needed before subjects perform more simple or complex simultaneous movements represent the preparatory period for programming muscle linkages (Bernstein, 1967; Turvey, 1977). These centrally programmed muscle linkages produce the tight coupling between the limits seen in simultaneous movements. Kelso et al. conclude:

Thus, the equilibrium points for each hand may be preset... the underlying temporal structure, however, remains invariant between the hands such that they maintain a synchronous relationship to each other. (p. 1031)

Applying all of these results to the present study leads to the suggestion that, prior to the initiation of the simultaneous asymmetrical movements, a central plan may have been set up for the pattern of muscles to be used. The plan included the coordination of muscles to determine both the direction and distance of movement for each hand. It is postulated that the right hemisphere provided the spatial estimation of the distance to the target for both hands. The evidence to support this arises from the fact that the unimanual perfor-

mance of the right hand was significantly altered in the simultaneous asymmetrical condition to match the performance of the left hand. The simultaneous asymmetrical condition produced one synchronous, pre-programmed movement which involved the interaction of both hands.

In order to confirm this hypothesis, more evidence would have to be obtained on the preparatory phase prior to bilateral simultaneous movement. Electrophysiological or regional cerebral blood flow patterns might be appropriate measures for studying this problem. In addition, in order to rule out peripheral motor factors (or to examine them), electromyographic recordings of the pre-movement muscle potentials in the right and left hands would be helpful.

In retrospect, the simultaneous asymmetrical condition used in the present study may not have been a truly asymmetrical motor task. Even though the hands had to move in different directions, the variable that was of interest--the subject's accuracy in localizing the target--was symmetrical for both hands. Both the side and the top targets were exactly five inches from the starting position. These "preselected" movements have been reported to be under central, feed-forward control, and to be guided by a movement plan rather than by peripheral feedback (Greenwald, 1970; Kelso, 1977). The same movement plan, in terms of the length of excursion, would be appropriate for both hands. One way to correct this would

be to vary the distances of the targets. In this way if the hands were equal in their performance, the distance travelled would be closer to one target than the other. This would make it easier to ascertain the dominant influence over the distance of the localization attempts. Another possibility would be to vary the time available to program the central motor plan. If the preparatory period is sufficiently shortened to the point that the information cannot be transferred from one hemisphere to the other, a left hand advantage might appear.

In summary, then, the present task has demonstrated that simultaneous asymmetrical target localization does affect the way in which the hemispheres interact. This is evidenced by the overall decrease in accuracy of both hands during asymmetrical performance as compared to their unimanual performance and the tendency for equalization in the performance of both hands to occur at the least efficient level during simultaneous movement. In addition, gender differences have been obtained via the use of this task in that women were significantly more accurate than men in all of the movement conditions and the suggestion that the impairment in accuracy shown by the right hand of right-handed men in the asymmetrical condition reflects the stronger lateralization of males for spatial abilities.

CHAPTER V

Significance of Cerebral Asymmetry

Even though there is some debate about the nature of cerebral asymmetries and the preferred method for assessing them, the overwhelming conclusion that emerges from the huge body of literature on the subject is that cerebral asymmetries do, in fact, exist in the human adult. The question arises as to what advantages cerebral asymmetries provide and what significance this type of cerebral organization has for behavior.

Some clues to the advantages of variation in patterns of the nervous system come from studying trends in both phylogenetic and ontogenetic development. Two commonly discussed processes that occur as one ascends the phyletic scale or follows the growth of an individual from conception to maturity are increasing cephalization and increasing specialization of structures and functions. One trend which is generally not mentioned is increasing asymmetry of function between the two halves of the brain system.

Phylogenetic Trends

Increasing body asymmetry. It has been suggested that evolution is characterized by increasing body asymmetry (Tschirgi, 1958). Representation of the two sides of the body

are "more equal" in the brains of animals lower on the phylogenetic scale (Jackson, cited in Critchley, 1972). Invertebrate animals possess a basically bilaterally symmetrical local nervous system (Dimond, 1972). Planaria exhibit a ladder-type structure where the symmetrical halves are connected by commissural fibers. At the level of the vertebrates, there is crossed control so that stimulation of one side of the brain results in movement on the opposite side of the body (Ferrier, 1886; Fritsch & Hitzig, 1870; Liddell, 1955). In the sensory systems, although there are ipsilateral fibers, the contralateral fibers are more numerous and/or more efficient (Nadel, 1966).

Handedness--the propensity to consistently use the same hand from one time to the next and from one task to another--clearly emerges in human beings. Collins (1977) has reported consistent paw preferences in mice; however, these mice are highly inbred and tested in unnatural situations for mice. The evidence for handedness in sub-human primates indicates that it is not a reliable feature of their behavior (Beck & Barton, 1972; Cole, 1957; Ettlinger & Moffett, 1964; Finch, 1941; Gautrin & Ettlinger, 1970; Hall & Mayer, 1966; Rothe, 1973; Warren, Abplanalp, & Warren, 1967). Kounin (1938) found that monkeys show little hand preference on easy tasks, but a more definite preference on difficult ones.

In reviewing Napier's (1961) and Jolly's (1964) work on the phylogenetic development of the hand, Reynolds (1975) concluded that while true handedness is a unique attribute of the human species, it can also be seen as the latest stage in a process of neural differentiation which exists in the other primates. Hamilton, Tieman, and Farrell (1974) found that the hemispheres of split-brain monkeys were equivalent in their ability to learn visual tasks except for a slight left hemisphere advantage for stimuli that differed only in orientation and were spatially redundant. This was viewed by Hamilton et al. as preliminary evidence for cerebral (left hemisphere) dominance.

While a small amount of functional asymmetry may exist in the higher primates, it is by no means present to the same degree that it is in humans. There have been no anatomical asymmetries found in the brains of anthropoid apes comparable to those found in humans (von Economo & Horn, 1930; Wada, Clark, & Hamm, 1975). Scheibel and Scheibel (1962) maintain that it is just this disparity between the hemispheres that parallels the emergence of higher cognitive functions in man, particularly speech (Critchley, 1972).

The only case of unilateral damage resulting in impaired communication in a non-human organism is found in Nottebohm's (1970) report of badly mutilated song patterns of birds follow-

ing destruction of the left descending nerve to the syrinx but not of the right descending nerve. Generally, then, in most animals other than humans, bilateral destruction of an area is required to bring out specific deficits (Milner, 1974b). Their homologous cortical regions appear to be more equivalent in both structure and function.

The symmetry present in lower organisms is reflected in their general inability to distinguish mirror images. Corballis and Beale (1976) cite several examples: Pavlov found it impossible to teach a dog to salivate when touched on one side and not to salivate when it was touched on the homologous part. Kornski could not teach a dog to lift one paw to a bell and the other paw to a buzzer if either sound came from one direction. Additionally, octopuses, fish, cats, rats, and monkeys have not been able to learn discrimination tasks using mirror-image stimuli. Thomas found that pigeons tended to peck equally at two keys that displayed lines angled at 60° or its supplement, 120° , even though they had only been trained to peck at the 60° key and had never been exposed to the 120° key. The pigeons did not peck as much at keys with lines slanted at other angles. Corballis and Beale suggest that these results may demonstrate that physical memory traces in these organisms may be laid down in duplicate, mirror-image form.

Other studies have supported the concept of mirror-image transfer of information in animals. In pigeons, who only have contralateral visual projections, when one hemisphere is trained to respond to a 45° line, the untrained hemisphere responds best to a 135° line, the mirror-image of the original stimulus (Mello, 1965). Similar results have been obtained with monkeys who have had their optic chiasms sectioned (Hamilton, Tieman, & Farrell, 1974; Noble, 1966, Riopelle, Rahm, & Itoigawa, 1964).

Evolutionary changes within homo sapiens also seem to have been directed towards greater asymmetry. Kimura (1973c) suggests that selective pressures have aided the development of asymmetry, particularly for visuo-spatial function among the male hunting members of the species, since accurate information about the immediate and distant environment was of paramount importance to them.

The left-right asymmetry in the human nervous system may have evolved along with the use of tools (Corballis & Beale, 1976). Most people generally use the left hand to hold an object while the right hand uses the tool. According to Corballis and Beale, left-right asymmetries are generally found in aspects of human-made environments such as tool use, language, and other symbolic behaviors.

Weber (cited in Critchley, 1972) claimed that the development of writing endowed the opposite cerebral hemisphere with a special ability for language. The scant evidence for this theory came partly from the observation that there are only infrequent references to speech loss as a result of unilateral lesions in historical times when few people were literate. However, the paucity of reports about aphasia in pre-literate times could be due to a variety of factors other than a lack of functional asymmetry for language, not the least of which is how well aphasia was recognized as an entity.

According to Jaynes (1976), the development of writing was significant because it led to the breakdown of the "bicameral" mind which occurred approximately 3,000 years ago. The bicameral, or two-chambered mind consisted of the right hemisphere which "spoke" and the left hemisphere which "obeyed" the commands of the right hemisphere. Jaynes maintains that during this phase, humans were not conscious in the same sense that we recognize consciousness in modern times--they were not introspective about their actions.

The available evidence presented thus far indicates that increasing asymmetry of both structure and function between the two sides of the body, and especially of the brain, is an evolutionary trend. The greatest degree of asymmetry of function appears to be present in human beings. It may well be

that these functional asymmetries may be correlated with the emergence of distinctive human capabilities.

Ontogenetic Trends

Presence of cerebral asymmetry at birth. There is some controversy as to whether the hemispheric asymmetries found in adults are present at birth and, if so, to the same degree. It was originally believed that there was no hemispheric asymmetry in the neonate or infant. This belief was derived largely from evidence that lesions of the left hemisphere in early ontogeny rarely resulted in significant language impairment (Basser, 1962), in contrast to comparable lesions in later childhood and adulthood.

In reviewing the data on infants and children with left hemispherectomies, Krashen (1973) found that language skills were recovered only if the hemisphere was removed prior to the age of 5. Based upon these findings, Lenneberg (1967) postulated that, early in life, the two hemispheres are equipotential in their ability to subserve language function. Therefore, in the event of early left hemisphere damage, the right hemisphere would be able to assume the necessary role. The increased incidence of language disorders consequent to right hemisphere damage in very young children, as opposed to that in adults, may indicate greater participation of both hemispheres in language function at these ages (Krashen, 1973).

Kinsbourne (1975) cautions against using recovery of language function following early lateralized lesions as evidence of a lack of hemispheric asymmetry and of hemispheric equipotentiality in the young child. The resilience of language function in children may be explained in terms of the plasticity of the immature nervous system rather than duplicity of function or structural equipotentiality. Even though the right hemisphere is able to assume language function in the event of early left hemisphere damage, it seems misleading to regard the two hemispheres as being truly equipotential for language. If this were true, the hemisphere specialized for language would be determined by chance. Since the left hemisphere is generally dominant for speech in most persons, it seems that the left hemisphere would have some initial differentiation that, barring any interference with its functioning, predisposes it to assume speech and language functions.

The limited anatomical evidence available indicates that the temporal planum region of the left hemisphere is larger than the homologous region of the right hemisphere in human neonates free of neurological pathology (Witelson & Pallie, 1973). This asymmetry has also been reported in fetal brains during the third trimester (Chi, Dooling, & Gilles, 1977; Wada, Clarke, & Hamm, 1975). Wada et al. also studied the area of the frontal operculum and found that even though the area of the operculum was slightly larger in the right hemi-

sphere, the gyri contained within the left frontal operculum were more tightly packed than the gyri within the right frontal operculum. Wada et al. suspect that the total cortical surface area of the operculum is larger in the left hemisphere. They conclude that:

The presence of measurable morphological asymmetry as early as the 29th gestational week in the cortical area known to be involved in the processing of speech and language function suggests that the human brain possesses a predetermined morphological and functional capacity for the development of lateralized hemispheric function for speech and language....

In our study, the degree of asymmetry was more prominent in the temporal planum than the frontal operculum. This finding is consistent with the fact that the posterior speech zone is of major importance in language function [Penfield & Roberts, 1959]; in contrast, the anterior speech zone seems less critical and damage to it often produces only transient effects (O. Zangwill, oral communication). (p. 245)

Rubens, Mahowald, and Hutton (1976) conclude that the presence of an anatomically larger area in the left temporal region of young infants and even fetuses known to be involved in speech in later ontogeny indicates that there is a larger area in the right parietal area known to be involved in visuo-spatial functions. There is some evidence that the right hemisphere may develop earlier than the left hemisphere. Chi et al. (1977) found that the transverse temporal gyri could be recognized 1-2 weeks earlier in the right hemisphere than in the left hemisphere of fetal brains. Carmon, Harishanu,

Lowinger, and Lavy (1972) suggest that since there is more blood diffused over the right hemisphere than left hemisphere during a resting state, the right hemisphere may be more physiologically developed. Knox and Kimura (1970) speculate that the right hemisphere may specialize early in life for visuo-spatial perception and recognition of environmental sounds, abilities which appear earlier than speech or manual dexterity.

Careful observation of the human neonate reveals that an asymmetrical pattern of response characterizes the neonates' basic approach to the environment (Sherick, Greenmam, & Legg, 1976). One example of this asymmetry can be found in lateralized threshold differences to various kinds of stimuli.

Visual stimuli appear to be detected better by infants when presented to the right side of the visual field (Wickelgren, 1967). In the auditory modality, newborn infants respond to a 66 db white noise stimulus presented to the right ear with a conjugate eye-turning response, but no such response occurs to left ear stimulation until the stimulus reaches 87 db (Turkewitz, Birch, Moreau, Levy, & Cornwell, 1966).

Not only do infants show an absolute threshold difference between the two ears in their conjugate eye movement responses, but the hemispheres also appear to respond differently to speech and non-speech stimuli. Infants show greater auditory

evoked potentials in the left hemisphere to speech-like stimuli and greater auditory evoked potentials in the right hemisphere to musical stimuli (Molfese, 1972, Note 8).

The lateralized responses shown by infants do not necessarily indicate that the infants are able to distinguish between verbal and musical stimuli per se, but that there may be a more basic element in each stimulus which is of selective interest to one or the other hemisphere. This element has been suggested by Davis and Wada (1977) to be whether the stimuli are primarily temporal or spatial in nature. Using preverbal infants, Davis and Wada found significantly larger auditory evoked potentials in the left hemisphere when a click was used, but only slightly larger visual evoked potentials in the right hemisphere when a brief flash of light was used. Their interpretation of the findings suggest that the left hemisphere's superiority in processing temporal information serves as a pre-linguistic mechanism for speech acquisition. Davis and Wada also explain the bilateral response to the flash stimulus as representing the combination of temporal and spatial elements in a brief flash of light. The click stimulus was regarded as having purely temporal elements.

Tactile stimulation has also been shown to be more effective on the right side of the body in young infants (Siqueland & Lipsitt, 1966). The neonate shows more frequent cardiac acceleration to stimulation of the right perioral region than

to stimulation of the left perioral region (Hammer & Turkewitz, 1974). The human neonate also makes more ipsilateral head turns in response to right perioral stimulation than to left perioral stimulation (Turkewitz, Gordon, & Birch, 1965). There is a much faster and greater decrement in the head-turning response to repeated left-sided perioral stimulation (Moreau, Helfgott, Weinstein, & Milner, 1978).

It appears that, even in the absence of perioral stimulation, the human infant spends a good deal of time with its head turned to the right (Gesell, 1938; Gesell & Ames, 1947; Gesell & Halverson, 1942; Turkewitz, Gordon, & Birch, 1965). The laterality differences in sensitivity to auditory, tactile, and visual stimulation that the neonate shows may be related to its initial head posture which, in 88% of neonates tested, was to the right of the body midline (Turkewitz & Creighton, 1974).

The right bias in head orientation demonstrated by neonates has been related to the development of right-handedness by producing differential experience in hand-eye coordination (Coryell & Michel, 1978; Michel & Goodwin, 1979; Turkewitz, Moreau, & Birch, 1966). Michel (1981) reports that the infant's head orientation to the right of the body midline is maintained for at least 2 months after birth and that it reliably predicts the infant's preferred hand when reaching

for objects. Michel does not conclude whether this relationship represents the greater experience the infant has with visually guided reaching or whether both head orientation and handedness are independently controlled by a third, underlying factor.

During the first few weeks of life, the infant's basic response to a lateralized stimulus is the tonic neck reflex, which is, from birth, directed to the right about 80% of the time (Turkewitz, Gordon, & Birch, 1968). In the tonic neck reflex the head turns and the ipsilateral arm extends in the direction of the stimulus; the contralateral arm is flexed. Caplan and Kinsbourne (1976) view the tonic neck reflex as a selective orienting response. It may facilitate the emergence of prehension by directing visual fixation towards the extended arm (Gesell & Amatruda, 1967).

While the infant's grasp is equally strong in both hands (Peiper, 1963), Caplan and Kinsbourne (1976) found that when a rattle was held in one hand at a time, the mean duration of maintained grasp was significantly longer for the right hand than the left hand in 3 month old infants. The asymmetry displayed in the grasp reflex, however, does not necessarily indicate future handedness. There do not seem to be consistent hand preferences in very young children (Belmont & Birch, 1963; Travis, 1931). The beginning of a manual preference

is seen during the last quarter of the first year of life (Cernacek & Podivinsky, 1971; Gesell & Ames, 1947; Giesecke, 1936; Seth, 1973). Strengthening of this hand preference appears to occur during the first few years (Gesell & Ames, 1947; Hildreth, 1948; Lippman, 1927; Cernacek & Jagr, Note 9).

The asymmetry that is expressed by a reliable hand preference appears to be on a higher, more integrated level than the asymmetry present during the first 16 weeks of life when the tonic neck reflex is present (Sherick et al., 1976). It is possible that similar behaviors may be mediated by different neural substrates at various ages (Goldman, Crawford, Stokes, Galkin, & Rosvold, 1974). Hemispheric specialization, as it is known in the adult, may emerge with CNS maturation (McNeil & Hamre, 1974).

Emergence of hemispheric synchronization. While there appears to be both morphological and functional differentiation of the cerebral hemispheres very early in ontogeny, what seems to be lacking is a certain degree of integration and synchronization between the hemispheres. Myelination of the fibers in the corpus callosum occurs rather late in development, indicating that there may be less capacity for transferring information between the hemispheres in very young children (Galín, Note 10).

Repetitive rhythmic visual stimulation produces a bilateral EEG response in adults called photic driving (Freedman, 1963). The appearance of this response seems to follow a developmental sequence (Crowell, Jones, Kapuniai, & Nakagawa, 1973; Jones, Crowell, Nakagawa, & Kapuniai, 1972). In the neonate, no photic driving occurs. Photic driving first appears in the right hemisphere and, slightly later in development, a bilateral response emerges. Crowell et al. (1973) interpret the initial development of a unilateral right hemisphere driving response as indicating a lack of interhemispheric integration and as an index of the right hemisphere's earlier differentiation for rhythmic visual stimuli.

The emergence of handedness in the child has been shown to correlate with the emergence of the early ipsilateral transcallosal somatosensory cortical evoked response (Cernacek & Podivinsky, 1971). While the contralateral cortical response of the dominant hemisphere was significantly greater than the ipsilateral cortical response of the non-dominant hemisphere, the appearance of the ipsilateral component signifies the integration of the two hemispheres via communication across the corpus callosum.

The lack of integration between the hemispheres may be manifest in the infant's propensity to avoid movements which cross the body midline. An object presented to the right of

the midline is reached for by the right hand while an object presented to the left of the body midline is reached for by the left hand (Caplan & Kinsbourne, 1976). When young children who can identify their left and right hand are asked to make hand movements which cross the body midline such as "put your right thumb on your left ear," they tend to respond with an ipsilateral response--that is, putting the right thumb on the right ear (Benton, 1955; Nathanson & Anderson, 1959; Schofield, 1976).

Sherick et al. (1976) postulate that the disappearance of the early asymmetry of the infant, as expressed by the tonic neck response, and the emergence of midline behavior--maintaining the head in a central position, mutual fingering of the two hands as they meet over the center of the chest--represents a new stage of bilaterality. Sherick et al. suggest that the bilaterality may promote the synchronization of the two cerebral hemispheres so that they can both be adequately developed to further specialize at a later age.

The postulated bilaterality of young children may explain certain behaviors. A fairly universal difficulty for young children is telling right from left (Aaron & Malatesha, 1974; Belmont & Birch, 1963; Bradshaw, Nettleton, & Patterson, 1973; Corballis & Beale, 1970, 1971, 1976; Tankle, Van Den Abell,

Bullard, & Taylor, Note 11). It is not just for decorative purposes that mothers have been known to purchase sneakers and mittens appropriately marked "left" and "right"--children appear to need all the help they can get in telling the difference.

Normal children up to the age of 7 or 8 often confuse mirror-image letters such as b,d and p,g (Davidson, 1935). Rudel and Teuber (1963) found that 3- and 4-year olds "confuse oblique lines oriented in different directions...although they can readily discriminate vertical from horizontal lines" (p. 82).

This left-right confusion is also seen in the large proportion of mirror-image responses young children make when they attempt to copy the movements of someone who is facing them (Wapner & Cirillo, 1968). There is a developmental trend in the ability to correctly imitate these movements and, with increasing age, the children begin to respond with the same limb the model used. Additionally, children often show confusion about turning left or right on command, and some children resort to identifying their right by referring to the hand used to write (Corballis & Beale, 1971).

The motor movements of a young child are characterized by a certain amount of symmetry (Washburn, 1929). The response of one limb is generally accompanied by synergistic

movement in the opposite limb. This strong tendency for symmetry apparently remains with most individuals throughout their lives (Nathanson, 1974). Most people have trouble simultaneously performing different tasks with each side of the body without interference (Broadbent, 1974). Some adults have never been able to master the art of rubbing their stomachs while patting their heads--a task of monumental proportions to the young child.

Mirror movements, where voluntary movement of one limb is accompanied by involuntary symmetrical movement of the contralateral limb, occur normally in young children but decrease in frequency through development (Abercrombie, Lindon, & Tayson, 1964). It takes a few years before a child can close one eye without having both eyes close (Chaco & Blank, 1974). Even in the present study, more than half of the normal adult sample could not wink one eye alone.

Studying developmental trends in motor behavior, Touwen and Precht1 (1970) found that until 4 years of age a child can jump only by using both feet. By the age of 4, however, the child is able to balance and hop on the right foot alone, but not the left. By the age of 5, the child is able to balance and hop on either the right or the left foot alone.

In bimanual activity, the development of a stable hand preference for motor tasks has been noted to emerge out of originally bilaterally integrated movements by the age of 4 (Gesell & Ames, 1947). In early childhood, bimanual movements appear to involve fairly equal contributions from both hands; however, with increasing age, a more mature pattern develops where one hand moves while the other remains relatively still. In a study of children in various school grades, Bruml (1972) found that when the kindergarten children clapped their hands, both hands tended to move equally, meeting at the body midline. By the 4th grade, clapping consisted of one hand being held still with the palm upturned (usually the left hand) while the other hand moved to meet it.

The tendency towards symmetry in hand movements occurs after the point where hemispheric asymmetries for language function have been demonstrated. Kimura (1973a, 1973b) found that, in adults, the asymmetry of free hand movements during speech was related to the side of speech lateralization. However, children who demonstrated language lateralization, as indicated by their performance on the dichotic listening task, still showed a large degree of bilateral hand movements during speech (D. Ingram, 1975b). In that study, an attempt was made to explain the findings in terms of greater activation of the motor centers in both hemispheres of the children than of the adults.

Overcoming bilateral symmetry. The importance of children being able to overcome their basic tendencies towards symmetrical motor movements may be an essential factor in the development of certain abilities. Being able to "break symmetry" allows the child to perform purposeful, unilateral, discrete movements which are the elementary components of many motor tasks such as running, alternately stepping up and down stairs, learning to write, or playing a musical instrument (Nathanson, 1974).

Crawford (1960) has suggested that in any voluntary act both motor cortices are innervated, but that there is immediate suppression of one side, resulting in unilateral pyramidal activity. Development of unilateral motor activity may depend on the maturation of the pyramidal's system's ability to inhibit contralateral activity in the interneurons innervated by pyramidal and brain stem pathways. Caplan and Kinsbourne (1976) propose that while hemispheric differentiation may be present at birth, development involves the increasing ability of the left brain to inhibit the right brain when both are activated and compete for control. Gazzaniga (1974) suggests an ontogenetic model of mutual inhibition between the hemispheres in addition to lateralized anatomical correlates of function such as the larger temporal planum on the left, the earlier left pyramidal tract development, and right hand superiority to explain the lateralization of functions. Kinsbourne (1974b) and Moscovitch (1973) present

similar arguments about the development of lateralized functions depending heavily on reciprocal inhibition between the hemispheres.

Even though adults show longer RT's to brief tachistoscopic presentation of mirror-image stimuli, they do not show increased error rates, while young children do. Tankle et al. (Note 11) suggest that adults are able to inhibit the discrepancy between presented and processed information while children have not yet sufficiently developed the interhemispheric inhibition to avoid confusion.

The emergence of asymmetry in older children and adults represents a different functional integration between the hemispheres. The original asymmetry may represent inherent hemispheric predispositions in a situation of little communication between the hemispheres. The symmetrical stage may represent a period where communication across the corpus callosum developed to the point where activation in one hemisphere could direct activation of the other hemisphere. The new stage of asymmetry may represent a dynamic balance between the respective powers of each hemisphere, where interhemisphere information can be transmitted, but can also be selectively inhibited. Unilaterality may represent a "compromise" reached between the hemispheres where the hemisphere better suited for the specific task to be done takes the task

over and inhibits similar analysis in the contralateral hemisphere (Gazzaniga, Note 12).

When, if ever, is lateralization complete? The increasing ability of the left hemisphere to inhibit speech in the right hemisphere with increasing age and cerebral maturation may explain why there is a developmental decrease in the right hemisphere's participation in language functions, a process which has been regarded as a normal maturational process (Lenneberg, 1967). In later childhood, aphasia becomes a more common result of left, but not right hemisphere damage (Brown & Jaffe, 1975). While many researchers agree that this developmental process occurs, a major debate centers about its chronology.

Numerous studies have demonstrated functional hemispheric asymmetries in children who are 5 years old or younger (Geffner & Hochberg, 1971; D. Ingram, 1975a; Kimura, 1963b; Nagafuchi, 1970). It has been suggested by some that cerebral lateralization is complete by the age of 5 (Berlin, Hughes, Lowe-Bell, & Berlin, 1973; Geffen, 1976; Knox & Kimura, 1970; Young & Ellis, 1976). Other researchers maintain that cerebral lateralization continues throughout childhood (Bryden, 1973; Bryden & Allard, 1974; Lenneberg, 1967; Satz, Bakker, Teunissen, Goebel, & Van der Vlugt, 1975; Zangwill, 1960; Bakker, Satz, Goebel, & Van der Vlugt, Note 13). Still others maintain that

cerebral lateralization continues throughout adulthood (Brown & Jaffe, 1975; Clark & Knowles, 1973). The issue has not yet been resolved, although recent evidence mitigates against the theory of increasing lateralization in the adult group (Borod & Goodglass, 1980; Johnson, Cole, Bowers, Foiles, Nikardo, Patrick, and Woliver, 1979).

Perhaps the increasing inhibition of right hemisphere language function with increasing age frees the right hemisphere to develop other more complex visuo-spatial abilities. This may explain some of the right hemisphere visuo-spatial abilities which appear to develop after the age of 10 (Carey & Diamond, 1977; Kohn & Dennis, 1974; Woods & Teuber, 1973).

Vulnerability versus capacity. The redundancy of the bilaterally symmetrical invertebrate nervous system makes it uniquely suited for survival. Splitting the cephalic region of a planarian in half does not really seem to produce any severe deficits in functioning. The planarian merely regenerates the missing half of each side and goes about its regular existence with two heads. The cerebral asymmetries of the human being may be responsible for some of their more flexible and creative abilities, but may also make them more vulnerable to deficits following localized lesions. However, since cerebral asymmetries appear to be the result of both selection pressures in evolution (Levy, 1974) and maturation processes

in humans (Lenneberg, 1967), the cognitive advantages it brings probably outweigh the increased vulnerability.

Corballis and Beale (1971, 1976) suggest that the human beings' asymmetrical nervous system allows for the discrimination of mirror-image stimuli in various modalities. They maintain that this asymmetrical structure evolved along with the use of tools, communication, and other symbolic behavior.

An advantage of asymmetry of brain function can be gleaned from the observations that bilateral representation of functions results in a decrease in overall proficiency. One viewpoint on this matter, the "bilateral symmetry" hypothesis discussed by Kershner (1974), states that there is a primary impairment in the function that is bilaterally represented. Thus, those people who have bilateral speech representation would be expected to show impaired language abilities as compared to people with strongly lateralized speech function. While young children have more bilateral representation of speech and are inferior in verbal ability to adults, it is not known whether this is due to bilateral speech representation per se. Another group of people who appear to have more bilateral representation of speech are left-handers (Benton, 1962; Branch, Milner, & Rasmussen, 1964; Jones, 1966; Levy, 1969, 1972; Levy & Sperry, 1968; Rossi & Rosadini, 1967). Unilateral lesions of either hemisphere are

more likely to produce some form of aphasia in the left-handed individual, but the speech disturbance produced is usually not as severe or as permanent as the aphasia produced by left hemisphere lesions in a right-handed individual (Annett, 1970a; Botez & Crighel, 1971; Chesher, 1936; Gloning, Gloning, Haub, & Quatember, 1969; Gloning & Quatember, 1966; Goodglass & Quadfasel, 1954; Hecaen & Piercy, 1956; Luria, 1947; Subirana, 1958).

While the bilateral representation of speech appears to make speech more resistant to the effects of damage, there is no real evidence that the verbal abilities of left-handed people are impaired. An alternative hypothesis is suggested by the finding that even though the verbal intelligence test scores of left- and right-handers are nearly identical, the left-handers show poorer performance on non-verbal intelligence tests (Berman, 1971; Gilbert, 1973; Levy, 1969; Miller, 1971). Left-handers have also been shown to do worse on certain visuo-spatial tasks usually known to be mediated by the right hemisphere (James, Mefferd, & Wieland, 1967; Mefferd & Wieland, 1965; Nebes, 1971; Silverman, Adevai, & McGough, 1966).

The "interference" hypothesis states that bilateral representation of language function interferes with visuo-spatial function in the right hemisphere. The presence of

language in the right hemisphere may encroach on the neural space usually devoted to mediation of visuo-spatial functions (Levy, 1969, Miller, 1971). Thus, while those with bilateral speech representation may be protected against severe language impairment, it may be at the expense of a wider range of visuo-spatial functions.

In a similar way, the greater degree of bilateral symmetry in the brain of a young child may be a form of protection at a time when the brain may be more vulnerable to traumatic injury due to the softness of the skull. The primary goal of the infant would appear to be survival rather than flexibility of behavior, even if the result of this early damage would be a subtle reduction in the potential human cognitive repertoire.

The main advantage, then, of an asymmetrical brain pattern may be to double the brain's capacity (Dimond, 1972; Dimond & Beaumont, 1971; Marshall, 1973; Sperry, 1968). The lateralization of the human brain thus results in greater flexibility, greater neural storage capacity, and greater ability to make distinctions (Corballis & Beale, 1971).

It has been suggested that one of the primary roles of the corpus callosum is to prevent duplication of neural traces in the two cerebral hemispheres (Doty & Overman, 1977). If an engram is laid down on only one side and each hemisphere has access to the information in the other, then there is much

more neural space in the brain for storage. The presence of duplicate neural traces is "safer" in that unilateral damage will not completely destroy the trace. In general, it is found that, in species other than man, bilateral damage is required to produce most behavioral deficits (Milner, 1974b).

Another possible function of the corpus callosum was revealed by the lack of sustained attention found in patients following commissure section (Dimond, 1976). Since each hemisphere seems to have periods of lapsed vigilance, the splenium of the corpus callosum may coordinate the two hemispheres so that there are not too many periods where both are inattentive. In this way the "fabric of attentional processes" is held intact.

Having two different hemispheres is not always beneficial since they can often get in each other's way by transferring information (Teuber, 1974). The purpose of mutual inhibition between the hemispheres may be to allow the differentiation of the hemispheres to occur with a minimum of interference.

Disorders of Laterality

If lateralization of brain function is an end product of development and it confers numerous benefits, then it might be suggested that the lack of strong lateralization or abnormal patterns of lateralization may be behaviorally disadvantageous. One would suspect that the functions sacrificed in disorders

of laterality would be more subtle, complex, cognitive processes. Disorders of laterality are found in children with developmental problems, patients with brain damage, and may, in fact, help explain certain types of psychiatric disorders.

Developmental disorders. The methods that are presently available for determining the neurological status of a neonate are, in general, too gross to pick up abnormalities unless the child is severely damaged (Turkewitz & Birch, 1971). The normal behavioral repertoire of the neonate is apparently simple enough to allow many forms of brain damage to go undetected until the time when more complex cognitive functions are supposed to develop. If this is true in cases of rather severe mental retardation and behavioral disorders such as autism, then it should not be unusual to find that children with much more subtle neuro-behavioral dysfunction are regarded as normal at birth and during early infancy.

Even children who are in suboptimal condition at birth and apparently "return to normal" within 24 hours may not recover as completely as their performance on standard behavioral tests would indicate. Such infants have been shown to exhibit a high frequency of abnormalities in motor, language, and intellectual abilities in later infancy and childhood (Graham, Ernhart, Thurston, & Craft, 1962; Klatskin, McGarry, & Steward, 1966; Edwards, Note 14). Thus, Turkewitz and Birch

(1971) maintain that the effects of poor condition at birth are not evanescent, and the routine clinical neurobehavioral evaluation done on these children is not sensitive enough to detect persistent problems.

Turkewitz, Moreau, and Birch (1968) evaluated neonates' head-turning responses to somesthetic stimulation of the perioral region as a function of their birth condition. Birth condition was determined by the Apgar score recorded 1 minute after birth. All of the babies were subsequently reported to be in good health. The babies that had been rated either Intermediate (7 or 8) or High (9 or 10) on the 10 point Apgar scale made significantly more head-turning responses to stimulation of the right side than to stimulation of the left side. Those babies who had been rated Low (6 or lower) on the Apgar scale made as many head turns as the others but showed no lateral differentiation in responsiveness. Thus, the magnitude of lateral differentiation was significantly greater for the neonates in good condition at birth than for those who were in poor condition at birth, even though they were all regarded as being in good condition a short time after birth.

The early appearance of lateral differentiation in behavior may thus provide evidence of the functional integrity of the neonate's nervous system. It may be postulated that atypical patterns of lateralized behavior result from subtle abnormalities of the nervous system early in life.

While it is generally found that there is greater sparing of function for lesions inflicted at an earlier age (Milner, 1974b; Rutter, Graham, & Yule, 1970; Teuber, 1971, 1975), it seems that the degree of functional sparing varies with both the age of testing and the types of tests employed (Hebb, 1942, 1949; Rudel & Teuber, 1971; Russell, 1959). Some abilities even appear to be more impaired following earlier lesions than later lesions (Bauer & Hughes, 1970; Goldman, 1971; 1974; 1975).

The kind of brain damage which may result in the reorganization of cerebral lateralization would probably be difficult to document. Schneider (1979) writes:

It is difficult to judge how common early brain damage, especially prenatal damage, in man may be since obvious behavioral signs of the type seen in cases of adult injury may not be found, because of functional sparing, except for the more massive lesions... neuropathological study of brains could not easily uncover morphological signs of very early focal damage since if lesions occur before a certain age they will not cause a glial scar. (p. 574)

Citing the unpublished studies by F. Gilles and co-workers at Children's Hospital in Boston, Schneider states that scar formation can only occur in the human telencephalon after 26-27 weeks of gestation. As a result, the only morphological traces of early brain damage may be in the size of certain structures, some alterations in cytoarchitectural details, and anomalies in axonal pathways and connections.

In a personal communication cited in Schneider's article, Woods claims that "the earlier the lesion, the greater the reorganization of neural mechanisms underlying behavior" (p. 558). The re-directed growth of axons consequent to early brain lesions could help explain many behavioral abnormalities found in people who do not show the usual evidence of brain damage. In the motor system, the abnormal persistence and severity of mirror movements in childhood hemiplegia (Woods & Teuber, 1978) may be due to an abnormally greater amount of uncrossed pyramidal tract fibers. Schneider also suggests that re-directed axonal growth in the limbic system may result in abnormal reorganization of emotional responsiveness, autonomic nervous system control, and cognitive control of these functions. Schneider concludes:

Thus, children who have suffered early damage to the cerebral hemispheres may show little of the specific sensory or motor impairments seen in cases of cortical injury in adulthood, but they commonly suffer from a harder-to-define cognitive retardation which is not a characteristic effect of later injury. (p. 557)

While it has been difficult to find anatomical substrates for many behavioral abnormalities, statistical relationships exist between pregnancy and birth complications and psychoses (Kinney & Jacobsen, 1978; McNeil & Kaij, 1978) and infantile autism (Folstein & Rutter, 1977). One implication of this research may be that there is a higher incidence of prenatal

or perinatal brain damage in these patients leading to the reorganization of brain structures. Early lesions of the neocortex have been shown to lead to the formation of abnormal corpus callosal connections (Cusik & Lund, 1977). Such abnormal connections may interfere with the usual relationship between the hemispheres.

Since it has been assumed that asymmetrical motor function is a sign of normal development, it has been used as an indicator of developmental status. A. Cohen (1966) reported that those 8 month old infants who showed a marked preference for the use of a particular hand were more advanced in terms of developmental landmarks than those who did not show a marked hand preference. Cohen maintains that the development of manual asymmetry represents a more effective way of dealing with the environment. Perceptual-motor development has been claimed to rely heavily on the development of body "laterality" (Kephart, 1971). Establishment of handedness has been found to be related to the acquisition of language and the development of complex cognitive functions (Geschwind, 1970; Kimura, 1973a; Harris, Note 15). Annett (1970b) and others found that there were significantly higher numbers of mixed-handed people in the lower scoring ranges.

A large number of children with central nervous system disorders show delayed, weak, or unusual patterns of later-

ality. In a longitudinal study of premature infants, Pasamanick and Knobloch (1966) found a significant association between those children who, when tested at 3 years of age, had not yet established handedness and those who had been diagnosed as brain-injured at 40 weeks. Lack of brain asymmetry as evidenced by electrophysiological measures has also been found for children with Down's syndrome (Bigum, Dustman, & Beck, 1970) and in mentally retarded people (Schenkenberg & Dustman, 1970). Inability to perform movements that cross the body midline on command has been shown to be characteristic of mentally retarded and institutionalized epileptic children (H. Gordon, 1922).

Laterality disturbances in brain damaged children may also be expressed in what may be called pathological hyper-lateralization (Denckla, 1973). They may be so lateralized that they are excessively clumsy on one side, usually the left. This hyper-lateralization may be expressed in those brain damaged children who show a greater degree of right hand superiority in handwriting tasks than do normals (Reitan, 1971) and increased left limb incoordination (Rudel, Teuber, & Twitchell, 1974).

A. Minimal brain dysfunction. One of the most heterogeneous and poorly understood diagnostic categories in childhood dysfunction is the one called Minimal Brain

Dysfunction (MBD). It has been said to be defined in terms of "an inputed, underlying pathophysiology rather than a uniform symptomatology" (Klein & Gittelman-Klein, 1975, p. 46). One of the underlying pathophysiologies suggested for this group (which may include hyperactive, learning disabled, and behavioral problem children) is some form of disordered laterality (Beaumont, 1976; Knights & Bakker, 1976; Orton, 1925, 1937; Satz, 1976).

MBD children have been shown to be poor in right-left orientation (Kaufman & Kaufman, 1974) and can be differentiated from normals on the basis of their performance on a variety of measures of lateralized function (Crinella, 1973). Beaumont (1976) reported that MBD children showed less stable preferences on laterality tests and no significant difference between the preferred and non-preferred hands on skilled motor tasks, in contrast to the performance of normals.

Sherick et al. (1976) described a group of MBD children who had trouble crossing their body midline. They did not draw a horizontal line that crossed their body midline and switched hands when they reached the point that corresponded to the center of their body axis. They moved their entire body laterally to finish the line. These children also often switched hands in the middle of drawing a circle.

Rather than specifying the degrees of lateralization in disorders associated with the MBD syndrome, some investigators have focused more on the interaction between the hemispheres. Malfunction of the cerebral commissures has been implicated in the abnormal development of lateralized behavior and the inattention, perceptual difficulties, and motor clumsiness often found in the MBD syndrome (Gazzaniga, 1973). Gazzaniga suggests that the poor establishment of a central processing system results in bilateral, double decisions initiating motor responses that cannot be coordinated normally. Thus, MBD has been described as a "partial disconnection syndrome" where there is relative difficulty integrating information received at the two sides of the body (Beaumont, 1976). Learning disabled children may require increased time for information to be transferred transcallosally, or there may be degradation of information during this transfer.

The benefit of stimulant medication in hyperactive children may work, in certain respects, because it superimposes a different balance between the two hemispheres by acting differentially on them. Connors (1971) found that the improved task performance of hyperactive children with stimulant medication was achieved by the enhancement of the auditory evoked potential (AEP) of the relevant stimulus in the left hemisphere by suppressing the "noise" in the right hemisphere. The stimulant medication, then, appears to bring about selec-

tive suppression of irrelevant stimuli and may, in some respect, serve a role similar to the cerebral commissures by inhibiting input from the hemisphere that is not primarily involved in the task.

B. Developmental dyslexia. Nearly four decades before the topic was to become a fertile area of investigation, Orton (1925, 1937) suggested that the high incidence of reversals and mirror-images of letters and words found in children with specific reading impairment in the absence of known brain damage or intellectual retardation could be related to an inappropriate pattern of cerebral organization. This disorder, which Orton called strephosymbolia (meaning twisted symbols), could be so severe that some children were reported to be able to read and write better backwards than forwards. Orton postulated that strephosymbolia was due to confusion of competing images in both hemispheres as a result of the failure of unilateral cerebral dominance to be established.

As further evidence of incomplete cerebral lateralization in reading disabled children, Orton pointed out that they also showed an increased incidence of laterality disturbances such as directional confusion, weak hand preference, left handedness, and noncongruent hand and eye dominance (crossed dominance). Satz (1976) suggests how these symptoms may have influenced Orton's theory:

These mixed lateral preferences apparently led Orton to postulate a similar ambilaterality at the level of the cortex (tertiary zones) which, in effect, would facilitate competition between the hemispheres in the perception of images and lead to reversals of letters and words. (p. 275)

There is some evidence to suggest that animals with bilaterally symmetrical brains cannot differentiate between stimuli perceived at homologous body parts (Corballis & Beale, 1976; Mach, 1959; Tschirgi, 1958). Additionally, laterality of the motor spheres appear to be important in the appreciation of direction in objective space (Kephart, 1971; Palmar, 1964).

Orton's basic premise of incomplete lateralization in reading disabled children re-surfaced in the 1960's when increased attention was directed to the problems of the dyslexic child and to the growing body of information about hemispheric asymmetries (Critchley, 1970; Delcato, 1966). Numerous studies have attempted to document whether, in fact, there is a higher incidence of mirror images, directional confusion, weak laterality, left-handedness, and crossed dominance in dyslexic children. While some studies have reported a greater incidence of crossed dominance in reading disabled children (Benton, McCann, & Larson, 1965; Dunlop, Dunlop, & Fenelon, 1973; Ginsburg & Hartwick, 1971; McBurney and Dunn, 1976), not all have found higher incidence of crossed dominance or left handedness in these children (Balow,

1963; Belmont & Birch, 1965; Coleman & Deutsch, 1964; de Hirsch, Jansky, & Langford, 1966; Satz & Friel, 1974; Shankweiler, 1963; Sparrow & Satz, 1970; Zurif & Carson, 1970). Satz (1976) maintains that, of the symptoms discussed, only reversals and mirror-images in the absence of brain damage represent the necessary symptoms of Orton's strephosymbolia.

While Orton was not specific about the exact nature of incomplete lateralization, the general assumption is that the important feature of brain organization in dyslexics is bilateral representation of language function. As a result, when non-invasive methods for assessing hemispheric asymmetries such as the dichotic listening and tachistoscopic procedures emerged, dyslexic children were tested for evidence of reduced perceptual asymmetries for verbal material between the hemispheres. Reduced asymmetries have been reported for certain groups of dyslexic children (Darby, 1974; Kimura, 1967; Leong, 1976; Marcel, Katz, & Smith, 1974; Zurif & Carson, 1970). However, Satz's (1976) review of the studies in this area indicate that the methodological and conceptual problems in the studies make it difficult to come to a firm conclusion about the nature of language lateralization in dyslexic children. A recent study by Allen and Wellman (1980) employs patterns of hand writing positions in dyslexic and

normal children to indicate reduced cerebral lateralization of language function in the dyslexic children.

Witelson (1976a, 1977) points out that most of the studies of reading-impaired children have shown that language appears to be lateralized to the left hemisphere, as it is in normal children (Bryden, 1970; Leong, 1976; Marcel et al., 1974; McKeever & Huling, 1970; Satz & Van Nostrand, 1973; Springer & Eisenson, 1977; Yeni-Komshian, Isenberg, & Goldberg, 1975; Zurif & Carson, 1970), even though some of the studies suggest reduced lateralization. In her dichotic listening task, Witelson (1977) found that both dyslexic and normal boys showed left hemisphere specialization for language, but that the total accuracy of the dyslexics was lower than that of the normal boys. This suggested to Witelson that there might be some type of left hemisphere deficit in dyslexic boys. This postulation is supported by the fact that dyslexics have significantly lower Verbal I.Q. scores than normals and show deficits on cognitive tasks that require sequential processing or verbal encoding of information (Doehring, 1968). This lower verbal ability does not seem to represent overall intellectual impairment since dyslexics' Performance I.Q. scores are not significantly different from normals, and their performance on non-verbal spatial tasks is equal to or even better than that of normals (Benton, 1975; Guyer & Friedman, 1975; Vellutino, Steger, & Kandel, 1972; Rosenberger, 1970).

On this basis, Witelson (1976a, 1977) postulated that the dyslexics have bilateral spatial representation. Referring to Levy's (1969) explanation of poorer spatial abilities in females and left-handers in terms of bilateral verbal representation (which encroached on neural space in the right hemisphere which would usually have been specialized for spatial function), Witelson offers a similar model for verbal deficits in dyslexics. Bilateral representation of spatial function would result in a competition for neural space in the left hemisphere which would usually have been specialized for verbal function. Thus, dyslexics would use a more spatial and holistic strategy for reading and would be less able than normal readers to use phonemic analysis (Shankweiler & Lieberman, 1976). Witelson (1976a) does not necessarily conclude that the bilateral spatial representation interferes with the verbal functions of the left hemisphere; it may be that primary left hemisphere dysfunction leads to bilateral spatial representation.

Another suggestion about the pattern of brain organization in dyslexia is that dyslexics may have reversed cerebral asymmetry. The evidence concerning structural asymmetries of the two hemispheres indicates that the posterior portion of the left hemisphere is larger than the homologous portion of the right hemisphere in the majority of right and left handed people (LeMay, 1976). Most of the information gathered about

structural asymmetries has been collected at post mortum, at which time it is rather difficult to obtain retrospective behavioral information to correlate with the subjects patterns of brain asymmetry. Hier, LeMay, Rosenberger, and Perlo (1978) used computerized brain tomography (C.T. scans) to measure the relative sizes of the two cerebral hemispheres in live dyslexic subjects. Only 33% showed a larger left than right parietooccipital region, 42% showed a larger right than left parietooccipital region, and 25% showed no asymmetry in size. Since the expected norm for perfect reversed asymmetry would be 9% of right handed and 27% of left handed individuals, one would predict that, in a sample of 18 right handers and 6 left handers, approximately 3 subjects would show greater right than left parieto-occipital regions; Hier et al. reported that 10 of the 24 dyslexic subjects showed reversed cerebral asymmetry. Hier et al. also reported that the dyslexic patients whose C.T. scans revealed wider right than left parieto-occipital regions had significantly lower Verbal I.Q. scores than the other dyslexic patients who did not show the reversed asymmetry. The authors suggest that the dyslexic patients with reversed cerebral asymmetry may have language lateralized to the left hemisphere even though the anatomic configuration of their left hemisphere may, in fact, be more similar to the configuration of the right hemisphere in most normal individuals (Dennis & Whitaker, 1976).

"Thus, the dyslexia and verbal disability of the ten patients with reversed cerebral asymmetry in this study may be a partial reflection of the mismatch between hemispheric specialization for language and structural asymmetry of the hemispheres." (Hier et al., 1978, p. 92)

Hier et al. conclude that a reversal of hemispheric asymmetry alone does not produce dyslexia since this pattern would be expected to occur in about 10-12% of the population while dyslexia, as it is presently detected, occurs in about 5% of the population (Benton, 1975). It would appear that, in vulnerable individuals, dyslexia develops as the result of the interaction of reversed cerebral asymmetry with other unknown factors. One of these unknown factors may be gender. Witelson (1976a, 1977) points out that sexual dimorphism does in fact exist in the human brain; therefore, a pattern of brain organization that may be adequate for one sex may not be so for the other. Since dyslexics are overwhelmingly male (Benton, 1975), reversed cerebral asymmetry may predispose males to dyslexia while females may generally be able to read adequately with this cerebral pattern.

C. Stuttering. Several investigators have suggested a disorder of cerebral lateralization as the cause of stuttering (Bryngelson, 1935; Jasper, 1932; Travis, 1931; Travis & Johnson, 1934). Searleman (1977) indicates that, due to the fine motor movements that are required for speech production, the ability to produce speech is usually more

lateralized than speech comprehension. The benefit of having only one hemisphere control the motor pathways for speech is to reduce the chance of interference from competing input if both hemispheres were involved. Jones (1966) reported that stuttering ceased in patients with bilateral speech representation when they were injected with sodium amytal which limited speech production to only one hemisphere. It seems that stuttering may result, in certain cases, from bilateral functional control of the speech musculature.

Maturational lag theory. One viewpoint concerning developmental disorders maintains that the brain pattern the child has is not an abnormal one--it is just appropriate for a younger child. Thus, the behavioral deficits appear because the child's brain has not matured fast enough for the child to perform well on age-appropriate tasks. The "maturational lag" concept is a common one among theories of dyslexia (de Hirsch, Jansky, & Langford, 1966; Kinsbourne, 1973a; Leong, 1976; Satz & Friel, 1974; Satz, Friel, & Rudegeair, 1974; Satz & Sparrow, 1970; Satz & Van Nostrand, 1973; Sparrow & Satz, 1970). Since many of the theories of dyslexia implicate reduced cerebral asymmetries as an important factor in dyslexia and since a commonly discussed ontogenetic trend is a shift from bilateral language representation and reading function to localization in one hemisphere, it is understandable that the

reduced cerebral asymmetry theory of dyslexia could be seen as a maturational lag.

The maturational lag theory can also be applied to the theories of MBD which suggest reduced interhemispheric communication as their basis for the behavioral deficits. Since the corpus callosum appears to become myelinated fairly late in childhood, the young child may naturally have reduced interhemispheric transfer (Galin, Johnstone, Nakell, & Herron, 1979; Galin Note 10). It is not difficult to extend the argument to indicate that exceptionally slow myelination of the corpus callosum may produce subtle behavioral deficits.

All maturational lag theories have a more encouraging prognosis than the disease or deficit models:

In all of this, it is assumed that the dyslexic child is developmentally similar to a younger normal child and that eventually he will "catch-up" to his age-mates in those skills that are crucial to the development of reading. (Rourke, 1976, p. 126)

Deficit Theory. In contrast to the maturational lag theory, the deficit theory does not propose that dyslexic children will ever out-grow their reading disability (Doehring, 1968; Reed, 1968; Reitan, 1964; Rourke, 1976). While they are generally not able to specify the exact nature of the deficit, the proponents of the deficit theory postulate some form of cerebral dysfunction underlying the development of dyslexia.

Witelson (1977) suggests that the good performance of the dyslexics on her dichhaptic letters test indicates that it may be possible to design an approach to reading more suited for such children, and that their problem with written language represents a qualitative neural deficit rather than a neural maturational lag.

The C.T. study of dyslexics done by Hier et al. (1978) appears to fit well into the deficit theory on a number of counts, not the least of which is that its sample of 24 dyslexics range in age from 14-47 years. If, indeed, developmental dyslexia is a maturational lag phenomenon, one would suspect that there would be evidence of dyslexic children outgrowing their deficit--which does not seem to be the case. In addition, Hier et al.'s finding of significantly lower Verbal I.Q. scores in the dyslexics with reversed cerebral asymmetry than in dyslexics without reversed cerebral asymmetry indicates that the disorder is associated with the structure of the cerebral hemispheres, predominantly the left.

Brain damage in adults. Disorders of laterality are characteristic findings in patients with a variety of neurological problems (Nathanson, 1974). Patients with brain damage may show persistent symmetrical mirror movements where voluntary movement in one limb is accompanied by an involuntary movement in the homologous limb. Mirror movements have been

found to be rather common in people with paresis, as indicated by electromyographic recordings from the impaired side (Chaco & Blank, 1974). The mirror movements have been described as a release phenomenon (Green, 1967) in that, in the damaged individual, there is a lack of inhibition of one motor cortex by the other.

Diffuse cerebral disease has also been shown to be associated with a return to symmetry in the performance of simultaneous asymmetrical motor tasks. All of the 50 brain injured patients tested on Nathanson's (1974) "Imaginary Piano Finger Test" which requires that they pretend to be playing a piano, showed symmetrical stops; that is, both hands were exactly in the same position when they stopped while "playing."

In a group of patients with organic mental syndromes (OMS) without aphasia or hemiparesis, 20% exhibited disturbances in laterality as evidenced by difficulty crossing the body midline on command (Nathanson, Anderson, & Cravioto, 1956). These patients even find it difficult to imitate the movements when the examiner touches his own ear with the opposite hand.

Disorders of sensation and perception also reveal laterality components. Bender and Nathanson (1951) describe the phenomenon of allesthesia in patients with diffuse brain disease. In allesthesia, stimulation of one area of the body is referred to the homologous area of the opposite side of

the body. Bender and Nathanson postulate that in diffuse brain disease one side of the body becomes dominant over the other side.

Additionally, Bender (1953) maintains that a deficit in the cutaneous sensory field not revealed by unilateral testing may be demonstrated by using double simultaneous stimulation (DSS). The most common DSS technique Bender used was the "Face-Hand Test" in which the patients, with their eyes closed, were simultaneously touched on the face and hand on opposite sides of the body. Among OMS patients there tends to be facial dominance in the errors they make on DSS; that is, when simultaneously touched on the face and hand, OMS patients tend to either extinguish the hand stimulation and only report being touched on the face, or displace the hand stimulation to the face and report being touched on both sides of the face. Bender indicates that DSS errors can differentiate OMS from other disorders such as schizophrenia, depression, and hysteria in which DSS errors are not made.

Heilman and Watson (1977) indicate that there is a general succession of stages a patient follows during functional recovery from unilateral cerebral damage. At first the patient fails to respond to stimuli contralateral to the side of the lesion or the subject shows allesthesia and responds as if the stimulus was applied ipsilaterally to the

lesion. Subsequently, the patient may respond appropriately to unilateral stimulation applied contralaterally to the lesion, but shows extinction of the stimulus applied to the affected side during bilateral simultaneous stimulation.

Heilman and Watson write:

When one side is stimulated, sensory information is transmitted not only to the contralateral hemisphere but also to the ipsilateral hemisphere. Thus, allesthesia need not be caused by a perceptual error of the impaired hemisphere, but perhaps by the normal hemisphere responding as if the stimulus were a signal for it to perform. This hypothesis would imply some type of reciprocal interhemispheric inhibition (e.g., under normal circumstances the hemisphere contralateral to a stimulus may inhibit the ipsilateral hemisphere from performing). (p. 296)

Disorders of laterality associated with brain damage may also be induced by temporary disturbances in neurological integrity. Ingestion of alcohol has been reported to abolish the amplitude asymmetry between the hemispheres in visual evoked potentials (Lewis, Dustman, & Beck, 1970). The inebriated person, who may be confused, disoriented, cognitively impaired, and incoordinated in motor performance may be manifesting certain symptoms of a change in the usual attentional balance between the hemispheres. The CT scans of chronic alcoholics suggest a reduction in the tissue density of the left hemisphere without significant change in the right hemisphere resulting in an equalization of densities between the hemisphere (Golden, Graber, Bloise, Berg, Coffman, & Bloch,

1981). This is in contrast to the CT scans of normal controls who show a denser left hemisphere. A reduction of cerebral asymmetry in EEGs has also been shown to occur following injection of psychotropic drugs (Hynek, Tosovsky, & Susova, 1975).

Levels of Function

Hughlings Jackson conceptualized the nervous system in terms of levels of integration. In this theory, the breakdown of higher integrative functions results in a release of "lower" types of organization; that is, patterns that are, to a limited extent, normal for a young child. It is not surprising, then, to find that, on certain tasks, young children perform similarly to brain damaged adults (Kiernan, Note 16).

Many of the laterality disorders that have been discussed (mirror movements, inability to cross the body midline or to break symmetry, extinction errors on DSS) are common in both young children and brain damaged adults (Nathanson, 1974). This raises the interesting possibility that many of the more complex abilities found in the mature, intact individual may be related to the development of certain functional balance between the hemispheres. The mechanism for this balance may be negative reciprocal inhibition (Kinsbourne, 1970).

While the neurologically immature or damaged individual may be well able to survive and perform most ordinary beha-

vivors, it may be the finer distinctions in behavior which are impaired when the interhemispheric balance is disturbed. In common parlance there is often a parallel drawn between childhood and senescence (especially when accompanied by declining mental status). Sociologically, both groups are often similar in their dependence on others. This fact may be influenced by the fact that neither is at their peak of mental capacity. Both may show some degree of concreteness of thought, emotionality, belief in magical, mystical experiences, and a tendency towards misperceptions under altered sensory conditions, especially in darkness. In both groups, another manifestation of the lower level at which their nervous systems are functioning may be disordered interhemispheric balance and its concomitant behavioral changes.

Psychiatric Implications of Hemispheric Asymmetries

At this point it seems appropriate to stray from a pure scientific discussion of hemispheric asymmetries to one of a more speculative nature. The existence of alternative modes of hemispheric processing may provide a paradigm for explaining other phenomena in various fields.

Duality of thought. The sense of a duality in thought has long pervaded literature, philosophy, neurology, and psychiatry. Much has been written about the dual nature of man or alternate forms of consciousness, but it is only recently, with the

increasing body of knowledge about the functional differences between the two hemispheres, that one can re-interpret many earlier theories as attempts to perhaps name and explain the parallel, but asymmetrical functioning of the two cerebral hemispheres. The two hemispheres may perceive and process stimuli in different ways. When this is coupled with the situation of one hemisphere, generally the left, being more in control of verbal abilities and so-called "conscious" thought while the other hemisphere continues to process and interpret the environment (but not "express" it in verbal thought), the stage may be set for the subjective experience of dual consciousness. During conditions of extreme stress or fatigue, altered perceptual input, and in certain forms of brain damage, this feeling may be expanded to the extent that one believes that there is another person residing in his or her own body.

Many different labels have been assigned to these alternate modes of thought, and Bogen (1969/1974) has compiled an interesting list of such dichotomies including Thomas Hobbes' "directed or purposeful" versus "free or unordered" thinking (cited in Murphy, 1951), William James' (1890) "differential" versus "existential" thought, and Jerome Bruner's (1962) "rational" versus "metaphoric" thought. Bogen concludes that:

The belief that man is possessed of two ways of thought, occasionally conflicting, is common in everyday speech, where it often takes the form of supposing a struggle between "reason" and "emotion" or between "the mind" and "the heart". (p. 120)

Despite the pervasiveness of references to duality of thought, each person also appears to possess a basic belief in an internal sense of unity. Sherrington (1947, p. xvii) wrote "This self is a unity... it regards itself as one, others treat it as one. It is addressed as one, by a name to which it answers. The Law and State schedule it as one." However, Galin (1974, p. 576) points out that "We have good reason to believe that the experience of mental unity is to some extent an illusion, resulting in fact from exactly the conventions of language and law that Sherrington cites."

Thus, there exists an apparent paradox since despite the person's belief in a basic sense of self, there is also a pervasive sense of another aspect to one's personality; an aspect that can never fully be specified, understood, or controlled. This paradox may be handled in a number of different ways. One way to deal with this situation is to ascribe the uncontrollable thoughts and actions to another person.

The concept of two people occupying one body was often referred to in the late 19th century. According to Sir Victor Horseley (cited in Bogen, 1969/1974, p. 114) "We are not single animals; We are really two individuals joined together in the middle line."

Perhaps the most famous metaphor for dual personalities located within one body arises from Robert Louis Stevenson's

Victorian novel, The Strange Case of Dr. Jekyll and Mr. Hyde (1886/1967). As Luhr (1978) notes in his analysis of Stevenson:

His works again and again reveal a dichotomous and not a unified view of life. The Strange Case of Dr. Jekyll and Mr. Hyde expresses this most clearly. Jekyll is a unity that does not work. (p. 29)

Despite the fact that Dr. Jekyll and Mr. Hyde share the same body, Jekyll never consciously admits that Hyde is part of him. When he reflects on the atrocities that Hyde has committed, Jekyll "still blames Hyde for all and accepts none of the guilt himself" (Luhr, 1978, p. 52). In a similar way, the sense of thoughts and actions that are not under one's control can be attributed to Stevenson's own perception of how the novel was conceived. Stevenson (1950) attributed the main concept and three scenes to the work of his "Brownies," or little people, who came to him in a dream. Just as Jekyll did not want to accept the blame for Hyde's evil deeds, Stevenson seems almost to feel the need to justify his acceptance of the credit for a novel conceived by others than himself.

In some cases of hemiplegia, the patient believes that the involved limb does not belong to him or belongs to someone else [somatoparaphrenia (Gerstmann, 1942)]. Juba (1949) described the phenomena of personification where a patient may find a nickname for a weak or paralyzed limb. In his

study of anosognosia phenomenon, Cutting (1978) cites the case of a woman who, following a right hemisphere stroke, called her left leg "Fred" and her left arm "Little Fred." Restak (1979) presents a description of a woman with left-sided paresis and neglect of the left side:

She would wake in the night with a very intense feeling that someone was in the room--a person she knew; indeed, with whom she was very familiar... She imagined that the "person" or alter ego was somewhere on her left but just beyond her range of vision. The impression was so vivid that she would leave her bed and go from room to room on tiptoe trying to surprise this familiar interloper. (p. 171)

Freudian theory. Few people, however, who exhibit such behavior, say that there is another individual abiding within them, or claim to be being aided in creative endeavors by "Brownies". One of the most interesting elements of early Freudian theory is that it addressed itself primarily to just the problem of a duality in thought and of how the conscious mind deals with unacceptable or bizarre thoughts--they are banned from consciousness. In his topographical model of the mind, Freud postulated that:

Repressed mental contents functioned in a separate realm that was inaccessible to conscious recall or verbal interrogation, functioning according to its own rules, developing and pursuing its own goals, affecting the viscera, and insinuating itself into the stream of ongoing consciously directed behavior (cited in Galin, 1974, p. 574).

The concept of there being dual modes of consciousness, with only one mode apparently capable of analysis, self reflection, and a sense of identity and responsibility, while the other is emotional and undisciplined, fits in rather well with the literature on hemispheric asymmetries. The information from the split-brain patients indicates that there is no apparent change in personality, intelligence, or temperament following commissurotomy (Sperry, Gazzaniga, & Bogen, 1969). Nor do these patients spontaneously complain about any kind of perceptual loss or division following surgery. These findings led Gazzaniga (1970) to conclude that before surgery, as well as after, the left hemisphere dominates most conscious mental experience and that, in the intact individual, the dominant mental system is largely unconcerned with--and probably unaware of--the minor mental system.

Thus, the persistence of the subjective sense of unity within an individual may result, at least in part, from the left hemisphere's domination of a sense of consciousness. The right hemisphere, therefore, may be the mediator of Jekyll's Hyde and of Stevenson's Brownies, the "other person" to whom the hemiplegic limbs belong, and the incarnate of Freud's unconscious (Galín, 1974; Ornstein, 1972; Bakan, Note 17).

Many of the descriptions of right hemisphere functions make it compatible with Freud's conception of primary pro-

cesses (Galín, 1974). Fenichel, a well-known disciple of Freud's, described primary processes as

Carried out more through pictorial, concrete images, whereas the secondary process is based more on words... [the primary process] is remote from any logic. But it is thinking nevertheless because it consists of imaginations according to which later actions performed... such pictorial thinking is relatively unorganized, primitive, magical, undifferentiated, based on common motor reactions, ruled by emotions, full of wishful or fearful misconceptions, archaic, vague, regressive, primal. (cited in Bogen, 1969/1974, p. 123)

It is often forgotten that Freud (1915/1948) himself felt that the anatomical correlates for his components of the psyche would be found when knowledge about brain functioning increased sufficiently. Galín (1974) writes:

All of the above considerations lead us to examine the hypothesis that in normal, intact people mental events in the right hemisphere can become disconnected functionally from the left hemisphere (by inhibition of neuronal transmission across the corpus callosum and other cerebral commissures), and can continue a life of their own. This hypothesis suggests a neurophysiological mechanism for some instances of repression, and an anatomical basis for the unconscious mental contents... In the human, the left hemisphere usually has preemptive control over the main stream of body activity as well as of propositional speech and repression in normal intact people is to some extent by a functional disconnection of right hemisphere processes, we might expect to see the expression of unconscious ideation through whatever output modes are not preempted by the left hemisphere. (pp. 574-575, 576-577)

If, in fact, one views the right hemisphere as a separate mental system denied direct access to conscious thought and

verbal expression, then one could regard Freud's techniques for delving into the unconscious also as techniques for giving right hemisphere processes means of expression. Bakan (Note 17) describes right hemisphere processes as being hallucinatory, concrete, visual, emotional, and unrealistic--similar to Freud's concept of primary processes--and the stuff that dreams are made of.

Freud is often quoted as regarding dreams as the "royal road to the unconscious." Consequently, dream analysis is an important technique in psychoanalysis. When Freud was given a verbal report of a dream, he evaluated it on the basis of two levels--the manifest and latent content. In relation to hemispheric asymmetries, the right hemisphere may be the "dreamer;" thus, the verbal report (manifest content) may be the left hemisphere's edited description of what was dreamt by the right hemisphere (latent content).

Cessation of dreaming has been reported more frequently following unilateral damage to the posterior right hemisphere than to the left hemisphere (Humphrey & Zangwill, 1951). Additionally, Bogen (1969/1974) reported that several patients claimed that they no longer dreamed following commissurotomy, whereas they had been vivid dreamers prior to the operation. It would be beneficial, however, to have sleep EEG's on these patients to determine whether, in fact, they no longer have

any REM sleep or whether the right hemisphere continues to dream unbeknownst to the left hemisphere which, after all, voiced the claim.

Citing Goldstein's work, Bakan (Note 17) points out that, while the left hemisphere shows more activity during waking hours, during REM sleep the right hemisphere becomes more active. Indirect evidence that supports this change in activation between the hemispheres comes from Luce's (1970/1974) report that skin temperature is usually higher on the right side of the body during the day, but becomes higher on the left side of the body during sleep.

Hypnosis, another technique used to tap unconscious thoughts, has been associated with a shift in hemispheric balance away from the usual left hemisphere dominance (Frumkin, Ripley, & Cox, 1978). Budzynski (1977) maintains that the right hemisphere is less critical than the left hemisphere and, therefore, more amenable to suggestions and commands. The right hemisphere may be the aspect of a person which responds to the emotional rhetoric of lecturers, preachers, and politicians rather than the logic of their arguments. By overloading the left hemisphere with a meaningless task, Budzynski attempts to plant favorable suggestions in the right hemisphere to help the patient stop smoking or overeating. McKeever, Larrabee, Sullivan, Johnson, Furguson, and

Rayport (1981) suggest that the right hemisphere's control of behavior during hypnosis brought about improvement in a patient with a severe tactile anomia for objects palpated with the left hand.

Jokes, slips of the tongue, primitive emotional outbursts, and contradictions between behavior and speech may all represent attempts of the right hemisphere to communicate. Prohovnik (1978) generates new interest in many traditional psychological tests by stating that:

Projective tests of the Rorschach type surely pose a challenge to the integration between right hemisphere perceived gestalts and left hemisphere dominant search for meaningful details and their verbal coding. (p. 182)

Schizophrenia. Several recent theorists have attempted to relate hemispheric asymmetries to schizophrenia. Some theories have implicated dysfunction of the dominant hemisphere in the display of schizophrenic symptomatology (Flor-Henry, 1969, 1976; Gruzelier & Venables, 1974; Gur, Note 18). Treatment with chlorpromazine has been shown to selectively increase left hemisphere activity of schizophrenics to make their hemispheric balance closer to that shown by non-psychotic patients and normal volunteers (Hammond & Gruzelier, Note 19).

Another group of theorists has suggested that schizophrenia results from faulty interhemispheric connections

(Bakan, 1975; Dimond & Beaumont, 1974; Butler, Note 20, Green, Note 21). Since a relationship has been found between complications of pregnancy and psychosis (Kinney & Jacobsen, 1978; McNeil & Kaij, 1978), Schneider (1979) postulates that prenatal brain injury may result in the formation of abnormal corpus callosal connections.

If there is, in fact, decreased interhemispheric connections in schizophrenics, each hemisphere may be able to process the same message differently without being able to integrate the different interpretations. Galin (1974) remarks:

Imagine the effect on a child when his mother presents one message verbally, but quite another with her facial expression and body language; "I am doing it because I love you, dear," says the words, but "I hate you and will destroy you" says the face. Each hemisphere is exposed to the same sensory input, but because of their relative specializations, they each emphasize only one of the messages. The left will attend to the verbal cues because it cannot extract information from the facial gestalt efficiently; the right will attend to the nonverbal cues because it cannot easily understand the words. Effectively, a different input has been delivered to each hemisphere.... the two hemispheres may decide on opposite courses of action; the left to approach, and the right to flee. (p. 576)

This situation sounds remarkably similar to Bateson, Jackson, Haley, and Weakland's (1956) description of the "double-bind" situation. Such double-bind messages may be more commonly given by a mother who may also have some degree

of faulty interhemispheric communication and may speak with one hemisphere while the other mediates intonation and facial expression. Perhaps this is Meehl's (1971) "schizophrenogenic mother".

Affective psychoses. Flor-Henry (1969) reported that patients with right hemisphere lesions were more likely to show a manic-depressive pattern of response than patients with left hemisphere lesions. It has been shown that the right hemisphere excels in the auditory perception of emotionally charged tones (Harding, Lolas-Stepke, & Jenner, 1976; Safer & Leventhal, 1977; Suvurova, Note 22; Van Lancker, Note 23) and in the memory storage of emotionally charged faces (Suberi & McKeever, 1977). Kolb and Taylor (1981) maintain, however, that the previous emphasis upon the right hemisphere control of affective behavior has neglected a complementary role of the left hemisphere.

Several investigations of lateralization of emotional responses has revealed that the left hemisphere may be specialized for positive emotions and the right hemisphere for negative emotions. When the left hemisphere is temporarily inactivated by sodium amytal, a large percentage of patients show depressive symptoms, while temporary inactivation of the right hemisphere has been shown to result in euphoria (Alema, Rosadini, & Rossi, 1961; Rossi & Rosadini, 1967; Terzian;

1964). Halliday, Davison, and Brown (1968) have reported better clinical improvement from depression following right unilateral ECT than left or bilateral ECT. Depression has been shown to be more common in patients with left hemisphere disease than right hemisphere disease (Gasparrini, Satz, Heilman, & Coolidge, 1978).

Robinson, Kubos, Starr, Rao, and Price (1978) report that lesion location is the most important variable in post-stroke depression. Depression is more often found after left hemisphere lesions than right hemisphere lesions. They also report that patients with right hemisphere lesions were more likely to exhibit inappropriate cheerfulness. Robinson et al. suggest that the depression following left hemisphere stroke is a result of a specific neural deficit following localized brain injury. They report that focal lesions can result in lateralized depletions of the catecholamine neurotransmitters which affect mood.

In normal adults, asymmetry of affect has also been documented. Recent studies have indicated that positive emotions are more strongly expressed on the right side of the face (left hemisphere) while negative emotions are more strongly expressed on the left side of the face (right hemisphere) (Sackheim & Gur, 1978; Sackheim, Gur, & Saucy, 1978; Schwartz, Ahern, & Brown, 1979).

On the basis of their finding of brain asymmetries in self-stimulation thresholds in rats, Glick, Weaver, and Meibach (1980) suggest that reward processes may be lateralized to some extent, and that this asymmetry may be related to levels of dopamine. In light of the evidence that the two cerebral hemispheres mediate different affects, Glick et al. extrapolate their results to humans:

One might hypothesize, for example, that the side of the brain having lower reward thresholds would also have higher aversion thresholds. An individual presented with mood-related material engendering mixed affect might have one side of the brain more receptive to perceiving it as pleasant and the other side more likely to perceive it as unpleasant. In this way, quantitative differences in neuronal mechanisms (for example, rates of firing) could be translated into apparent qualitative specialization, with one side of the brain appearing to be specialized for high mood and the other for low mood. The results might also be relevant to our understanding of how different drugs act as reinforcers and maintain different patterns of addictive behavior. (p. 1094)

Neuroses and psychosomatic disorders. The principal characteristic of most neurotic disorders is anxiety. If psychosis can be seen as the unbridled expression of the id due to a breakdown of ego function, then neurosis can be seen as the result of an overly strong ego which attempts to smother the id. The id, however, still makes its presence known by causing unconscious inner conflicts. One way in which these conflicts are expressed is through anxiety.

While anxiety is a common emotion, appropriate to certain situations, neurotic anxiety is of a different nature:

What makes neurotic anxiety an acutely frightening experience is that it is all-pervasive and yet objectless and nameless..... Since the neurotic is not clearly aware of the cause of his anxiety and is therefore uncertain as to what he should do, the anxiety remains free-floating and diffuse..... Physiological disturbances associated with emotional overreaction, which may include cardiac irregularities, breathing difficulties, excessive perspiration, tremors, and nausea, may be misinterpreted as signs of heart failure and impending death. (Page, 1971, p. 366).

Galín (1974) suggests that the autonomic nervous system may provide an accessible channel for the expression of inhibited attitudes associated with right hemisphere processes. Thus, as the left hemisphere continues to function with the belief that everything is fine and under control, the right hemisphere may initiate a whole variety of autonomic responses and emotions with which the left hemisphere is not in contact. This might explain the unnameable element to free floating neurotic anxiety. In Sperry's (1968) description of a split-brain patient who was being tachistoscopically presented with neutral geometric figures in either the left or right visual fields, when a figure of a nude pin-up was projected to the left visual field, the subject blushed and giggled, but could not explain why, when asked. This situation demonstrates that the right hemisphere is capable of initiating an emotional response without the cooperation or knowledge of the left hemisphere in cases of severed connections of the two hemispheres.

Not all neurotic disorders are characterized by anxiety in a recognizable form. Hysterical conversion and hysterical

dissociative reactions are regarded as "unplanned attempts to avoid anxiety by the exclusion of part of the self" (Page, 1971, p. 267). In hysterical conversions, it is assumed that the emotional energy that is associated with anxiety is transformed to bodily symptoms. In general, the symptoms involve the loss of sensory or motor functions. If the repressed anxiety emanates from the right hemisphere, one would predict a preponderance of left-sided hysterical symptoms. Ferenczi noted the following about hysterical stigmata:

It struck me that in general the hemi-anesthetic stigmata occurs more frequently on the left than on the right, which, in consequence of the more powerful attention-excitation of this more active and skillful half of the body, is better protected against influences from the unconscious. It is possible that--in right-handed people--the sensational sphere for the left side shows from the first a certain predisposition for unconscious impulses, so that it is more easily robbed of its normal functions and placed at the service of unconscious libidinal fantasies. (cited in Galin, 1974, p. 577)

It has been found that asymmetry exists in the autonomic nervous system (Varni, Doerr, & Franklin, 1971) and this asymmetry may reflect asymmetrical cerebral activity (Holloway & Parsons, 1969). The right vagus nerve has been shown to primarily affect heart rate while the left vagus primarily affects systolic pressure (DeGeest, Levy, Zieske, & Lipman, 1965). Galin (1974) suggests:

If this lateral specialization of visceral control is extensive, it may help in explaining psychosomatic symptom choice, eg, hypertension

vs tachycardia or dysrhythmia. Just as there appear to be individual differences in cognitive style, with a predominance of the mode of the left or right hemisphere, [Cohen, Berent, Silverman, 1973, Cohen, 1969; Bogen, DeZure, Ten Houten et al., 1972; Lee, 1950], so there may be a preferred visceral mode. We might expect those psychosomatic symptoms that are the expression of right hemisphere processes to appear in the right visceral mode, as the stigmata of hysteria are alleged to appear in the left side of the body. (p. 577)

Dissociative hysterical reactions such as amnesia, fugue states, and multiple personalities can also be placed within a framework of an alternate sphere of consciousness which can take over control of the body at times and also be banned from consciousness at other times. The classic description of multiple personalities by Thigpen and Cleckley in The Three Faces of Eve (1957) can be discussed in terms of the conscious persona of Eve White--sexually inhibited, practical, dull, and unimaginative--representing the isolated left hemisphere, the emergence of Eve Black--promiscuous, lively, and uninhibited--as the repressed right hemisphere, and the evolution of Jane as a balance between them once the left hemisphere was made aware of and began to exchange information with the right hemisphere.

Thus, hemispheric asymmetries offer an interesting alternative explanation for many of the traditional psychiatric disorders. However, no purpose is served in merely re-naming the ego the left hemisphere or the id the right hemisphere.

What is needed now is more information about how and why the hemispheres function differently and how they interrelate with each other. Then, and only then, will we have an idea about the physiological mechanisms of these disorders and their significance for understanding human behavior.

Significance of Study Findings

The preceding sections have discussed the apparent importance of cerebral asymmetries for human behavior, especially in the ability to voluntarily perform asymmetrical motor activities. The significance of this behavior becomes much clearer when one observes those groups of people who have difficulty performing asymmetrical activities, namely young children and brain-damaged adults.

The present study was limited to normal, relatively young adults in the hope of obtaining unambiguous patterns of hemispheric interaction created by the introduction of simultaneous asymmetrical motor activity. It was thought that these patterns would provide the groundwork for further research in other populations. The goal of potentially using this method in other populations affected the selection of a task that might be easily used with children or in a clinical setting.

However, the patterns which were observed for even strongly right-handed normal adults were not unambiguous. The introduction of simultaneous asymmetrical motor activity did

not bring about a greater functional separation between the hemispheres, as was predicted. What was found was that the right and left hands of normal adults were less accurate during competitive simultaneous asymmetrical movement than during unimanual movement and that there was a strong tendency for symmetry in bilateral movements. The results also indicate that gender appears to be a significant factor in understanding the patterns of hemispheric interaction. Although the results suggest that the men may be more lateralized for spatial abilities, this pattern did not give them an advantage on the task since the women were more accurate than the men on all of the movement conditions.

Perhaps the significance of these findings with a normal population will take on more meaning when compared to the patterns obtained in children and brain-damaged adults. The one thing that was assumed in this study was that all of the participants would be able to perform the task, an assumption that may not be true for people who cannot sufficiently inhibit contralateral motor overflow.

Much work remains to be done in order to understand the way in which the brain mediates competitive motor activities involving both sides of the body. What is fascinating about such behaviors is that they appear to require a fairly high level of neural integration in order to occur and, as such, may represent the uniqueness of the human nervous system in its most sophisticated form.

APPENDICES

Appendix A
Subject Data Sheet

Name:	Date:
1. Age:	1.
2. Sex: 0, Male 1. Female	2.
3. Occupation: 0. w/out manual asym. 1. with	3.
4. Musical Instruments Rating: 1. (Fair) 2. (Good) 3. (Excellent)	4.
5. Wink right eye: 0. No 1. Yes	5.
6. Wink left eye: 0. No 1. Yes	6.
7. Touch type: 0. No 1. Yes	7.
8. Other manual asymmetry:	8.
9. Left-handed mother: 0. No 1. Yes	9.
10. Left-handed father: 0. No 1. Yes	10.
11. # Male sibs: # Left-handed:	11.
12. # Female sibs: # Left-handed:	12.
13. History severe head injury: 0. No 1. Yes	13.
Nature & Location:	
14. Writing position: 1. RNI 2. RI 3. LNI 4. LI	14.
15. Neurological status: 0. Normal 1. Patient	15.
Diagnosis:	
16. Mirror Movements:	16.

Appendix B

Behavioral Tasks Used in Handedness Inventory

1. Write your name legibly.
2. Throw a softball.
3. Movement for striking a match.
4. Movement for threading a needle.
5. Movement for dealing cards.
6. Movement for opening a jar.
7. Hold toothbrush while brushing your teeth.
8. Movement for applauding.
9. Hold scissors when cutting paper.
10. Dial a telephone.
11. Hold comb while combing your hair.
12. Hold racquet while playing ping pong.
13. Arrange six matches to copy picture of a house.

Appendix C

Instructions Read for Target Localization Task*

I would like you to look at the four black targets on this board. There are two side targets (POINT TO EACH OF THEM) and two top targets (POINT TO EACH OF THEM). There are also two pens in these holders (POINT TO HOLDERS). I will now place each hand on one of the pens. You will hold each pen like a dagger with all of your fingers wrapped around it (POSITION S's HANDS). You may move your arms until you have found a comfortable position with both elbows resting on the table (WAIT UNTIL S IS READY). I will place a small pillow under each elbow so that you will always be able to find the same spot (TACK PILLOWS IN PLACE).

This is the starting position. Before we begin each trial I will say "READY" and you will place both hands around the pens and your elbows on the pillows. I will then tell you which of the targets you will aim for. I will first say which hand to use and then whether to aim for the side or top target. On some trials you will have to aim for only one target; on other trials you will have to find a different target with each hand.

* Words in parenthesis indicate the activity of the experimenter while explaining task.

After you hear me say which target or targets to aim for, do not move until you hear me say "GO". Upon hearing "GO" lift the pen out of the holder and bring it down on the board where you believe the target to be. If I tell you to find two targets you must lift the pens and bring them down at exactly the same time. Once the pen hits the board, don't move it. I will remove the pen from your hand. I will change pens after each trial.

Before we actually start the experiment, we'll do a few practice trials. First we'll go through all of the combination of targets with me moving your hands to the proper targets so that you will know what to do. Next you will practice moving the pens by yourself. Do you have questions so far?

Appendix D

Trial Sequence and Pen Colors

<u>Trial Targets</u>	<u>Right Pen</u>	<u>Left Pen</u>
1. Right Side	dark purple	maize
2. Left Side	maize	dark purple
3. Right Top	grey	orange
4. Right Side, Left Side	orange	turquoise
5. Right Top	grey	orange
6. Right Side	dark purple	maize
7. Right Top	grey	orange
8. Left Top, Right Side	light green	pink
9. Right Side, Left Side	orange	turquoise
10. Left Side, Right Top	dark green	light green
11. Right Side, Left Top	light green	pink
12. Right Top, Left Top	red	light purple
13. Left Side, Right Top	dark green	light green
14. Left Top	navy	brown
15. Right Top, Left Top	red	light purple
16. Right Side, Left Top	light green	pink
17. Left Top	navy	brown
18. Left Side, Right Top	dark green	light green
19. Right Side, Left Top	light green	pink
20. Left Top	navy	brown
21. Right Top, Left Top	red	light purple
22. Right Top	grey	orange

Appendix D (cont'd)

Trial Sequence and Pen Colors

<u>Trial Targets</u>	<u>Right Pen</u>	<u>Left Pen</u>
23. Right Side	dark purple	maize
24. Left Side	maize	dark purple
25. Left Side, Right Side	orange	turquoise
26. Right Side	dark purple	maize
27. Right Top, Left Top	red	light purple
28. Left Side	maize	dark purple
29. Left Side, Right Side	orange	turquoise
30. Right Side, Left Top	light green	pink
31. Left Side, Right Top	dark green	light green
32. Right Side	dark purple	maize
33. Left Top, Right Top	red	light purple
34. Right Top	grey	orange
35. Left Side	maize	dark purple
36. Left Top	navy	brown
37. Left Side, Right Top	dark green	light green
38. Right Side, Left Side	orange	turquoise
39. Left Side	maize	dark purple
40. Left Top	navy	brown

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