THE PREDICTION OF CEREBRAL SPEECH LATERALIZATION AND COGNITIVE ABILITY IN LEFT AND RIGHT HANDERS ON THE BASIS OF MANUAL SKILL

by

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B.A., University of Victoria,B.C., 1974

A THESIS SUBMITTED IN PARTIAL FULFILMENT

OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF ARTS

in the Department

of

Psycholog[redacted]

We accept this thesis as conforming

to the required standard

[redacted]

UNIVERSITY OF VICTORIA

May 1977

ABSTRACT

Relationships were investigated between handedness, speech lateralization and verbal and spatial cognitive abilities. The subject sample consisted of 30 male and 30 female adults. Handedness was measured by: a) subject's self-classification (SC), b) Hand Preference Questionnaire data, and c) right minus left hand difference scores on five manual skill tests (MS). Speech lateralization was measured by ear advantage (EA) on a verbal dichotic listening task: Right ear advantage was considered representative of speech lateralization to the left hemisphere. Verbal and spatial cognitive abilities were measured by selected subtests from the Wechsler Adult Intelligence Scale (Wechsler, 1955). Three-handedness-speech lateralization hypotheses and two handedness-cognitive abilities hypotheses were tested.

Left hemisphere control of speech processing was demonstrated to be greater for right handers than for left handers. The SC right handed group had a higher mean right EA than the SC left handed group. Manual skill was shown to be related to speech lateralization. The greater the right hand superiority on manual skill tests, the larger the right EA tended to be. The relationship between subjects' self-classification as right or left handed and speech lateralization was shown to be associated with manual skill. When the influence of MS on the SC-EA correlation was held constant, the correlation was reduced to nonsignificance. The conclusion

was reached that the manual skill method of measuring handedness is more accurate and has more exploratory power than the self-classification method for investigation of handedness-speech lateralization relationships.

Handedness-cognitive abilities hypotheses were not supported. Handedness, defined by manual skill scores, was related to spatial ability such that the greater the tendency toward right hand superiority, the lower the spatial score tended to be. Partitioning subjects according to Levy's (1969) operational definition of handedness resulted in no significant differences between right and left handed subjects' spatial ability. The Male group had a significantly higher mean spatial score than the Female group. No reliable relationship was found between either of the two measures of handedness and verbal-spatial discrepancy scores. It was concluded that the investigation of posited relationships between handedness and cognitive abilities should await the development and validation of a model of hemispheric specialization which would account for variation in the lateralization of speech processing and manual skill.

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CHAPTER I

INTRODUCTION

It has been recognized since the latter half of the nineteenth century that the cerebral hemishperes are not equal in terms of their roles in language comprehension and production. Evidence of language deficit after left hemisphere injury indicates left hemisphere dominance for this process in right handers. Asymmetry favoring the left hemisphere for the perception of verbal stimuli also supports the view that the left hemisphere is dominant for language processing in right handers. However, brain organization for left handers is not the mirror image of brain organization for right handers. Studies of brain injured and normal populations have demonstrated that left handers are rarely right hemisphere dominant, often left hemisphere dominant, and some exhibit bilateral hemispheric control of language processing. The paradoxical left hander has stimulated research into the relationship between handedness and differential hemispheric control of language processing. This research is discussed in the first section of this chapter.

The view of the right hemisphere as the minor or subordinate hemisphere with little functional significance has changed with the accumulation of evidence for deficits of a nonverbal nature with injury to this hemisphere. The evidence available for normal as well as brain injured subjects is suggestive of a controlling role for the right hemisphere in the processing of visual-spatial information for right handers. As is the case for language processing, the cerebral locus of control for nonverbal processes for left handers is a puzzle. The current consensus is that left handers have a greater tendency toward bilateral hemispheric control of verbal and nonverbal processing than right handers. Research into differential hemispheric control of nonverbal processes is discussed in the second section.

The third and fourth sections examine asymmetrical cerebral control of handedness and posited relationships between handedness and cognitive functioning. Much theorizing has centred around the possible role of dominance--or the lack of it--in the occurrence of cognitive deficit; particularly the occurrence of discrepancies in two types of cognitive ability, verbal and spatial reasoning. There are correlations between signs of mixed dominance and perceptual and cognitive deficits in children. Recently, cognitive deficit or discrepancy has been hypothesized for adults who exhibit signs of mixed dominance. The only indices of dominance used in the majority of the investigations of this hypothesis have been measures of handedness. The left hander, because he may be processing speech and spatial information with both hemispheres, is posited to be relatively poorer at spatial than verbal reasoning than right handers. Hemispheric specialization for verbal and spatial processing and posited relationships to cognitive deficits are discussed in the fourth section.

While handedness has played an important role in each of the above areas of research, agreement regarding the most appropriate measures of handedness is lacking. However, there is evidence to suggest that the most appropriate operational definition of handedness is the relative superiority of one hand over the other on tests of manual skill. The definition and measurement of handedness are discussed in the fifth section.

Hypotheses are developed in the last section of this chapter. The present study investigated the relationship of handedness to speech lateralization (i.e. lateralization to the left hemisphere) and to cognitive ability. Following a representative, but not exhaustive, review of the literature in each of the above areas, research particularly relevant to the present investigation is discussed. Hypotheses are developed for the examination of: a) left hemisphere dominance for speech processing and handedness; and b) the relationship of dominance to cognitive abilities.

Terminology is a problem in the area of cerebral dominance research because there is not a set of generally accepted terms or agreement about the meaning of any one term. In the following chapters, the terms described below are used to denote cerebral hemispheric asymmetries for the functional control of the processes described above.

Three terms are used interchangeably to denote the greater propensity of the left than the right hemisphere for speech processing and hand control. These are: left hemisphere dominance; hemispheric specialization; and lateralization to the left hemisphere.

The greater propensity of the right than the left hemisphere for the processing of visual spatial information is most often referred to as asymmetry favoring the right hemisphere or right hemisphere lateralization of spatial processes.

The left hemisphere also tends to dominate for higher level language processing and the right for spatial reasoning ability. These abilities are referred to jointly as cognitive ability. A glossary of terms and definitions has been provided in Appendix D.

1. Hemispheric Asymmetry for Verbal Processing

Clinical evidence. In the latter half of the nineteenth century, Broca (1861) published autopsy findings on two patients who had lost the capacity to use language after the occurrence of cerebral damage. Broca concluded because of lesions found in the third frontal convolution of the left hemisphere of each of these patients, that in right handers speech was localized in the left hemisphere. In 1865 he further concluded that with rare exceptions, left handers' speech was localized in the right hemisphere. Thus, handedness and hemispheric localization of language have been considered related phenomena since contemporary research into the speech-brain relationship began (Benton, 1965). Broca's left handedness - right hemisphere speech localization rule did not for long withstand contrary evidence: aphasia occurred in left handers more often after left than right hemisphere injury. But despite contrary evidence and hypotheses like those of Hughlings Jackson, who considered language to be to some degree bilaterally represented and the right hemisphere to be primary for some nonlanguage processing, the view of one hemisphere as controlling language prevailed (Benton, 1965). From this view developed the concept of hemispheric dominance: the left hemisphere was considered to be dominant and the right hemisphere nondominant or minor for speech and sensorimotor processing and for cognitive functioning.

Since Broca's time, a great deal of evidence has accumulated against this simplistic view. World War II resulted in a large number of head injury cases which stimulated research into disorders related to brain damage. These investigations confirmed previous evidence that aphasia is more often related to left than to right hemisphere injury. However, that left handers differ in cerebral organization with regard to language has also been confirmed by these investigations.

In an investigation of 509 right handers and 48 left handers with unilateral brain injury, Russell and Espir (1961) found that 186/288 right handers and 9/24 left handers with left hemisphere lesions and 3/221 right handers and 4/24 left handers with right hemisphere lesions were aphasic. Of the aphasic right handers in this group 98% were aphasic after left hemisphere injury and only 2% after right hemisphere injury. Aphasic left handers were also more likely to have left hemisphere lesions (69%) but a sizeable minority (31%) had right side lesions. It is evident that aphasia occurred more often for both right and left handers in this group after left than right hemisphere injury.

Summarizing the results of a number of investigations of aphasia in left handers, Zangwill (1960) found that aphasia was reported in 24/54 cases with left hemisphere lesions and in 13/39 cases with right hemisphere lesions. The percentage of the total number of aphasics with left hemisphere lesions, approximately 65%, and right hemisphere lesions, 35%, in left handed aphasics are similar to those of Russell and Espir (1961). Hecaen and Sanguet (1971) estimated from their survey of published reports that from 20-30% of left handed aphasics have right hemisphere lesions.

If language deficit after unilateral brain injury can be regarded as demonstrating left or right hemisphere control of language processing, then obviously no simple relationship holds between a simple bivariate handedness measure and cerebral dominance, since two-thirds of left handers appear to be left hemisphere dominant as are most right handers.

Many researchers have suggested that left handers tend toward bilateral hemispheric language representation (cf. Conrad, 1949; Hecaen and Piercy, 1956). The supposition of language bicerebrality in left handers is based on: the number of left handers who become aphasic after right hemisphere injury; the greater incidence and degree of recovery observed in left handers (after right or left hemisphere injury); and the constellation of language and nonlanguage disturbance in left handers after right hemisphere injury (Hecaen and Sauget, 1971).

Mixed hand preference and familial history of left handedness have been implicated in cases of aphasia after right hemisphere injury (Subirana, 1973). Ettlinger, Jackson, and Zangwill (1956) examined 15 published cases of aphasia with right hemisphere lesions in right handers and found that 3 were ambidextrous and 9 had a familial history of left handedness. Hecaen and Sauget (1971) found that left handers with a familial history of left handedness showed disturbances of oral language and reading whether the left or the right hemisphere was the injured one, while left handers with no familial history of left handedness showed almost no language disturbance with right hemisphere lesions.

Data from studies where the right or left hemisphere has been temporarily anaesthetized provide figures similar to those of the aphasia literature for hemispheric dominance for language processes. The technique developed by Wada (1949), where sodium amytal is injected via the internal carotid arteries into the right or left hemisphere, renders the affected hemisphere nonfunctioning. Utilizing the Wada technique Milner, Branch and Rasmussen (1966) found that the speech of 93% of their right handed patients was affected by left hemisphere injection. For left handers, 65% showed speech disturbance after left hemisphere injection and 15% after injection to either hemisphere.

Split brain evidence. Reports on epileptic patients, for whom transection of the major bands of fibres connecting the two hemispheres is carried out to eliminate generalized seizures, have provided further evidence of the differential roles of the right and left hemispheres in verbal and nonverbal processing. When the two hemispheres are thus disconnected, information going to one hemisphere cannot be readily transmitted to the other. Comissurotomized patients therefore provide the researcher with a unique opportunity to examine the role of each hemisphere in verbal and nonverbal processing without aid or interference from the other hemisphere. When objects are placed in the left hand of such patients but out of the patient's sight, information is transferred only from the left hand to the right hemisphere. In this situation, the patient is unable to name the objects, although he can demonstrate the use of the object. Similarly, words flashed tachistoscopically to the left visual half-field and therefore transmitted only to the right hemisphere are not reported by the patient although they may be appropriately responded to. While no verbal response can be elicited to verbal stimuli to the right hemisphere, auditory comprehension of speech by the right hemisphere is indicated by retrieval by the left hand of objects named by the experimenter (Sperry, Gazzaniga and Bogen, 1973).

The right hemisphere is superior in split brain patients for visual material and can recognize, if not produce, verbal response to words. But Levy and Trevarthen (1973) demonstrated that when pictures were presented tachistoscopically to the right and left visual half fields and patients required to point to the picture in an array that rhymed with the one they had seen, the left hemisphere was clearly superior. When bilateral asymmetric words (e.g. de/ed, no/on, se/es) were presented tachistoscopically to the visual half-fields so that half a word was received by one hemisphere and half of another word by the other (e.g. de/on, no/ed, se/ed), the response choice made was for the left visual field stimulus on 93% of the trials. But when response choice was made from pictures rather than words, the right visual field - left hemisphere stimulus was chosen on 90% of the trials. While the right hemisphere can accomplish visual closure to produce a whole word and the patient can select this word from a response array, the right hemisphere does not perform the more complicated task of matching words to pictures. It appears that the right hemisphere can recognize words but is unable to perform when linguistic analysis is required or verbal response demanded.

These results support other evidence that the right hemisphere has some capacity for language comprehension. Sperry et al. (1973) point out that there is a great deal of variability among their split brain patients in the capacity of the right hemisphere to respond to verbal stimuli.

Data from sodium amytal and split brain studies must be viewed with caution since amytal investigation is typically used with epileptics and split brain patients are also epileptics; the epileptic foci may have resulted in cerebral reorganization in these patients.

Dichotic listening evidence. The development of the dichotic listening technique by Broadbent (1954) has provided one of the means of testing speech lateralization in normal subjects. The dichotic listening test involves simultaneous presentation of a different stimulus to each ear via stereophonic headphones, in sets of 2 or more stimulus pairs.

Kimura (1961a) found that temporal lobectomy patients administered a dichotic listening test had a greater decrement in the amount of recall from the ear contralateral to the lobectomized side but that left temporal lobectomy produced a greater deficit in both ears than right temporal lobectomy. Kimura concluded that both temporal lobes were involved in the perception of verbal material but the left temporal lobe is more important to speech perception than the right.

In a second study, Kimura (1961b) administered dichotically presented digits to epileptic patients who were classified as left or right hemisphere dominant for speech from sodium amytal results. For both right and left dominant groups, recall of digits was: a) independent of handedness and site of epileptic foci, and b) superior for the ear contralateral to the dominant hemisphere. Kimura postulated from the results that the crossed contralateral auditory pathways are stronger and occlude information from uncrossed ipsilateral pathways and that one hemisphere is more involved than the other in the perception of verbal stimuli.

Electrophysiological evidence for stronger contralateral than ipsilateral auditory pathways from research on subhuman species (cf. Tunturi, 1946; Rosensweig, 1951) and humans (Bocca, Calcaro Cassinari and Miggliavacca, 1955) supports Kimura's hypothesis.

When verbal dichotic listening tests are administered to normal subjects a right ear superiority generally occurs whether the stimuli are digits, words or CV syllables; whether presentation rate is fast (1 pair/.5 seconds) or slow (1 pair/2 seconds); and whether recall is instructed, or free, or a recognition procedure is used (Satz, 1968). However, ear asymmetry increases with number of stimuli, increased rate of presentation and deviation from meaningfulness (Satz, 1968). Ear asymmetry does not occur for vowels

(Shankweiler and Studdert-Kennedy, 1967), and is reversed for melodic stimuli (Kimura, 1964; Spellacy, 1970).

Early dichotic listening studies comparing right and left handers demonstrated that, as a group, left handers tend to show right ear superiority for verbal stimuli, but to a smaller degree than do right handers. Stimuli used in these studies varied, including digits (Satz, Achenbach, Pattishall, and Fennell, 1965), nonsense syllables and one syllable words (Curry and Rutherford, 1967), and meaningful and nonsense words (Curry, 1967).

Some researchers have also noted more reversals, i.e. higher left than right ear scores among left than right handers, particularly when dichotic listening was made more difficult by the use of nonsense words than meaningful words (Curry, 1967) or by the inclusion of white noise on the dichotic tape (Knox and Boone, 1971). Smaller difference scores and reversals have been cited by these researchers as supporting the view of a greater tendency toward bicerebrality of language in left handers.

Familial history of left handedness has also been examined as a variable in dichotic listening. A decrease in ear asymmetry with a positive familial history of left handedness was found by Zurif and Bryden (1969), while Satz Achenbach and Fennell (1967) found that in a group with a positive familial history of left handedness, the superior ear was the one ipsilateral to the preferred hand.

Satz, Achenbach and Fennel (1967) deviated from the routine of previous studies by classifying subjects as right or left handed according to the results of a hand preference questionnaire and tests of manual speed and dexterity. Using a composite handedness score derived from test results, Satz et al. found that they could more accurately predict the superior ear than when subjects' self-classification as right or left handed was used to group subjects.

Shankweiler and Studdert-Kennedy (1975) theorized that handedness and speech lateralization are related because of an underlying hemispheric specialization for fine sensori-motor control, which varies in degree across individuals. They hypothesized that, if this is the case, manual skill and ear asymmetry gradients should be related. Shankweiler and Studdert-Kennedy (1975) demonstrated support for their hypothesis with significant multiple correlations between manual skill tests and a verbal dichotic listening task for two different groups of adult subjects. Based as it is on a more fully developed construct of hemispheric specialization than previous dichotic research, Shankweiler and Studdert-Kennedy's approach to the question of handedness-speech lateralization relationships is promising for future exploration. Their study is discussed in greater detail in Section 5 of this chapter.

<u>Visual half-field evidence</u>. In visual half-field studies, stimuli are presented tachistoscopically to the left or right visual field or bilaterally to both fields. White's (1969) review of the literature indicates that words (Harcum and Finkel, 1963; Harcum and Jones, 1962) and letters (Bryden, 1966; Harcum, 1964) presented unilaterally to the right visual field (RVF) are recalled more accurately than words or letters presented unilaterally to the left visual field (LVF). Right visual field superiority has been attributed to the more direct pathway between the RVF and the left hemisphere (Kimura, 1966).

But bilateral presentation generally results in LVF superiority; this may be due to left to right scanning and left to right order of report of stimuli with a resultant memory loss affecting stimuli presented in the RVF (White, 1969).

Visual half-field studies support dichotic listening findings of smaller differences between left and right sides for left than for right handers. Bryden (1965) found that while right handers showed the expected right side-left hemisphere superiority, left handers failed to show any consistent right-left differences. Orbach (1967) also found a greater right-left difference for right than for left handers.

If both dichotic listening and visual half-field differences reflect cerebral asymmetry in the processing of verbal stimuli, a high correlation is to be expected between visual half field and dichotic listening results. Bryden (1965) and Zurif and Bryden (1969) found no significant relationship between the two. Hines and Satz (1975) have suggested that the failure to find a significant relationship in the previous two studies might be due to: a) grouping right handers and the more heterogeneous left handers together; b) the use of unreliable difference scores; and c) the use of the simultaneous visual half-field procedure with resultant scanning effects. Hines and Satz used a visual half-field procedure in which stimuli were presented at fixation and to the left or right of fixation. They also administered a dichotic listening test to each subject. They found the dichotic listening test scores but not the visual half-field scores to have high split half reliability. Significant correlations were found between dichotic listening and visual half-field tests for right handers but not for left handers. Hines and Satz suggest that, for left handers, auditory and visual processing of verbal stimuli may be dissociated. A resolution of this puzzle awaits further study. The greater reliability of dichotic listening scores would seem to make dichotic listening a more valid test of asymmetry in the perception of verbal stimuli than the visual half-field scores.

Summary. Clinical data is suggestive of left hemisphere superiority for language processing in the majority of the population. However, there is also evidence of right hemisphere comprehension, if not verbal response to or analysis of language, in split brain patients. The aphasia literature and sodium amytal results indicate bilateral language organization or right hemisphere superiority for some 30% of left handers. Some researchers have suggested that the data imply that differential cerebral language control varies in degree, from left hemisphere superiority, through bilaterality to rare cases of right hemisphere superiority (cf. Luria, 1966; Annett, 1975).

The development of dichotic and tachistoscopic techniques have provided methods for the study of differential cerebral language control in normal subjects. Asymmetries in the perception of verbal stimuli favouring the right ear and the right visual field reflect left hemisphere superiority for language processing. The smaller degree of asymmetry in left handers has been interpreted as reflecting the lesser degree of left hemisphere superiority, or bilateral language organization for this group. Shankweiler and Studdert-Kennedy (1975) provided tentative support for the hypothesis that left hemisphere language control varies in degree in normal subjects by demonstrating a correlation between handedness and ear asymmetry gradients.

Hemispheric Asymmetry for Nonverbal Processing

Clinical evidence. Some deficits other than language impairment occur more often after left hemisphere injury while others occur more often after right hemisphere injury. The apraxias (inability to perform a familiar act) provide a good illustration. DeAjuriaguerra et al. (1960) in a study of 415 brain injury cases, found that ideatory and ideomotor apraxia occur only with left or bilateral lesions and not with lesions restricted to the right hemisphere. Constructional apraxia, originally attributed to left hemisphere lesions, was found by De Ajuriaguerra et al. to occur in 39.8% (82/206) of their left lesion cases and in 61.58% (93/151) of right and 74.07% (40/54) of their bilateral lesion cases. Dressing apraxia, which is associated with constructional apraxia, occurs after right but seldom after left hemisphere lesions (Hecaen, 1973).

An accumulation of cases of visuospatial agnosia (in which objects are incorrectly localized in space) with right hemisphere lesions, particularly with involvement of the posterior parts of the right hemisphere, provide evidence for the greater involvement of the right hemisphere in this disorder (Patterson and Zangwill, 1944; McFie, Piercy, and Zangwill, 1950).

Hecaen's (1973) summary of deficits occurring after right hemisphere injury includes agnosia for one side of the body compared to bilateral localized (finger agnosia) or generalized (autotopagnosia) disorder of body image after left hemisphere injury, apraxia for dressing, severe and frequent visuo-constructional defects, visuospatial disorders, agnosia for faces, dyscalculia and spatial agraphia. The differences in the types of apraxic and agnosic disorders occurring with left in contrast to right hemisphere lesions will be discussed in another section which deals with theories formulated to explain these differences.

Split brain evidence. In tachistoscopic presentation of visual material: objects, geometric figures, colours, lines, dots or arrows pointing in different directions, when presented to the left visual fields of commissurotomized patients, can be recognized and identified through correct matching, matching the stimulus to the name of the stimulus or by pointing to the correct stimulus in a stimulus array (Sperry, Gazzaniga and Bogen, 1973). Bogen and Gazzaniga (1965) found that the left hands of their right handed split brain patients were superior to the right hand in constructing Kohs Block patterns and in copying Necker Cubes. They suggested that the right hemisphere is superior to the left in visual understanding which concurs with the previously described unilateral lesion evidence of impairment in visual-spatial and constructional abilities with right hemisphere injury.

Utilizing the split stimulus technique (described in the previous section) with four commissurotomized patients, Levy, Trevarthen and Sperry (1972) and Levy and Trevarthen

(1973) found that when half of one face was presented to one visual half-field simultaneous with the presentation of one half of a different face to the other, patients presented with both complete faces after the split stimulus presentation always chose the one matching the stimulus presented to the left visual half field (right hemisphere) as the one they recognized. Nebes (1971) found that when commissurotomized patients' perception of part-whole relationships was tested by having subjects haptically examine an arc with the right or left hand, and then visually select the size of the complete circle from which the arc had come, this was most efficiently carried out by the left hand; the hand under the control of the right hemisphere.

Dichotic listening evidence. In normal populations, dichotic listening studies have demonstrated a left ear superiority for melodies (Kimura, 1964; Spellacy, 1970). Shankweiler (1966) found that brain damaged subjects' perception of dichotically presented melodies was impaired for both ears by right temporal lobe lesions, just as left temporal lobe lesions result in greater impairment of the perception of verbal material (Kimura, 1961a).

Of two studies which examined differences between right and left handers for nonverbal dichotic stimuli, Curry (1967) found the mean left ear score to be higher for nonverbal (environmental) stimuli for both right and left handers; but mean ear differences were smaller for left handers than for right handers. Dee (1971) also found a group of right and two groups of left handers to show a left ear superiority for nonverbal (melodies) stimuli. All three groups of subjects showed left ear superiority for nonverbal material and percentages of subjects with left ear superiority were similar for the three groups.

Visual half-field evidence. A left visual field superiority for tachistoscopically presented nonverbal material would be comparable to the right visual field superiority observed for verbal material and compatible with previously discussed studies which demonstrate the importance of the right hemisphere in the processing of nonverbal stimuli. White's (1969) review of the literature in this area shows contradictory findings; some researchers report equal recognition by both half fields of nonsense figures and geometric forms (e.g. Bryden and Rainey, 1963; Terrace, 1959), and others report left field superiority for the recognition of designs (Schell and Satz, 1970) and right visual field superiority for the recognition of outline drawings of common objects (Wyke and Ettlinger, 1961). The ease or difficulty with which stimuli can be verbally labelled may be the explanation for these contradictory results; verbally labelled stimuli resulting in a right field superiority and stimuli which cannot be given a verbal label resulting in a left field superiority.

In some visual half-field studies, response time was the dependent measure. Geffen, Bradshaw and Wallace (1971), and Gibson, Filbey and Gazzaniga (1970), found that non-verbal stimuli were responded to more quickly when presented to the left visual field and verbal stimuli were responded to more quickly when presented to the right visual field.

Kimura (1966) has found a left visual field superiority for the processing of visuospatial information: she found a left field superiority for a task in which subjects were required to count groups of dots and geometric designs and a left field superiority in a later (1969) experiment when subjects were required to locate dots on a spatial map after tachistoscopic presentation.

Kimura and Durnford (1974) found a left visual field superiority for a number of basic visual tasks: visual point location, rapid scanning of stimuli for enumeration, perception of line orientation and stereoscopic depth perception. Kimura and Durnford interpreted these findings to mean that the right hemisphere is more specialized for certain basic perceptual processes than the left hemisphere, and that this asymmetry may underlie the superiority of the right hemisphere for the more complex visuospatial functions.

Cohen (1972), in a visual half field study comparing right and left handers, found the usual smaller and less consistent differences between half fields in the left handed group. In this experiment, letter pairs were presented tachistoscopically to the right or left visual half field, and could be matched by either physical identity (AA) or name identity (aA). Name identity matching was better for right visual field stimuli and physical identity matching for left visual field stimuli. Visual half field differences were smaller for left than right handers, but in all conditions, left handers responded more quickly than did right handers.

Summary. The right hemisphere is dominant for some nonverbal processing, particularly the processing of visuo-spatial and visuoconstructional information. Damage to the right hemisphere results in deficits in facial recognition, constructional ability and the ability to process topographical information, and much less often in language disorder. Split brain patients are more able to accurately process spatial and constructional information when the right hemisphere is stimulated than when the left hemisphere is. The tachistoscopic research carried out with normal populations is equivocal but nonverbal stimuli to which no verbal label can be attached seem to be processed more quickly when presented to the right rather than the left hemisphere. Kimura's (1966; 1969) visual half field studies show superiority of the right hemisphere for spatial abilities and the recognition of geometric shapes. In contrast to the superior recall of verbal dichotic stimuli to the right ear, the perception of nonverbal dichotic stimuli is more accurate for stimuli presented to the left ear. While the dichotic listening and visual half field studies comparing right and left handers are few in number, each found smaller differences between ears or between half fields for left than for right handers.

3. Hemispheric Asymmetry for Hand Control

The majority of the population (approximately 90%) is self-classified as right handed. Previous sections of this chapter presented evidence that for most right handers (98%), speech and language processing are controlled primarily by the left hemisphere. Some nonlanguage processing, particularly of visuospatial information, is controlled by the right hemisphere. Available evidence is suggestive of a tendency in the left hand group toward bilateral hemispheric control of both speech and visuospatial processing. These observations have led to speculation regarding the neural organization underlying left hemisphere superiority for both speech processing and hand control. To illustrate, Dimond and Beaumont (1974) propose a model, based on their research, of cerebral organization and cognitive processing which includes the role of hand control. Dimond and Beaumont suggest that to an extent the brain is a duplicate mechanism, that basic patterns of learning are shown by each hemisphere. The capacity to process information, the ability to hold information in perceptual stores, simple motor responses, incidental learning and fatigue processes are organized and occur in each hemisphere. But with respect to more complex abilities, the left hemisphere is more proficient in speech and language, complex motor functions, vigilance and paired-associate learning while the right hemisphere is more proficient at spatial integration, calculation and creative-associative thinking.

Dimond (1971, 1972) further suggests that areas of special capacity, speech being one example, are linked with motor output areas, or the motor output areas of the hands, and that these links might be utilized at the command of either hemisphere. Some evidence does not fit a strict interpretation of this view, for example, the finding that the right hand of split brain patients is inferior to the left in constructional ability (Sperry, Gazzaniga and Bogen, 1973) indicates that right hemisphere control of the right hand is minimal.

With regard to differences between right and left handers in brain organization, Beaumont (1974) suggests that the brain of the right hander is characterized by a system organized in terms of "medium scale specialized units" connected by a series of long but well organized pathways. The brain of the left hander is seen as composed of smaller units linked by short but diffuse connections which result in less specialization and greater homogeneity of function. The diffuse system of the left hander carries an advantage for complex integrative operations, but a disadvantage for rapid simple communications.

If the two hemispheres do process incoming sensory information in different ways, the neural substrate may, as

Beaumont suggests, be different for the right hemisphere than the left. Semmes (1968) cites evidence of differences between the hands in sensory ability and in deficit after cerebral injury and provides a model for differences between the hemispheres in neural organization. Semmes states that asymmetries of the hands are of two sorts: one a difference in contralateral function, the other a difference in ipsilateral function. The former is represented by the phenomenon of handedness--a preferential use and greater agility of the right hand, which to Semmes suggests finer sensorimotor control from the left hemisphere than from the right. Asymmetry of ipsilateral function is exemplified by ipsilateral as well as contralateral effects on the hands of left hemisphere lesions compared to the strictly contralateral effects of right hemisphere lesions.

Examples of this are provided by Hecaen's (1973) observation that when a disorder of the body image (somatagnosia) occurs after minor hemisphere injury it is on one side of the body or of a contralateral limb whereas after major hemisphere injury, somatagnosic disorders are bilateral, either localized (finger agnosia) or generalized (autoagnosia). Benton (1959) has suggested that unilateral somatagnosia occurs because of a disturbance of nonverbal perceptual functioning while bilateral somatagnosia results from a disturbance of symbolic functions. Hecaen (1973) provides incidence figures from a series of 308 unilateral postrolandic lesion cases (left handers excluded): unilateral somatagnosic disorders with right lesions, 28.67% (39/136); with left lesions, 3.38% (7/172) and bilateral somatagnosic disorders with right lesions, 2.94% (4/136); with left lesions 19.01% (34/172). These figures indicate a greater degree of ipsilateral control for the left than the right hemisphere.

Research carried out with split brain patients also suggests differences in the cerebral organization underlying hand control. Sperry, Gazzaniga and Bogen (1973) presented outlined sketches of hands and fingers in different postures tachistoscopically to the right or left visual fields of commissurotomized patients. Subjects were then required to mimic these postures with the hand on the same side or side opposite the visual field stimulated. When the contralateral hand was employed, simple postures, e.g. closed fist or open hand, were mimiced but complex postures were not. The deficit was especially marked when the nondominant right hemisphere attempted to control the right hand. Sperry et al. concluded that the occasional success of the left hand - left hemisphere combination might be due to ipsilateral (left hemisphere) control of the left forearm musculature. Those findings, along with Semmes' own findings, discussed below, support Semmes' contention of a difference between the two hemispheres in the ipsilateral sensorimotor control of the hands, with the left hemisphere exhibiting dominance in its role in the bilateral control of sensation and movement.

In studies reported by Semmes, Teuber and Weinstein (1960) and Semmes (1960), the hands of 124 subjects with penetrating brain injury (36 bilateral, 44 left and 44 right hemisphere injuries) and 33 control subjects were tested on somatosensory thresholds, simple motor reaction times, and discrimination of object-qualities. In the two unilateral lesion groups, deficits of the contralateral hand were found on these tests. The severity of the deficits were approximately equal for the two groups. But when examined in terms of locus of lesion, the results for the three cutaneous tests: touch pressure thresholds, two-point discrimination and point localization, were different for the right than the left hand. Deficits of the right hand were maximal after lesions of the left sensorimotor region but for the left hand, degree of severity and incidence of deficit were not related to the locus of the lesion in the right hemisphere. The same results occurred for tests of reflex action. Moreover, right hemisphere lesions seldom produced sensory deficit in the right hand, whereas left hemisphere lesions did produce sensory deficits in the left hand, if the lesion was in the sensorimotor area. This pattern of results suggests: a) more focal representation of sensation and movement for the left than the right hemisphere, and b) ipsilateral as well as contralateral sensory hand control by the left hemisphere to a greater extent than by the right hemisphere.

When spatial orientation ability of these subjects was tested, impaired orientation was related to locus of lesion (posterior parietal) only for left and not for right hemisphere lesions. Complex functioning therefore also appears to be focally represented in the left and diffusely represented in the right hemisphere. Further, sensory and spatial orientation impairments were associated only for right hemisphere lesions. Semmes hypothesizes this result to be due to diffuse representation of functions in the right hemisphere so that an extensive right hemisphere lesion disturbs both functions.

Semmes (1968) proposes that focal representation of elementary functions in the left hemisphere favors the integration of similar units and consequently specialization for behaviours which demand fine sensorimotor control, such as manual skills and speech. Conversely, diffuse representation of elementary functions in the right hemisphere may lead to integration of dissimilar units and hence specialization for behaviours requiring multimodal coordination, such as the various spatial abilities. Semmes also suggests that brain mechanisms serving language are different for left handers than they are for right handers, with a restricted and unilateral representation if the right hand is dominant and diffuse and possibly bilateral language representation if the left hand is dominant.

Semmes' (1968) conclusions implicate a greater role for the ipsilateral sensorimotor pathways in left handers than in right handers. For right handers, hand control is primarily contralateral (i.e., left hemisphere - right hand control; right hemisphere - left hand control) and the right hand is generally more skilled than the left. However, Semmes has presented evidence for some ipsilateral hand control by the left but not the right hemisphere. For left handers, ipsilateral control from the left hemisphere may be as great as contralateral control. Ipsilateral, left hemisphere control of the left hand might account for left handedness. Alternatively, the right hemisphere may be superior for fine sensorimotor control and thus dominant for speech processing and manual skill in left handers. Clinical evidence indicates left hemisphere speech control for approximately 70% of left handers and right hemisphere or bilateral control for the remaining 30% (see Chapter I:1). Therefore, if Semmes' conclusion regarding a relationship between manual skill and speech processing is accurate, both ipsilateral hand control and right hemisphere dominance must contribute to the phenomenon of left handedness.

Summary. Some researchers have postulated differences in the neural organization of the right and left hemispheres as the basis for observed differences in function. Semmes' research and views on neural organization are the most clearly explicated of these. Semmes (1968) concludes that various functions are focally organized in the left hemisphere and diffusely organized in the right. Semmes suggests that focal organization underlies left hemisphere superiority for speech and manual skills, while the diffuse organization of the right hemisphere underlies its primacy in the control of the processing of visuospatial information. Brain organization in left handers may be more asymmetrical, i.e., the two hemispheres are closer to being mirror images of one another. In the following section, the relationship of differences in hemispheric organization of speech and hand control to cognitive abilities is discussed.

4. Hemispheric Specialization and Cognitive Ability

Some researchers speculate about the effect of incomplete lateralization, or hemispheric symmetry, on cognitive abilities. Gazzaniga (1974) predicts the occurrence of severe cognitive deficit with incomplete lateralization, while Beaumont's (1974) research provides some evidence that mixed laterality may be advantageous for complex integrative functions, but disadvantageous for rapid, simple communications.

Studies of children have revealed a relationship between hemispheric asymmetry and cognitive functioning. Berman (1971) used a number of measures of handedness along with measures of foot, eye and ear dominance and eye-hand coordination and correlated scores on these tests of peripheral dominance with scores on the Columbia Mental Maturity

Scale (CMMS), for brain damaged and normal children. The correlation between a laterality index computed from the peripheral dominance measures and the CMMS was .81 for normal and .41 for brain damaged children. Berman interpreted the lower correlation for the brain damaged group to be due to the unpredictable effect of brain damage when the site of the lesion is not taken into account. Berman concludes that the results demonstrate a relationship between the degree of intelligence and the degree to which one side of the body is dominant over the other, the implication being that the peripheral asymmetry parallels asymmetry in the localization of control for cognitive functioning. "The less asymmetry, the more interference that occurs in cognitive functioning."

Orlando (1971) found that children classified as less well lateralized by their scores on a battery of manual skill tests scored lower on the verbal portion of the Wechsler Intelligence Scale for Children than did well lateralized children. Orlando obtained significant correlations between the handedness tests and a verbal dichotic listening test. In children, however, functional hemispheric organization is in a state of change; lateralization of language to the left hemisphere takes place gradually during the first ten to twelve years of life so that intelligence tests are measuring in part, the degree of cerebral maturity. The effect of incomplete lateralization, if any, to be observed in adults, for whom functional cerebral organization is presumably static, may be quite different.

Levy (1969; 1974) has produced and tested a hypothesis concerning the effect on cognitive functioning of incomplete lateralization in adults. Levy suggests that optimal non-verbal (spatial) and verbal reasoning processes cannot be simultaneously organized in two hemispheres "designed according to the same plan." This premise led Levy to hypothesize that when lateralization is incomplete, either verbal or nonverbal functions will suffer. According to Levy, for the incompletely lateralized individual the mean discrepancy between measures of nonverbal and verbal intelligence will be non-zero and the greater the symmetry of the two hemispheres, the greater the deficit will be in either left or right hemisphere functioning. Levy suggests that either language and conceptual abilities are so important that if both hemispheres are engaged in language processing a spatial deficit may occur, or that functionally symmetric individuals are distributed bimodally, some having two left and some two right hemispheres, the choice depending on both environmental and genetic factors (Levy, 1974). Levy assumes all right handers to be well lateralized and left handers to be incompletely lateralized. Therefore, it is left handers whom she hypothesizes to have either a verbal or nonverbal deficit.

To test a hypothesis such as Levy's, it is necessary to consider the possible effect of pathological left handers in the subject pool. Left handers constitute only approximately 10% of the population: if an equal number of switches in handedness due to brain damage occur for right and left handers, a larger percentage of the left handed population will be of pathological origin than will be the percentage of right handers whose handedness is pathologically determined. Since brain damage resulting in a switch in handedness might also result in cognitive deficits, the result of including pathological left handers would be to confound the brain damage effect with the hypothesized effect. To minimize such confounding, Levy (1969) used subjects of superior intellectual ability, for whom there is less likelihood of brain damage, to test her hypothesis. Levy (1969) selected 15 right handers and 10 left handers from the male graduate students at the California Institute of Technology. Only right handers with no family history of left handedness were included and subjects were classified as right handed only if there was no skilled activity for which they preferred the left hand. Conversely, subjects were classified as left handed if there was any activity for which they preferred the left hand. The Wechsler Adult Intelligence Scale (WAIS, Wechsler, 1955) was then administered to each of the 25 subjects. The WAIS was chosen because it has been shown that the Verbal Intelligence Quotient (VIQ) measures left hemisphere abilities and the Performance Intelligence Quotient (PIQ) measures right hemisphere abilities (cf. Matarazzo, 1972; and Reitan, 1955, for review articles on

WAIS profiles for brain damaged patients). The mean Verbal Intelligence Quotient (VIQ) and Performance Intelligence Quotient (PIQ) for right handers were 138 and 130 respectively. For left handers, the mean VIQ was 142 and the mean PIQ was 117, a 25 point difference. The difference between the right and left handed groups' VIQ-PIQ discrepancies was highly significant. The minimum discrepancy shown by any left hander was 15 IQ points. From these results Levy concluded that the left handers in this subject sample tended toward cerebral symmetry and that this symmetry produced "two left hemispheres" with the consequence that right hemisphere capacities suffered. Levy used a small sample selected from a population with a restricted IQ range to test her hypothesis.

Studies by other researchers have produced both supportive and non-supportive evidence for Levy's (1969, 1974) hypothesis. Miller (1971) used first year university undergraduate students as subjects to test Levy's hypothesis. Miller divided his subjects into two groups, right handers (n = 29) and mixed handers (n = 23) according to the results of a handedness questionnaire (Annett, 1967). Miller found that right and mixed handers did not differ on a test of verbal intelligence, but right handers performed better than mixed handers on a visuospatial test, supporting Levy's hypothesis. Miller does not elaborate upon the reliability and validity of the measures he used, nor does he state their relationship to the WAIS. Miller excluded two pure left handers from his study but speculated that pure left handers are right hemisphere dominant for language rather than symmetrically organized and might be expected to show a similar pattern of abilities to right handers. Miller points out that this hypothesis is difficult to test because pure left handers comprise such a small percentage of the total population (cf. Annett, 1967; Subirana, 1973).

Nebes (1971a) compared the perceptual abilities of left and right handers, using an arc-circle matching task which a previous study of commissurotomized patients (Nebes, 1971b) had shown to be most efficiently carried out by the right hemisphere. Subjects were equal numbers of male and female undergraduate and graduate students, self-classified as right or left handed. Left handers performed more poorly than right handers on this task, which Nebes suggests is due to "less efficient organization" of right hemisphere functions in left than in right handers.

Utilizing 120 male and female undergraduate students classified as right, left or mixed handers according to Annett's (1970) preference questionnaire, Nebes and Briggs (1974) compared these groups for their retention of verbal and nonverbal visual material. They found that left and mixed handers performed significantly less well on a task requiring the reproduction of sets of geometric shapes from memory (Benton, 1963) than did right handers. An analysis of the types of reproduction errors showed the nonright handed groups to differ from the right handers only in the frequency of rotational errors, indicating a faulty retention of spatial orientation. The three groups performed equally well on the verbal task which involved the recall of arbitrary associates. Familial incidence of left handedness had no significant effect on the results.

Subjects in each of the aforementioned studies were university graduate and undergraduate students. The resultant restriction in IQ range may have an effect on results which would not occur with a more heterogeneous group of subjects. Newcombe and Ratcliffe (1973) tested the hypothesis that nonright handers would show a spatial reasoning deficit by administering a shortened form of the WAIS to a large, heterogeneous group composed of 409 men and 414 women assessed as right, mixed or left handed by a hand preference questionnaire. An analysis of variance comparing differences between sexes and between handedness groups on VIQ and PIQ yielded a significant difference for the sex factor only; women scored less well than men on both Verbal and Performance tests.

While Newcombe and Ratcliffe (1973) and the other researchers cited tested the hypothesis of spatial reasoning deficit in nonright handers (Levy, 1969), they did not test the hypothesis of either spatial or verbal reasoning deficit in nonright handers. To test the latter hypothesis, the difference between VIQ and PIQ would have to be tested. Such a test would demonstrate any between group difference in the VIQ-PIQ discrepancy whether the discrepancy was in the direction of a performance decrement or a verbal decrement.

A comparison was made by Newcombe and Ratcliffe (1973) between the left handed group and a matched subsample of the right handed group. No significant differences in ability were found between the two groups. No further comparisons were made between the right and mixed handed groups. But, as Miller (1971) states, it is those subjects of mixed handedness who might be expected to show symmetry in cerebral language organization and therefore a verbal or performance decrement. Within group variance was less for the very small group of left handers (n = 26) than for the right and mixed handed groups. The authors state that this difference is significant and unexpected but do not state whether it is statistically significant. It is not clear how the authors adjusted the analysis of variance procedure for heterogeneity of variance and unequal sample sizes.

McGlone and Davidson (1973) point out that Levy (1969) did not directly test for speech lateralization and included only male subjects in the study. McGlone and Davidson compared right and left handed male and female subjects to determine if right hemisphere specialization for speech and language processing is associated with impaired spatial ability. Demonstrated hand use for several manual activities was used to classify secondary school subjects as right or left handed and self-classification was the handedness criterion for university student subjects. No significant differences were found between these two groups due to differences in handedness measures. Subjects were tested for visuospatial ability on the Block Designs subtest of the WAIS (Wechsler, 1974) and the Primary Mental Abilities Test (PMA). A difference between ears of two or more points on a verbal dichotic listening test was used to classify subjects as having a right or left ear superiority and therefore as left or right hemisphere dominant for speech. Because of small n's in some cells McGlone and Davidson used nonparametric rather than parametric methods of analysis. They report that: a) males performed significantly better than females on the PMA; b) an ear by sex interaction occurred with females having higher left ear scores showing the greatest deficit on the PMA; and c) a higher number of left than right handers had a left ear superiority. Similar but nonsignificant trends are reported for the Block Designs test.

To test the hypothesis that observed spatial impairments result from competition between verbal and nonverbal processes when both are mediated by the same hemisphere (Levy, 1969), a second study was carried out with 79 of the 99 subjects who participated in the first study. Subjects were tested on a tachistoscopically presented dot enumeration task (DET) which Kimura (1966) has shown results in right visual superiority in normal subjects and on which patients with right hemisphere lesions show impairment relative to patients with left hemisphere lesions (Kimura, 1963). The DET was used as a test of the lateralization of nonverbal, visuospatial functions. McGlone and Davidson hypothesized that if lower spatial scores reflect intrahemispheric competition, subjects with both functions mediated by the same hemisphere (right ear, right visual field superiority) should perform worse on the PMA than subjects with each function served by a different hemisphere. Results were in the expected direction but not significant. In fact the only significant difference obtained in the second study was the greater number of females than males exhibiting right visual field superiority on the DET (Chi square = 7.79, 2 df, $p < .03$). While McGlone and Davidson conclude that lower scores on a visuospatial task may result from competition when both verbal and nonverbal tasks are served by the same hemisphere, or when nonverbal stimuli are processed by the left hemisphere, their conclusions are based on trends rather than significant results.

Summary. This section has dealt with models of hemispheric organization which attempt to integrate what is known about asymmetries in hemispheric functioning. Some researchers have concluded that when lateralization of speech processes to the left hemisphere is incomplete, cognitive deficits may result. Levy has formulated specific hypotheses: nonright handers will show a decrement in spatial and constructional abilities (Levy, 1969) or nonright handers will show a decrement in either spatial and constructional, or verbal abilities (Levy, 1974). Some tests of Levy's (1969) hypothesis show a deficit in spatial ability for left handers, but this may be limited to those individuals in the upper ranges of intellectual ability.

All of the studies that tested Levy's hypothesis used self-classification or hand preference questionnaires to classify subjects into two or three handedness groups. While there is a rationale for concluding that lack of asymmetry in hand skill reflects incomplete speech lateralization, the use of self-classification and hand preference questionnaires to assess differential hand skill may be misleading. Left handers, and to a lesser extent, right handers, are heterogeneous groups; some self-classified left handers actually display greater skill with the right than the left hand.

5. <u>Definition and Measurement of Handedness</u>

Semmes (1968) hemispheric specialization model provides a rationale for the view that a relationship exists between asymmetric hemispheric control of speech processing and handedness. However, the investigation of this relationship and of the closely allied handedness - cognitive abilities relationship requires a handedness measure that will maximally reflect hemispheric differences in the control of manual skill, and minimally reflect extraneous factors such as social pressure. The measures most frequently used, subjects' self-classification as right or left handed and subjects' stated preference for the right or left hand, are influenced by social and cultural pressures, as many researchers have pointed out (cf. Levy, 1974; Teng, 1977). The social pressure effect renders self-classification and stated hand preference suspect as measures of differential hemispheric effects on hand control. Direct tests of the competence of the right versus the left hand may be more suitable handedness measures. The following two studies illustrate the lack of concensus between self-classification, preference and manual skill measures of handedness.

Benton, Myers and Polder (1962) compared subjects according to three operational definitions of handedness: subjects' classification of themselves as right or left handed; a hand preference questionnaire; and two tests of the relative manual dexterity of right and left hands; a scissor cutting task and the Crawford Small Parts Dexterity test (Crawford, 1956). Benton et. al. found that many self-classified left handers showed inconsistent preference for the left hand and that some showed marked superiority for the right hand on the manual dexterity tests. The authors concluded that left handers are such a heterogeneous group with respect to preference and dexterity that self-classification is virtually meaningless.

Satz, Achenbach and Fennell (1967) demonstrated that self-classification does not accurately reflect preference and manual speed and dexterity. Reclassifying their right and left handed subjects according to a composite score computed from these criteria, Satz et al. concluded that of the left handed group, 61% were left handed, 17% were strongly right handed and 22% were ambidextrous.

The inadequacy of self-classification as a criterion for relative hand competence is evident from the results of the preceding two studies. Whether hand preference by itself is an adequate measure of manual skill should be considered, since preference can be measured quickly and is therefore more economical than a battery of manual skill tests would be. Annett (1970) administered such a questionnaire to over 2000 subjects and submitted the results to an association analysis. She found that several different handedness groups could be distinguished and that left handers were, as Benton et al. (1962) concluded, a more heterogeneous group than right handers. Annett also tested the relationship between groupings resulting from the preference questionnaire and a test of manual speed. She found that several classes of preference could be distinguished whose asymmetries of manual speed showed a fairly systematic progression between greater skill with the right hand to greater skill with the left. Thus, some evidence exists for a relationship between Annett's preference questionnaire and one measure of manual skill.

However, factor analytic studies yield a different result. Studies utilizing a large number of handedness tests of demonstrated high test - retest reliability have resulted in the extraction of from 4 to 10 factors. Barnsley and Rabinovitch (1970) extracted 10 factors which were common to males and females and to the preferred and non-preferred hands. Each of three studies examined (Seashore, 1949; Fleishman, 1962; Barnsley and Rabinovitch, 1970) had two factors in common, Reaction Time and Dexterity. Other factors extracted in one or more of these studies (and previous studies by Fleishman, 1957; Hempel and Fleishman, 1955; Fleishman and Hempel, 1956) also involved components extraneous or additional to manual skill, such as the factors, Skill in Manipulating Spatial Relationships and Aiming, which have visuospatial components. Other factors, such as Wrist-Finger Speed, show little difference between preferred and nonpreferred hands. Barnsley and Rabinovitch (1970) obtained a very weak Stated Hand Preference factor. The only significant loadings on this factor were for a hand preference questionnaire, a printing task and subjects' verbal statement about his or her preferred hand. Barnsley and Rabinovitch state that the failure of other tests of handedness to load on this factor casts doubt on the validity of the questionnaire method of measuring handedness.

Self-classification and Preference Questionnaire appear to be inaccurate measures of manual skill. Since the handedness - speech lateralization relationship has been posited to be due to left hemisphere specialization for the fine sensorimotor control of manual skills and speech, direct tests of manual skill are most appropriate for the examination of this relationship. However, the use of manual skill tests to define handedness requires consideration of the test-retest reliability of each of the tests.

Provins and Cunliffe (1972) and Shankweiler and Studdert-Kennedy (1975) provide test-retest reliability coefficients on several manual skill tests. Provins and Cunliffe tested 10 right handers and 10 left handers, matched for degree of handedness on a 31-item preference questionnaire, twice on 7 different manual tasks. Testing sessions were three or more days apart. For the preferred hand, individual differences were significantly consistent from one testing session to another on all 7 tests while this was true of only 4 tasks for the nonpreferred hand. However, differences between hands were significantly consistent for only two tasks: Handwriting Speed, time in seconds to write the alphabet as one word, six times ($\underline{r}$ = .94); and Finger Tapping Rate, number of taps with metal stylus on metal plate, counted electrically over five 10-second trials ($\underline{r}$ = .70). Obviously, the difference scores between hands are effected by the low reliability of tests for the non-preferred hand. Reliability coefficients may also have been attenuated by the small samples used.

Shankweiler and Studdert-Kennedy (1975) tested 22 young adults at approximately two-week intervals and obtained reasonably high test-retest correlation coefficients on 5 of 7 tests: Finger Tapping ($r \doteq .80$), Scissors ($r = .93$), Tracing ($r = .80$), Crawford Small Parts Dexterity Test, Pegs ($r = .78$) and Screws ($r = .69$). Reliability coefficients for two other tests, the Purdue Pegboard and the Stoelting Dynamometer, were less than .30. Reliability coefficients for a group of 30 right handed males on the 7 tests were lower. Shankweiler and Studdert-Kennedy point out that lower correlations are to be expected when the handedness range is restricted.

Enough reasonably reliable measures are available to construct a battery of manual skill tests to represent handedness for examination of the handedness - speech lateralization and handedness - cognitive abilities relationships. One further consideration is necessary for the construction of an operational definition of handedness. Annett (1970) has shown that handedness, whether measured by hand preference questionnaire or by right minus left hand scores on manual skill tests, ranges along a continuum. Annett (1970, 1975), among other researchers, (cf. the review of the handedness literature by Hardyck and Petrinovich, 1977), has also suggested that the underlying hemispheric specialization for manual skill and speech processing varies in degree across individuals. Therefore, handedness might most appropriately be treated as a continuum. However, available evidence is suggestive of left hemisphere superiority for manual skill and speech in the majority of the population. Satz's (1975) recommendation for the treatment of laterality measures can be applied to manual skill scores. Using Bayes theorem Satz demonstrated that the probability (given specified antecedent probabilities of speech lateralization) of left hemisphere speech lateralization with a left ear superiority on a verbal dichotic listening test is .90 while the probability of right hemisphere speech lateralization with a left ear superiority is .10. The probability of misclassification when subjects with a left ear superiority are classified as right hemisphere dominant for speech would therefore be 90%. Satz recommends that to minimize errors in classification left ear or left visual field superiority for verbal stimuli be considered as representative of less complete lateralization of speech in the left hemisphere rather than of lateralization of speech in the right hemisphere. To minimize error, manual skill scores are probably best considered as more representative of varying degrees of left hemisphere specialization rather than as representative of left or right hemisphere specialization.

Handedness is therefore defined for the purpose of the present study as a continuum of manual skill, which is most appropriately measured by manual skill tests. The degree of difference between the right and left hands for any given subject on the manual skill tests is considered to reflect the degree of left hemisphere specialization for behaviour requiring fine sensorimotor control.

Summary. A definition of handedness was constructed for the examination of handedness - speech lateralization and handedness - cognitive abilities relationships. Manual skill was posited to be the basis of handedness. Self-classification and preference questionnaires were shown to be inadequate measures of manual skill. A battery of reliable manual skill tests was proposed for the measurement of handedness. Subjects' right minus left hand difference scores on these manual skill tests would be considered representative of varying degrees of left hemisphere specialization.

6. Development of the Hypotheses

The review of the literature presented evidence for left hemisphere control of speech and language processing and right hemisphere control of spatial processing in the majority of the population. Posited relationships between handedness, speech lateralization and cognitive abilities in normal adults were discussed. Aspects of this research pertinent to the present study are discussed below for the purpose of developing a set of specific hypotheses concerning relationships between handedness, speech lateralization and cognitive abilities.

Handedness and speech lateralization. Little is known about the handedness - speech lateralization relationship, beyond the clinical evidence that 90% or more of the right handed population and 60% or more of the left handed population appear to be left hemisphere dominant for speech processing (see Chapter I:1). The development of the dichotic listening technique has made possible study of the handedness - speech lateralization relationship in normal subjects. The common finding of a smaller right ear advantage (EA) on the dichotic listening test for left handers than for right handers is considered by most researchers to reflect a smaller degree of left hemisphere control of speech processing for left than for right handers (cf. Curry, 1967; Knox and Boone, 1971). However, a model of hemispheric functioning that would clarify the role of the left hemisphere for speech processing and hendedness in the majority of the population has not yet developed out of the dichotic listening research.

Shankweiler and Studdert-Kennedy's (1975) study provides a promising approach to the development of such a model. Based on Semmes' (1968) hemispheric specialization construct and on the observation that handedness and speech lateralization vary in degree (cf. Annett, 1975; Luria, 1966; Hardick & Petrinovich, 1977). Shankweiler and Studdert-Kennedy stated that handedness and speech lateralization are both expressions of the same underlying hemispheric specialization which varies in degrees across individuals. They hypothesized, therefore, that handedness and speech lateralization should be significantly correlated. Shankweiler and Studdert-Kennedy tested their hypothesis on two samples: the first consisted of subjects unselected for sex and handedness ($\underline{n}$ = 22) and the second consisted of right handed males ($\underline{n}$ = 30). For both samples they found significant multiple correlations between their battery of manual skill tests and EA on the dichotic listening test. Their results provide tentative support for their hypothesis.

Because of the promise it holds for the development of a model of hemispheric specialization, Shankweiler and Studdert-Kennedy's (1975) hypothesis is worthy of further investigation. But the methodological and theoretical problems inherent in their study require resolution. These problems and means of resolving them are discussed below.

As the authors themselves point out, sample sizes were too small for the multiple regression technique used to analyze the data (Shankweiler and Studdert-Kennedy, 1975). Beta weights and $\underline{R}^2$ values from small samples tend to be unreliable (Kurlinger and Pedhazur, 1973). Substantiation for the hypothesis that handedness and speech lateralization are related gradients requires the demonstration of a multiple correlation for a larger subject sample; a minimum of 10 subjects for each variable included is desirable for multiple regression analysis (Harris, 1974).

Only five left handers were included among Shankweiler and Studdert-Kennedy's (1975) subjects, an insufficient number to allow conclusions regarding the relationship of MS to EA for left handers. However, the model Shankweiler and Studdert-Kennedy propose, if it is to be consistent with available evidence, implies that left handers fall at one end of the continuum of hemispheric specialization. Dominance may range through varying degrees of left hemisphere control, with right hemisphere control for 20 to 30% of the left handed group, or approximately 2 to 3% of the total population. This view is supported by the clinical evidence (presented in the first section of this chapter) of left hemisphere speech control for approximately 70% of left handers and bilateral or right hemisphere control for the remaining 30%. Handedness studies by Benton et al. (1962) and Satz et al. (1967) further indicate that many individuals who classify themselves as left handed actually demonstrate superior manual skill with the right hand. If manual skill and speech lateralization are related gradients for left handers, as they appear to be for right handers, then MS and EA scores for a group of left and right handers should form continuous, unimodal distributions, skewed in favour of right MS and EA (therefore, left hemisphere) superiority. A significant multiple correlation between MS and EA would be expected for the combined right and left handed groups.

The common finding of a significantly larger mean right EA for self-classified right handers than for self-classified left handers may be due to the correlation between MS and EA. Evidence that hand self-classification is related to speech lateralization because of the influence of manual skill on the relationship would lend further support to the views of Semmes (1968) and Shankweiler and Studdert-Kennedy (1975). That is, the basis of the relationship may be left hemisphere control of manual skill and speech processing, which is greater for self-classified right handers than for self-classified left handers.

The rationale behind the selection of the manual skill measures used by Shankweiler and Studdert-Kennedy (1975) is unclear. However, in a discussion of their results they suggested that the relationship between speech lateralization and manual skill may have a common source in neural specialization for rapid, sequentially organized, rule-governed behaviour (Shankweiler and Studdert-Kennedy, 1975, p. 222). Support for this premise requires the demonstration of a relationship between speech lateralization and MS tests requiring rapid, sequentially organized, rule-governed behaviour and only for tests requiring this behaviour.

Convergent validation for the handedness - speech lateralization relationship requires the demonstration of a relationship between MS tests and other classes of verbal stimuli than the CV syllables used by Shankweiler and Studdert-Kennedy (1975). The MS-EA correlation should be demonstrated to hold for other linguistic classes, particularly for words.

If Shankweiler and Studdert-Kennedy's (1975) results were demonstrated to be generalizable and reliable, their view of the handedness - speech lateralization relationship would provide a promising basis for further development of a model of differential hemispheric control for handedness and speech processing. The basis of the model is the hypothesized left hemisphere specialization for the control of rapid, sequentially organized, rule governed behaviour, which varies in degree across individuals. The model would thus account for left hemisphere control of handedness and speech processing in the majority of individuals and for observed variation in the left hemisphere control of these processes.

One purpose of the present study was further verification of Semmes (1968) and Shankweiler and Studdert-Kennedy's (1975) views of the handedness - speech lateralization relationship, controlling for or examining the issues discussed above. The handedness - speech lateralization relationship was tested for a group of 60 male and female, right and left handed adults. The MS tests used were chosen to represent the factors, Reaction Time and Dexterity (discussed in Chapter I:5) and to meet the criterion of adequate test-retest reliability. Words rather than CV syllables were used to measure EA on the dichotic listening test. Hypotheses concerning the handedness - speech lateralization relationship are listed in the hypothesis section.

Handedness and cognitive abilities. Attempts have also been made to relate handedness to cognitive ability. The term, cognitive ability, refers here to ability on a) verbal reasoning tasks, such as WAIS Verbal Scales (Wechsler, 1955), and b) spatial reasoning tasks, such as WAIS Performance scales (Wechsler, 1955). Levy's (1969, 1974) research into handedness - cognitive ability relationships in adults (discussed in section 4) was the basis of the present investigation.

Successful replications of Levy's (1969) finding of a spatial decrement in left handers have been obtained, by Miller (1971), Nebes (1971), and Nebes and Briggs (1974), while other researchers have found a weak or no relationship between handedness and spatial ability (cf. McGlone and Davidson, 1973; Newcombe and Ratcliffe, 1973). Notable among the factors which may differentially effect results is the lack of concensus about the relationship of handedness to the hemispheric control of spatial and language processes. Handedness has usually been assessed in these studies by subjects' self-classification or by hand preference questionnaire. The group (or groups) in each study for whom a spatial deficit was hypothesized were labelled as left, mixed or nonright handed. Because of hand classification, these subjects were assumed to be bilaterally organized, weakly lateralized or right hemisphere dominant for speech and language processes. Clearly, there is a need for an operational definition of handedness consistent with a specified handedness - speech lateralization model. An adequate test of Levy's (1969, 1974) hypotheses requires support for the assumption that subjects who are right handed are well lateralized in terms of hemispheric language representation, while subjects showing equal ability with both hands or left hand superiority are weakly lateralized, i.e. have a lesser degree of left hemisphere control for speech and manual skill. If, as Shankweiler and Studdert-Kennedy (1975) suggest, left hemisphere control of speech processing and handedness can be demonstrated to vary in degree across individuals, the manual skill gradient can be considered representative of this variation. Subject classification for tests of cognitive ability hypotheses can then be made on the basis of manual skill scores.

Handedness - cognitive abilities relationships were investigated, with the relationship between handedness and speech lateralization for the subject sample taken into account.

7. <u>Hypotheses</u>

The view that there are systematic relationships between handedness, speech lateralization and cognitive ability was investigated. Handedness was measured by self-classification, Preference and manual skill. Speech lateralization was measured by ear advantage for dichotically presented words. Cognitive ability was measured by four WAIS subtests (Wechsler, 1955).

The following hypotheses were tested.

Handedness and speech lateralization.

1. Left hemisphere control of speech processing is greater for right than for left handers. Therefore, a self-classified (SC) right handed group has a significantly larger mean right ear advantage (EA) than a SC left handed group.

2. Because manual skill and speech lateralization both reflect an underlying hemispheric specialization, they are systematically interrelated continuua. Therefore, manual skill gradients correlate with the EA gradient.

3. The relationship between subjects' classification of themselves as right or left handed and speech lateralization is due to the association of manual skill with self-classification and speech lateralization. Therefore, if the effect of MS is controlled for, the correlation between SC and EA is reduced to nonsignificance.

Handedness and cognitive abilities.

4. Degree of hemispheric specialization affects spatial ability such that strongly lateralized (SL) Male and Female adults have greater spatial ability than weakly lateralized (WL) Male and Female adults. Therefore, since MS reflects hemispheric specialization, MS scores are positively related to spatial test scores.

5. Degree of hemispheric specialization affects cognitive ability such that WL Male and Female adults show greater discrepancies between verbal and spatial ability than SL Male and Female adults. Therefore, since MS reflects hemispheric specialization, MS scores are negatively related to absolute verbal minus spatial discrepancy scores.

Derivation of MS scores and data analyses are discussed in the Methods section.

CHAPTER II

METHOD

1. Subjects

A total of 60 University of Victoria students were drawn from the Psychology Department subject pool. To allow appropriate handedness comparisons, the ratio of right to left handers chosen for the study is not representative of population ratios. Subject selection was made so that the sample consisted of 15 male and 15 female self-classified right handers and 15 male and 15 female self-classified left handers. Left handers constitute only 10% of the general population (cf. Hardyk and Petrovitch, 1977) and are therefore over represented in this sample. Three subjects with hearing loss and one epileptic subject were replaced with subjects of the same sex and hand classification.

2. Measures

Dichotic listening test. The dichotic word tape consisted of 22 sets of 3 single syllable word pairs presented at a rate of one pair every .50 seconds and with simultaneous onset of the word pairs. The dichotic test was presented via earphones from a stereophonic tapedeck. Sound level was calibrated and set at 65-70 decibels. The dichotic stimuli are listed in Appendix A.

The dichotic tape was provided by the University of Victoria Neuropsychology lab. Simultaneity of onset of the word pairs on the tape was made as precise as possible by categorizing the words used according to the constellation of articulatory features characterizing their initial consonants. Words were then paired so as to prevent competition between different articulatory features of initial consonants, e.g. "port" would be paired with another unvoiced front stop, e.g. "pack." For a list of the word pairs see Appendix A.

Handedness tests. The hand preference questionnaire listed the 6 activities which Annett (1970) found to be the best discriminators of handedness groups. These activities are writing, throwing a ball, holding a tennis racket, lighting a match, hammering a nail, and holding a toothbrush. Subjects were required to state their preference for the right, left or both hands for each activity.

Five MS tests were administered. For each test the subjects' dominant hand was tested first. Thus, SC right handers always performed an MS test with the right hand before they performed the test with the left hand. The order was reversed for SC left handers, who performed with the left hand first.

a) Handwriting. The alphabet was written as one word three times with each hand. The score for each hand was the total time taken to complete the task.

b) Scissors. The test required the cutting of complex shapes accurately. Three trials were given for each hand, alternating hands. The score for each hand was the total time taken.

c) Reaction Time. The apparatus consisted of a telegraph key mounted on a board with a light directly above the key. The light was connected to a lever placed behind a screen. The test required the subject to hold his wrist on the board, rest his index finger lightly on the key, and watch the light. Two to four seconds after giving a ready signal, the tester turned the light on. Time between onset of the light and the subject pressing the key to turn it off was recorded by a Hunter Timer. The score for each hand was the total time taken over five trials.

d) Tapping. The finger tapper consisted of a metal stylus mounted on a wooden board to which an electric counter was attached. The test consisted of tapping the stylus as fast as possible with the index finger. After 50 practise taps, 3 ten second trials were given for each hand. The score for each hand was the total number of taps counted over three trials.

e) Pegs. The apparatus consisted of a wooden board covered by a metal plate containing 7 rows of small holes and a well containing collars and pins. Tweezers were used to pick up and place a pin in the first hole followed by the insertion of a collar over the pin. One row of holes was used for a practise trial and the remaining 6 rows for the test trial. The score for each hand was the number of pins and collars correctly placed within two minutes.

Cognitive Tests. Subtests from the WAIS (Wechsler, 1955) were used to measure verbal and spatial abilities. The Verbal subtests, Vocabulary and Similarities, measured verbal ability and the Performance subtests, Block designs and Object Assembly, measured spatial ability. Raw scores were converted to scale scores (normalized: $\bar{X} = 10$, $sd = 3$) and the Verbal scores added together to provide the verbal score and the Performance scores added together to provide the spatial score. The rationale for the choice of these tests as measures of verbal and spatial ability is given in Appendix B.

3. Procedure

Subjects were tested individually in a quiet room. The hand preference questionnaire was administered, followed by dichotic listening test, the MS tests, and the cognitive tests.

Prior to administration of the dichotic listening test, each subject was screened for hearing loss. A set of three words was presented to the right ear via earphones from a tape deck. The sound level was set at 65 decibels. After presentation of the three words, the subject was asked to repeat them. This process was repeated twice to each ear.

For the dichotic listening test, each subject was instructed that he or she would hear a set of three words to each ear, that the word heard in the left ear would be different from the word simultaneously at the right ear, and that at the end of each three pair set, he or she was to report to the tester as many of the six words as he could recall. Instructions stressed that different words would be heard by each ear and that the subject was to attend to both ears. Responses were recorded by the tester on a sheet containing all the stimuli by ticking each correct response. Six practice trials were followed by 20 test trials. To control for channel effects (one channel louder than the other), half the subjects within each handedness group and sex received the first 10 trials with headphones in the normal position (order one) and the second 10 trials with headphones in the reverse position (order two). The other 30 subjects received order two followed by order one.

Manual skill tests were administered in the following order: Scissors, Tapping, Pegs, Reaction Time, Handwriting. This test order interspersed tests that required greater concentration and hand use with less strenuous tests.

The order of administration and scoring procedure for the cognitive tests, Vocabulary, Similiarities, Block Design, and Object Assembly was according to instructions in the WAIS manual (Wechsler, 1955).

4. Data Analysis

Handedness. To achieve MS scores, a converted difference score was computed: $R-L/\sqrt{R+L}$ where R = right hand score and L = left hand score (Shankweiler and Studdert-Kennedy, 1975). Use of Shankweiler and Studdert-Kennedy's difference score permitted comparison of their results to those of the present study.

Satz's (1975) recommendation to minimize misclassification for tests of hemispheric lateralization was followed. The tests were treated as measures of degree of left hemisphere control rather than measures of left versus right hemisphere control (see Chapter I, p. 46). Therefore, a large positive MS score represented strong right hand superiority and left hemisphere control; a small or negative MS score represented weak lateralization, or bilateral hemisphere control. If clinical estimates can be considered representative, approximately 30% (9 subjects) of the SC left handed group may be misclassified. However, if left handedness was considered representative of right hemisphere control, 70% (21 subjects) might be misclassified.

Prior to testing the hypotheses, MS scores were examined in terms of SC. Previous researchers have observed that left handers' performance and preference are more heterogeneous than are right handers. Differences between SC left and right handed groups were tested via separate analyses of variance (ANOVAS) for each MS test. The 2 x 2 ANOVAS tested the effects of SC and Sex on MS scores. No interaction or Sex effects were expected but significant SC effects were expected on each MS test. SC left handers' MS scores were expected to distribute around means close to zero (equivalent ability with both hands) while right handers' MS scores were expected to distribute around means favouring right hand superiority. Whether SC left handers are a more heterogeneous group than SC right handers in terms of their MS scores was checked via F_{max} tests for each MS test.

Handedness and speech lateralization. Transformed dichotic listening scores were computed using Kuhn's (1973) phi coefficient: $\text{phi} = \frac{R-L}{\sqrt{R+L\ [2T-(R+L)]}}$; where R = the number of right ear correct responses, L = the number of correct left ear responses, and T = the number of dichotomous presentations. Kuhn has shown that a difference score for dichotic responses based on the phi coefficient compensates for variations in accuracy. The weight attached to the ear difference (EA) is systematically increased as performance departs from the point where the maximum right minus left ear score can be obtained. Kuhn's phi coefficient was used by Shankweiler and Studdert-Kennedy (1976) to compute dichotic listening scores. The use of phi in the present study simplifies comparison of the results of the two studies.

A *t*-test compared order effects on EA for the two groups.

Hypothesis one. A 2 x 2 ANOVA tested the effects of SC and Sex on EA. The interaction and Sex effect were not expected to reach significance. SC was expected to have a significant effect on EA; the SC right handed group was expected to have a significantly larger mean EA than the SC left handed group.

Hypothesis two. Stepwise regression was used to test the relationship between the MS predictors and the criterion, EA on the dichotic listening test. Predictor variables were entered into the equation one at a time. The variable with the largest correlation with EA entered first, followed at each step by the entrance of the variable with the next largest partial correlation with EA. A significant multiple correlation was expected between the set of MS tests and EA.

Hypothesis three. It was hypothesized that the common finding of the SC-EA relationship is due to the association of MS on SC and EA. To test this hypothesis, the correlation between SC and EA was computed, with the effects of each of the 5 MS measures controlled. The resulting partial correlation between SC and EA was not expected to be significant. For comparative purposes, the correlation between SC and EA with no control for the effect of MS was also computed. This correlation was expected to reach significance (see Hypothesis one).

Handedness and cognitive ability. Hypotheses five and six were tested by a multiple regression procedure analagous to ANOVA, but which handles both categorical and continuous variables. The procedure is described in Appendix C.

For a direct comparison of the results to those obtained by Levy (1969), the subjects were then divided according to Levy's definition of handedness into right and left handed groups. Those subjects who stated preference for the right hand for every activity on the Hand Preference Questionnaire were classified as right handed. Those subjects who stated preference for the left hand for one or more of the activities on the Hand Preference Questionnaire were classified as left handed. The effects of sex and handedness on spatial ability scores and on verbal-spatial discrepancy scores were then tested via separate 2 x 2 analyses of variance.

CHAPTER III

RESULTS

1. Handedness

There is no concensus regarding the definition and measurement of handedness. For purposes of comparison, three commonly used measurement methods were examined. Separate 2 x 2 ANOVAS to test the effects of Sex (S) and Self-classification of Handedness (SC) on transformed manual skill difference scores yielded no significant S x SC interaction or Sex effects on 4 of the 5 MS tests. Sex had a significant effect on Pegs: Females had larger MS scores than males. SC had a significant effect on each of the MS tests (Tables 1 to 5). The right handed group had mean difference scores favouring right hand superiority and the left handed group had mean difference scores favouring left hand superiority on each MS test (Table 6). With one exception, the variance for each MS test was equivalent for the SC right and left handed groups. *Fmax* analyses testing the size of the smaller variance against the size of the larger for each MS test was not significant for Handwriting, Reaction Time, Scissors, or Finger Tapping. The variances were significantly different for Crawford Pegs (*Fmax* = 3.19; *df* = 59, 59;

$p < .01$). The SC right handed group was more variable than the SC left handed group on this MS test.

Examination of MS score distributions for the combined groups of SC right and left handers reveals continuous, unimodal distributions for 4 of the 5 MS measures (Figures 1-5). Scores on the MS test, Handwriting, yielded a bimodal distribution; SC right handers obtained MS scores favouring right hand superiority and SC left handers obtained MS scores favouring left hand superiority. Handwriting was also the only activity for which all left handers stated preference for the left hand, despite the choice of the 6 questions on the Preference Questionnaire as the ones Annett (1970) found to be the best discriminators between right and left handers. Of the total number of responses for the remaining 5 questions, the 30 SC left handers gave 78.66% left hand responses, 16.66% right hand responses and 4.66% both hand responses. SC right handers stated preference for the right hand for every activity on the Hand Preference Questionnaire. These results are consistent with previous researchers' findings that left handers are more variable with respect to manual preference and skill than are right handers (cf. Benton, Myers and Polder, 1962).

In summary, Figures 1-5 show that the range of manual skill scores is approximately the same for SC left as for SC right handers; group means tend to be smaller for SC left handers than for SC right handers; and the score distributions overlap for the combined right and left handed

Table 1

ANOVA: Self-Classification of Handedness (SC) and Sex (S) Effects on Reaction Time[1]

Source	Sums of Squares	df	F	η^2
SC	131.894	1	35.62**	.38
S	.074	1	.02	.00
S x SC	.293	1	.08	.00
Error	207.344	56		
Total	339.605	59		

**p<.001

[1]Reaction Time = $R-L/\sqrt{R+L}$; where R = the right hand score and L = the left hand score on the Manual Skill Test.

Table 2

ANOVA: Self-Classification of Handedness (SC) and Sex (S) Effects on Scissors[1]

Source	Sums of Squares	df	F	η^2
SC	518.696	1	64.71**	.53
S	2.082	1	.26	.00
S x SC	2.046	1	.26	.00
Error	448.897	56		
Total	971.722	59		

**p<.001

[1]Scissors = $R-L/\sqrt{R+L}$; where R = the right hand score and L = the left hand score on the Manual Skill Test.

Table 3

ANOVA: Self-Classification of Handedness (SC) and Sex (S) Effects on Tapping[1]

Source	Sums of Squares	df	F	η^2
SC	20.879	1	47.85**	.45
S	.517	1	1.18	.01
S x SC	.420	1	.96	.01
Error	24.434	56		
Total	46.250	59		

**$p<.001$

[1]Tapping = $R-L/\sqrt{R+L}$; where R = the right hand score and L = the left hand score on the Manual Skill test.

Table 4

ANOVA: Self-Classification of Handedness (SC)

And Sex (S) Effects on Crawford Pegs

Source	Sums of Squares	df	F	η^2
SC	129.355	1	22.05**	.26
S	30.496	1	5.19*	.06
S x SC	9.571	1	1.63	.02
Error	328.585	56		
Total	498.008	59		

**$p<.001$

* $p<.025$

Crawford Pegs = $R-L/\sqrt{R+L}$; where R = the right hand score and L = the left hand score on this Manual Skill Test.

Table 5

ANOVA: Self-Classification of Handedness (SC) and Sex (S) Effects on Handwriting[1]

Source	Sums of Squares	df	F	η^2
SC	705.454	1	273.69**	.83
S	.894	1	.35	.00
S x SC	.828	1	.32	.00
Error	144.343	56		
Total	851.520	59		

**p<.001

[1]Handwriting = $R-L/\sqrt{R+L}$ where R = the right hand score and L = the left hand score on this Manual Skill Test.

Table 6

Means and Standard Deviations for Right and Left Handers on Five Manual Skill Tests[1]

	Right Handers		Left Handers	
	Mean	Standard Deviation	Mean	Standard Deviation
Reaction Time (seconds)	1.23	1.71	-1.73	2.06
Scissors (seconds)	5.29	2.36	0.59	3.17
Tapping (no. of taps)	0.84	0.71	-0.49	0.54
Pegs (no. of pegs)	1.98	3.11	-0.96	1.74
Handwriting (seconds)	4.12	1.12	-3.06	1.24

[1]The formula $R+L/\sqrt{R-L}$; where R = right hand score and L = left hand score, was used to derive each subject's score on each Manual Skill Test.

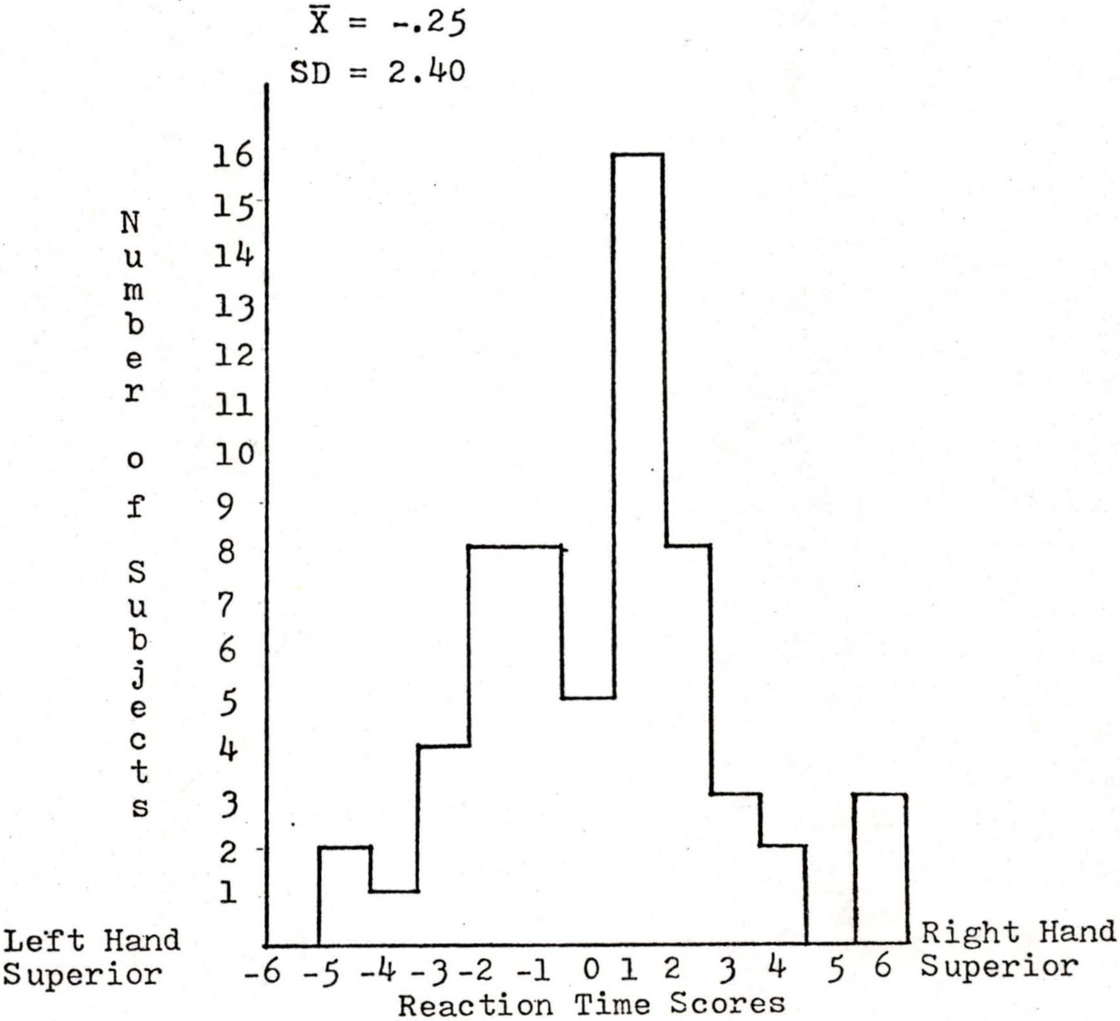

Figure 1. Subjects' right minus left hand score distributions on the manual skill test, Reaction Time: $R-L/\sqrt{R+L}$.

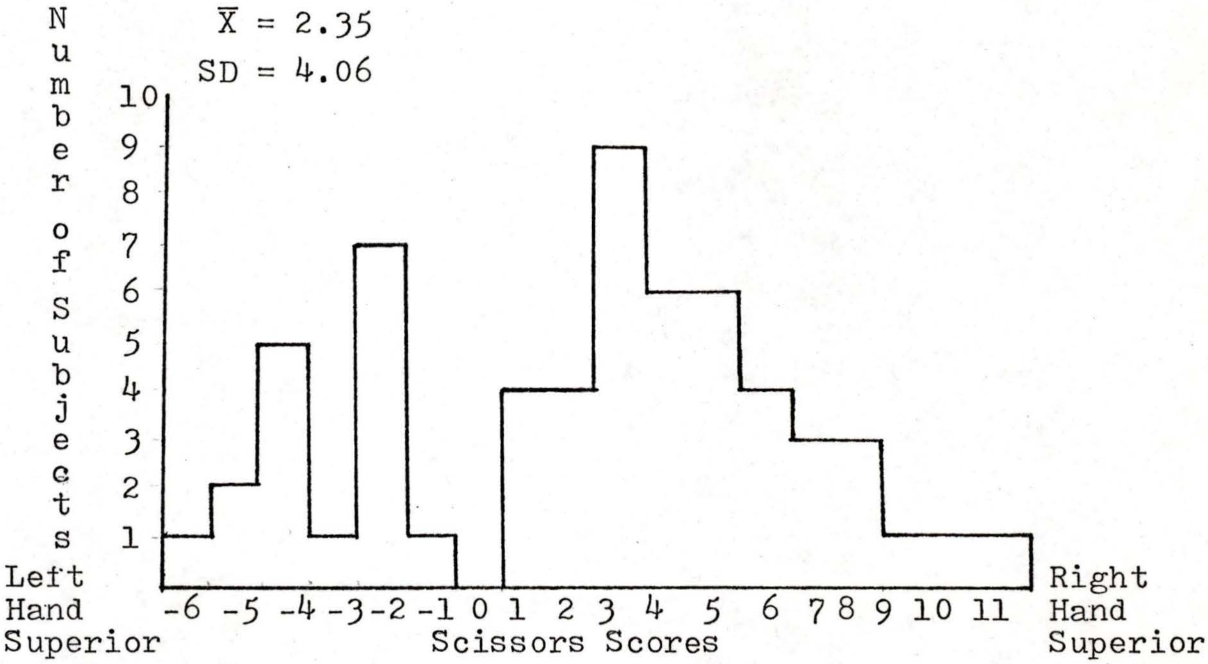

Figure 2. Subjects' right minus left hand difference scores on the Manual Skill test, Scissors: $R-L/\sqrt{R+L}$.

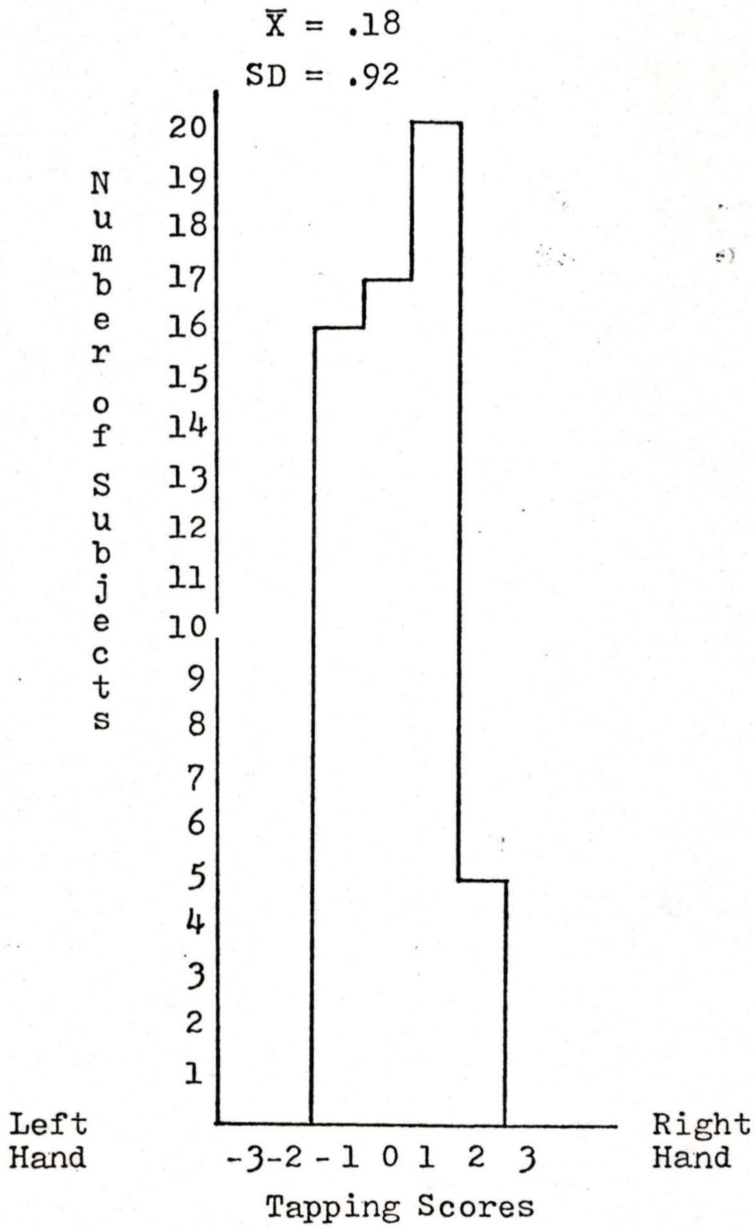

Figure 3. Subjects' right minus left hand score distributions on the Manual Skill Test, Tapping: $R-L/\sqrt{R+L}$.

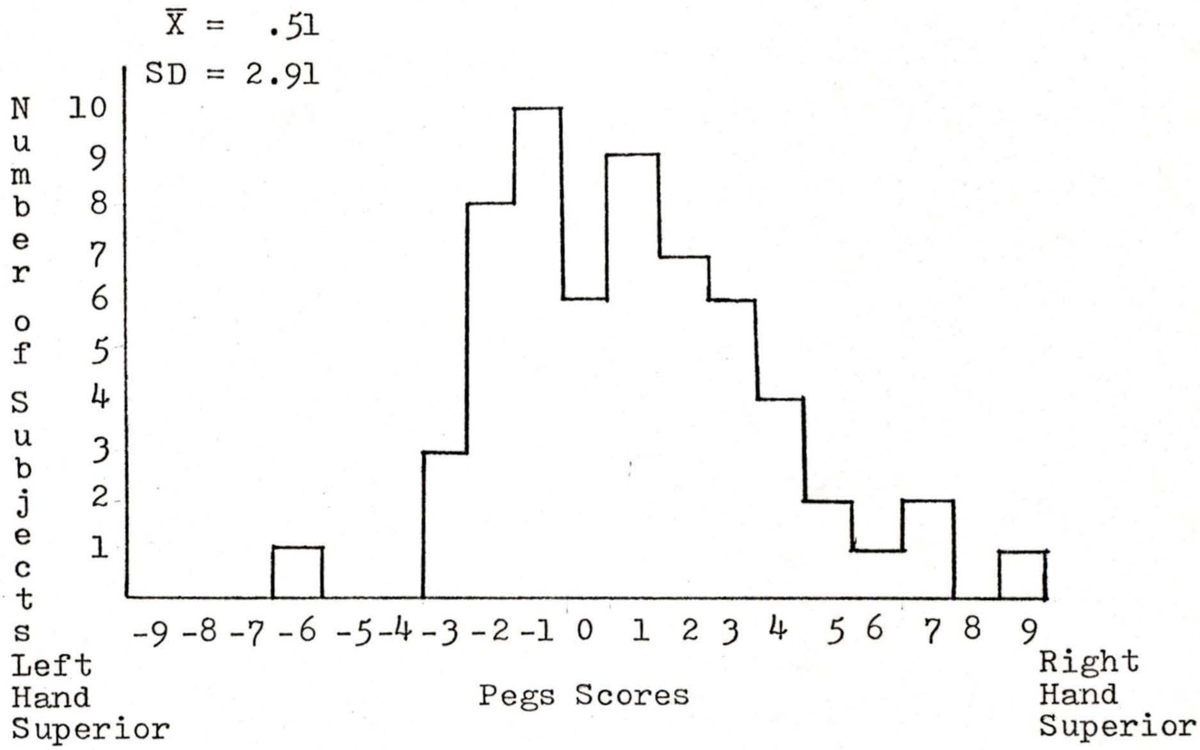

Figure 4. Subjects' right minus left hand score distributions on the Manual Skill test, Pegs: $R-L/\sqrt{R+L}$.

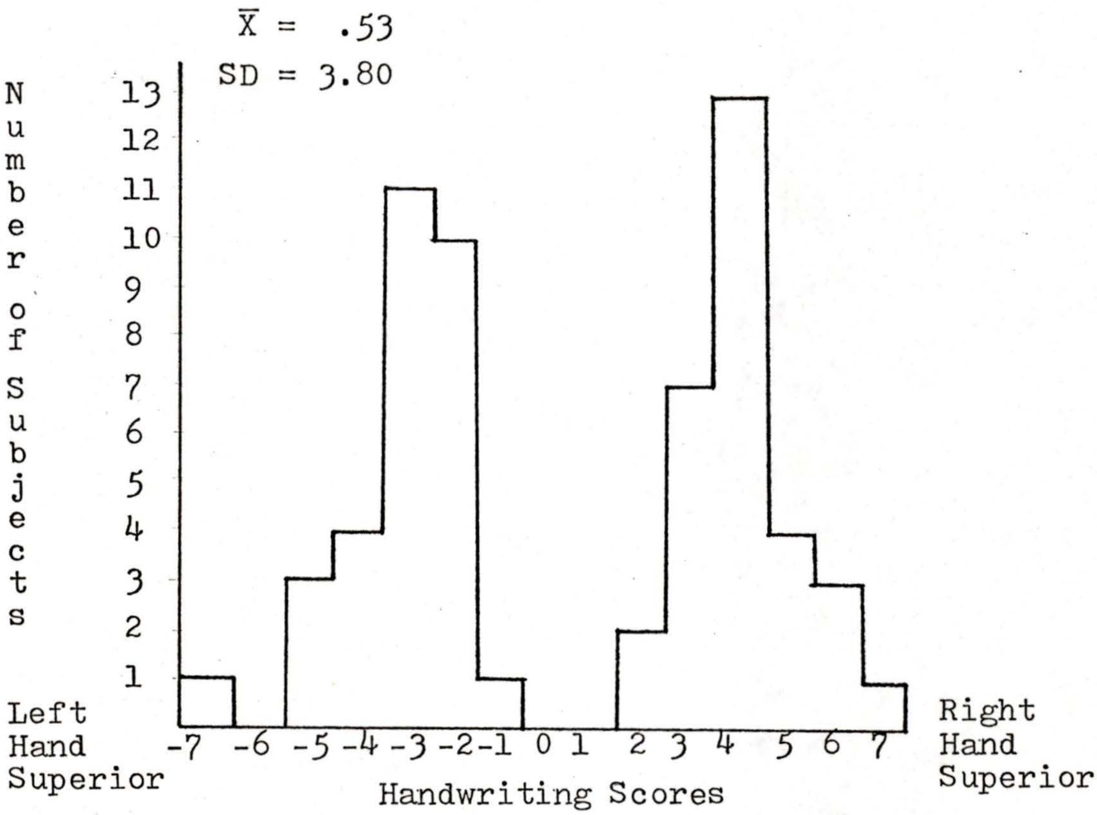

Figure 5. Subjects' right minus left hand difference scores on the Manual Skill test, Handwriting: R-L/ $\sqrt{R+L}$.

groups. Taken together, these factors indicate a greater tendency among SC left handers than among SC right handers toward superior skill with the nonpreferred hand. That is, the individual left hander may exhibit superior right hand skill, superior left hand skill or equivalent ability with both hands, on different tasks, while the individual right hander is more likely to exhibit some degree of right hand superiority.

2. Handedness and Speech Lateralization

Counterbalancing by the presentation of dichotic stimuli in two different orders had no effect on EA scores: the *t*-test for order effects in the presentation of dichotic listening stimuli was not significant: ($t = .08$; $df = 58$; $p = >.10$).

Hypothesis one. It was hypothesized that left hemisphere control of speech processing was greater for right handers than for left handers. The 2 x 2 ANOVA testing the effects of Sex and SC on EA yielded no significant Sex by SC interaction or Sex effects. As expected, the SC effect was significant: the mean right EA was greater for the SC right handed group ($\overline{X} = .117$; $sd = .210$) than for the SC left handed group ($\overline{X} = .007$; $sd = .222$), supporting the first hypothesis (Table 7).

The combined right and left handed groups' EA scores formed a symmetrical distribution with a mean of .062 and a standard deviation of .221 (Figure 6).

Hypothesis two. Because manual skill and speech lateralization were hypothesized to reflect hemispheric specialization which varies in degree, MS and EA were expected to be significantly correlated. The stepwise multiple regression relating the 5 MS tests to EA for the total N of 60 subjects yielded a significant multiple correlation of .50 and a squared multiple correlation of .25, supporting the second hypothesis (Table 8).

Scissors, the first predictor to enter the equation, accounted for 17% of the explained variance. The inclusion of the other four predictors in the regression equation did not significantly increase the explained variance:

$$(R_s^2 - R_1^2: \quad F = \frac{(R_5^2 - R_1^2)/(K_5 - K_1)}{(1 - R_5^2)/(N-k-1)} = \frac{.254 - .174/5-1}{1-.254/60-5-1} = 1.44,$$

$df = 4,54$; $p > .05$)

Whereas only one MS measure made a significant contribution to the regression equation for the present study, Shankweiler and Studdert-Kennedy (1975) reported that significant contributions were made to the stepwise regression by 4 of 5 MS measures in their study of the handedness - speech lateralization relationship. Differences between the two studies in the relative contributions of the predictors can be attributed in part to high intercorrelations between the MS tests and to the addition of two new MS tests in the present study. Regression coefficients tend to be unstable, changing when variables are added to the equation and changing from sample to sample, particularly when the predictors are highly correlated (Kurlinger and Pedhazur, 1973).

Hypothesis three. It was hypothesized that SC was related to EA because of the influence of MS on SC and EA. The partial correlation between SC and EA with MS effects controlled for was not significant, supporting this hypothesis (r = .07; df = 53; p>.30). As expected, the EA-SC correlation was significant when the MS effect was not controlled (r = .25; df = 58; p<.03). Correlations between EA, SC and the 5 MS tests are given in Table 9. The manual skills incorporated in the MS measures can tentatively be considered the basis of "handedness," accounting for the common finding of a handedness - speech lateralization relationship such that SC left handers show smaller right EA than SC right handers (Hypothesis one).

3. Handedness and Cognitive Abilities

Lateralization was operationally defined by the MS test, Scissors, to test handedness - cognitive abilities hypotheses because Scissors correlated highly with other MS tests and made the only significant contribution to the MS - EA regression equation.

Hypothesis four. The hypothesis that strongly lateralized adults have greater spatial ability than weakly lateralized adults was not supported. The multiple regression procedure used to test the hypothesis yielded the following results: a significant

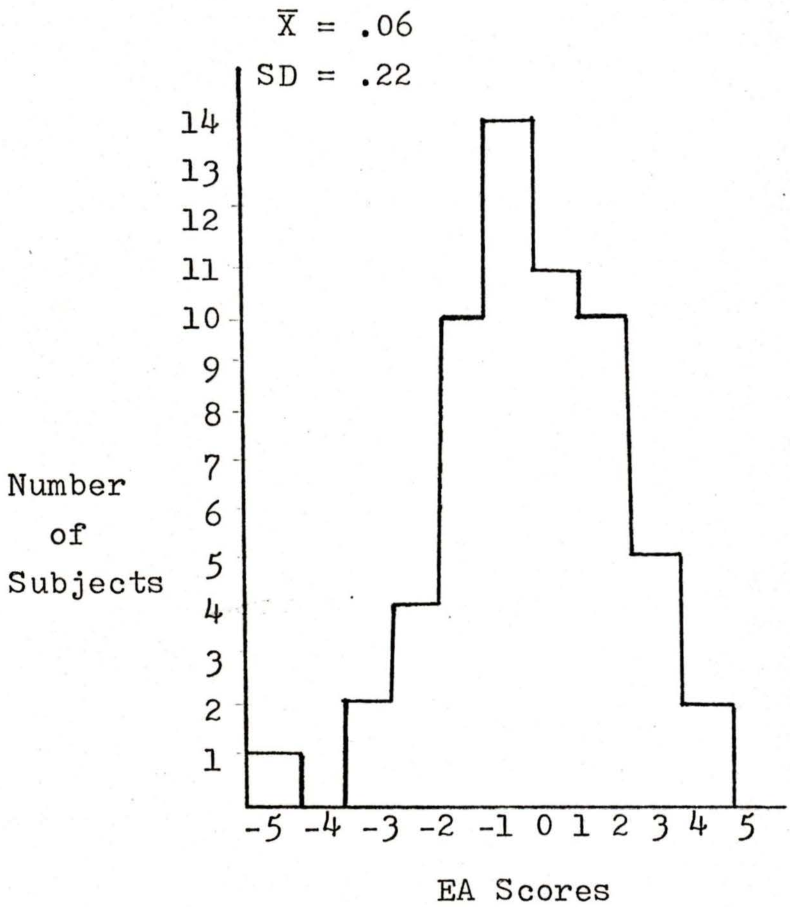

Figure 6. Subjects' right minus left ear (EA) score distributions on the dichotic listening test: phi = $R-L/\sqrt{R+L\,[2T - (R+L)]}$.

Table 7

ANOVA: Handedness and Sex Effects on Dichotic Listening Scores[1]

Source	SS	df	F	η^2
Handedness (H)	.112	1	4.78*	.08
Sex (S)	.004	1	.17	.00
H x S	.014	1	.61	.01
Within	1.311	56		
Total	1.441	59		

*p<.05

[1]Dichotic listening scores were derived via the formula: $R-L/\sqrt{R+L\,[2T-(R+L)]}$; where R = the number of correct right ear responses, L = the number of correct left ear responses, and T = the number of dichotomous presentations.

Table 8

Multiple Regression of Difference Scores for Five Manual Skill Tests on Dichotic Listening Ear Advantage

Variable	R	R^2	R^2 change	SS	df	F
Scissors	.418	.175	.174	.506 2.391	1 58	12.28**
Handwriting	.437	.191	.017	.555 2.342	2 57	6.75*
Tapping	.474	.225	.033	.651 2.246	3 56	5.41*
Pegs	.503	.254	.029	.734 2.163	4 55	4.67*
Reaction Time	.504	.254	.000	.737 2.160	5 54	3.68*

**p<.001
*p<.01

Table 9

Intercorrelations Between Self-Classification of Handedness, Manual Skill and Dichotic Listening Scores for 60 Subjects

	Dichotic Listening	Self-Classification	Hand Writing	Reaction Time	Scissors	Finger Tapping	Crawford Pegs
Dichotic Listening	1.00						
Self-Classification	.25*	1.00					
Hand Writing	.19	.95***	1.00				
Reaction Time	.11	.62***	.64***	1.00			
Scissors	.42***	.73***	.69***	.51***	1.00		
Finger Tapping	.33**	.73***	.70***	.46***	.62***	1.00	
Crawford Pegs	.09	.51***	.47***	.41***	.43***	.63***	1.00

***p<.001
**p<.01
*p<.05

squared multiple correlation of .173 between Sex, MS, the Sex by MS interaction and spatial test scores; a nonsignificant percentage of the variance accounted for by the interaction; and significant percentages of the variance accounted for by Sex, Males achieving higher spatial scores then Females; and by MS. The relationship between MS and spatial ability was opposite to the expected direction. The more strongly the MS score favoured the right hand, the lower the spatial score tended to be (Table 10).

In order to compare the effect on the results of handedness defined by MS to those obtaining when Levy's (1969) method of hand classification was used (see page 55) subjects were divided on the basis of Self-Classification into right and left handed groups, each group containing 15 male and 15 female subjects. These groups met Levy's criteria for right or left handedness: right handers stated preference for the right hand for every task on the Hand Preference Questionnaire; left handers stated preference for the left hand for at least one task. A 2 x 2 ANOVA was used to test the effects of Handedness and Sex on spatial ability. The interaction and Handedness effects were not significant, although left handers tended to achieve slightly higher spatial scores than right handers (Table 11). The Sex effect was, of course, significant, since the same Male and Female subjects were used for both the regression analyses and the ANOVA (Table 12).

Table 10

Multiple Regression: Manual Skill and Sex Effects on Spatial Ability

Source[1]	SS (R^2)	df	F
$R^2_{SA.S,MS,SMS}$	.173	3	3.93*
$R^2_{SA.S,MS}$	.162	2	5.52**
a) $R^2_{SA.MS}$ adjusted for S	.069	1	4.71*
b) $R^2_{SA.S}$ adjusted for MS	.086	1	5.87*
$R^2_{SA.SMS}$	.011	1	.75
Residual $(1 - R^2_{SA.S,MS,SMS})$	.821	56	

**$p<.01$

*$p<.05$

[1]SA = Spatial Ability, S = Sex, MS = Manual Skill and SMS = the Sex by Manual Skill Interaction.

Table 11

Means and Standard Deviations for Male and Female Right and Left Handers on the Spatial Ability Test

	Males		Females	
	Mean	Standard Deviation	Mean	Standard Deviation
Right Handers	25.40	3.21	22.20	2.73
Left Handers	25.80	4.00	24.60	3.56

Table 12

ANOVA: Handedness and Sex Effects

on Spatial Ability

Source	SS	df	F	n^2
Handedness (H)	29.40	1	2.50	.04
Sex (S)	72.60	1	6.18*	.09
S x H	15.00	1	1.28	.02
Within	658.00	56		
Total	775.00	59		

*$p<.02$

Hypothesis five. The hypothesis that WL subjects show greater discrepancies between verbal and spatial ability than SL subjects was not supported. The overall squared multiple correlation between Sex, MS, the Sex by MS interaction and verbal - spatial difference scores was not significant ($R^2 = .040$; $F = .79$; $p > .05$). Therefore the analysis was discontinued.

Subjects were again divided into right and left handed groups for a comparison of the effects of the two methods of defining handedness on the results (see page 88). A 2 x 2 ANOVA testing the effects of Sex, Handedness, and the Sex by Handedness interaction on verbal - spatial difference scores yielded no significant F values (Table 13). However, the tendency for Females to have higher verbal - spatial difference scores than Males, and right handers to have higher verbal - spatial difference scores than left handers is consistent with the results found for both the ANOVA and regression analyses for Hypothesis three (Table 14).

In summary, no support was found for a spatial decrement for WL subjects or for a greater discrepancy between verbal and spatial abilities for WL subjects. Redivision of subjects in accordance with Levy's (1969) definition of handedness into right and left handed groups revealed no significant differences between these groups in spatial ability or in the discrepancy between verbal and spatial abilities.

Table 13

ANOVA: Handedness and Sex Effects

on Verbal-Spatial Discrepancy

Source	SS	df	F	η^2
Handedness (H)	21.60	1	1.76	.03
Sex (S)	15.00	1	1.22	.02
S x H	1.07	1	.09	.00
Within	687.73	56		
Total	725.40	59		

Table 14

Means and Standard Deviations for Male and Female Right and Left Handers' Verbal-Spatial Discrepancy

	Males		Females	
	Mean	Standard Deviation	Mean	Standard Deviation
Right Handers	4.87	3.30	6.40	3.33
Left Handers	4.13	3.03	4.87	3.14

CHAPTER IV

DISCUSSION

1. Handedness

The present results are in accord with previous cerebral dominance related research into the parameters of handedness. The reports by Benton, Myers and Polder (1962) and Satz, Achenbach and Fennell (1967) that self-classification results in misclassification in terms of manual preference and skill were supported by the finding that SC left handers frequently stated preference for, or showed superior skill with, the right hand. Annett's (1970) view of handedness as a continuum of preference, applied to manual skill by Shankweiler and Studdert-Kennedy (1975) was also verified by the present results.

Oldfield (1971) found that writing hand was the basis of self-classification in his investigation of handedness. That all left handers stated preference for the left hand for writing but varied in their hand preference for other activities supports the view that writing hand was also the basis of self-classification for subjects in the present study. Handwriting was also the only MS test for which subjects' scores were bimodally distributed; all SC left handers attained higher left hand scores and all SC right handers attained higher right hand scores. The SC left handers' consistent statement of left hand preference for Handwriting on the Hand Preference Questionnaire indicates consistent practise with the left hand and no practise with the right hand for the SC left handed group on this task. A practise effect might therefore account, in part, for SC left handers' consistent left hand superiority on the Handwriting MS test and their tendency toward equivalent right-left hand ability on other MS tests. Presumably, practise has less effect on the other, somewhat more novel MS tests.

The SC right and left handed groups' difference scores on each of the other four manual skill measures overlapped to form continuous, unimodal distributions. The MS distributions may be representative of varying degrees of hemispheric specialization for behaviours requiring fine sensorimotor control (Shankweiler and Studdert-Kennedy, 1975). The implications of the handedness data for a model of hemispheric specialization are discussed in greater detail below.

2. Handedness and Speech Lateralization

While a relationship between cerebral control of speech processing and handedness is accepted by most cerebral dominance researchers, little is known about this relationship beyond the evidence that SC left handers do not show the same pattern of left hemisphere dominance for speech and language processing as SC right handers. The common finding of a smaller EA on the dichotic listening test for left than right handers is considered to reflect the atypical dominance pattern of left handers and is generally interpreted as due to a tendency toward bilateral organization of speech processing for this group. The finding of a smaller mean EA on the dichotic listening test for SC left than for SC right handers is consistent with previous research results. However, the interpretation of this finding as due to bilateral control of speech processing in left handers does little to clarify the handedness - speech lateralization relationship.

Investigators have attempted to expand knowledge about the handedness - speech lateralization relationship by examining the effects of variables such as family history of left handedness and strength of hand preference on EA on the dichotic listening test. These investigations have contributed little to the development of a model of cerebral dominance capable of generating further hypotheses concerning the relationship of handedness to speech processing. There is some evidence that right hand preference is influenced by the relatively greater right than left hand skill for tasks which require fine sensorimotor control (cf. Barnsley and Rabinovitch, 1970; Provins and Cunliffe, 1972). Relative to this evidence, Semmes (1968) has suggested that the underlying basis of left hemisphere dominance is the superiority of this hemisphere for behaviours requiring fine sensorimotor control, such as manual skills and speech. Of the atypical left handed group who appear not to fit the left hemisphere speech control - right hand preference rule, Semmes concludes that there is a tendency in this group towards diffuse, bilateral hemispheric representation of manual skills and speech. Extending Semmes' construct, Shankweiler and Studdert-Kennedy (1975) concluded that left hemisphere dominance for manual skill and speech processing is a matter of degree. They supported a hypothesis of a continuum of hemispheric specialization that is observable as a correlational relationship between right ear (left hemisphere) advantage on the dichotic listening test and right hand superiority on manual skill tests.

The findings of the present study, particularly the finding of a significant multiple correlation between MS and EA for the sample of 60 right and left handed male and female adult subjects, lend support to the view that manual skill and speech lateralization are related gradients. Shankweiler and Studdert-Kennedy's results were obtained from subject samples consisting primarily of right handed males. The present results, obtained from male and female, right and left handers extend the generalizability of their construct of hemispheric specialization.

The use of different verbal dichotic stimuli in the present study demonstrate that the result is not peculiar to the processing of one type of verbal stimuli. That Sex had no effect on EA, or on 4 of 5 MS tests, indicates that the distribution of EA and MS scores are similar for males and females, supporting the view that the hemispheric specialization construct, which MS and EA are considered to represent, is the same for females as for males.

The EA and MS scores were biased in favour of right side superiority, indicating a tendency for contralateral, left hemisphere control of speech processing and manual skill for the total sample of 60 subjects. However, when the SC left handed group's EA and MS are examined separately, the bias toward right EA is less pronounced, and MS scores reflect a slight left hand superiority on the manual skill tests.

Adapting Shankweiler and Studdert-Kennedy's (1975) construct to fit the clinical evidence of right hemisphere speech control for an estimated 30% of the left handed population, dominance may be considered to range through varying degrees of left hemisphere control, with a shift to right hemisphere control for approximately 3% of the total population (See Chapter I:1). Left handedness, then, may represent one end of a continuum of hemispheric specialization, rather than deviation from a typical dominance pattern. Many of the SC left handers in this study exhibited right hand superiority on MS tests and right EA. The results indicate that control of manual skills and speech can be considered to be primarily from the left hemisphere for these subjects, despite their self-classification as left handed. Other SC left handed subjects demonstrated left hand superiority on MS tests and left EA on the dichotic listening test. It is reasonable to assume that the left side superiority reflects greater right hemisphere control for these subjects, just as right side superiority was assumed to reflect greater left hemisphere control for the other subjects. Alternatively, control of manual skills and speech processing may be posited from the left hemisphere via stronger ipsilateral than contralateral sensorimotor pathways and ipsilateral cortical control (cf. Levy, 1974). Evidence of the dominating role of the contralateral auditory pathways for speech perception (cf. Kimura, 1961), plus incidence figures indicating right hemisphere control for approximately 30% of all left handers implicate varying degrees of contralateral right hemisphere control as the more important factor for subjects exhibiting left hand and ear superiority. While, more than 30% of the SC left handed group showed superior skill with the left hand on manual skill measures, a degree of unreliability in manual skill difference scores plus the unknown effects of previous practise would account in part for the over representation of subjects in this group.

In summary, the results support Semmes' (1968) view that hemispheric control for manual skills and speech processing are related and Shankweiler and Studdert-Kennedy's (1975) view that this control varies in degree across individuals. Varying degrees of hemispheric specialization for manual skills and speech, while generally a function of the left hemisphere, may be reversed and a function of the right hemisphere for some subjects.

Confirmation of the hypothesis that the SC-EA correlation is diminished when the influence of MS on the correlation is held constant supports the view that manual skill requiring fine sensorimotor control is the basis of the handedness parameter for the relationship of hand self-classification to speech lateralization. The common finding of a smaller mean right EA for SC left handers than for SC right handers (cf. Knox and Boone, 1971) is attributable to the influence of manual skill on the relationship. Because SC left handers more often than SC right handers have left EA or equivalent right-left ear scores on the dichotic listening test, and EA is correlated with MS, a left handed group's mean EA will be smaller than a right handed group's EA on the dichotic listening test.

The results discussed above demonstrate the greater potential of the manual skill method over the self-classification method of determining handedness for clarification of the handedness - speech lateralization relationship. The specific parameters of manual skill integral to the relationship require further investigation.

The manual tests used in the present study required rapid, sequentially organized movement. Thus, the MS-EA correlation lends some support to Shankweiler and Studdert-Kennedy's (1975) premise that the handedness - speech lateralization relationship is due to left hemisphere superiority for fine sensorimotor control of rapid, sequentially organized, rule governed behaviour. The recently published finding of a significant correlation between MS and EA for dichotically presented temporal (i.e. sequenced) rhythm patterns also supports this premise (Natale, 1977). Further verification would be obtained by examining the divergent validity of the premise: manual tests requiring rapid, sequentially organized, rule governed behaviour would be expected to correlate more highly with each other and with EA than manual tests requiring other factors, such as steadiness and strength.

3. Handedness and Cognitive Abilities

Posited differences between right and left handers in the cerebral control of verbal and spatial abilities led to the formulation of hypotheses concerning the relationship of these abilities to differing patterns of dominance. Levy (1969) concluded that because there is a tendency to bilateral language processing among left handers, they would show a spatial deficit relative to right handers. Levy (1974) later suggested that the left handed population is bimodally distributed such that either verbal or spatial decrement would be present. Therefore, the discrepancy between verbal and spatial ability would be larger for left than for right handers.

In the present study, Levy's (1969, 1974) suggestions regarding the relationship of handedness to speech lateralization were assessed. The results discussed above support the view that left handers as a group are weakly lateralized in terms of cerebral hemispheric control of manual skill and speech processing. The SC left handers as a group showed smaller right minus left difference scores than right handers on manual skill and dichotic listening tests. The results also support the view that handedness and speech lateralization are related; but it was demonstrated that lateralization of speech processing and handedness varies in degree across individuals for right as well as left handers.

Since Levy (1969, 1974) based her hypothesis on the assumption that left handers are weakly lateralized (or have bilateral language control), it was expected that weakly lateralized subjects would show a spatial decrement and a larger verbal-spatial discrepancy than strongly lateralized subjects. These hypotheses were not supported. There was no relationship between lateralization, as defined by MS difference scores, and verbal-spatial discrepancy. The relationship between lateralization and spatial ability was opposite to the expected direction: weakly lateralized subjects tended to have higher spatial scores than strongly lateralized subjects. There was a significant Sex effect on spatial scores: Males performed better than Females, but the absence of a MS (lateralization) by Sex interaction indicated that degree of lateralization had the same effect for Females as for Males.

Inferring greater spatial ability for left than for right handers on the basis of one MS test would be questionable. The lateralization - spatial ability correlation may be an artifact due to similarities between the MS test and the spatial tests. Both required hand use and spatial scores were partially dependent on speed, just as MS difference scores were based on time taken to complete the task. Further investigation with different subject samples would demonstrate the validity or invalidity of superior spatial ability with a lesser degree of lateralization. With larger subject samples it would be possible to examine the relationship of spatial ability to a number of manual skill tests, and to make within sample comparisons of intercorrelations between manual skill test and spatial ability, e.g., comparison of the intercorrelations for self-classified right and left handed groups.

Reanalysis of spatial scores and verbal-spatial discrepancy scores after division of subjects according to Levy's (1969) handedness criterion yielded no significant differences between right and left handed groups. However, mean spatial scores were slightly larger and the mean verbal-spatial discrepancy slightly smaller for left handed Males and Females than for right handed Males and Females. Therefore the results are internally consistent. The occurrence of the expected Sex effect on spatial scores is compatible with previous findings of superior spatial ability in Males (cf. McGlone and Davidson, 1975).

Failure to replicate Levy's results may be related to the ability level of the subjects tested. Newcombe and Ratcliffe (1973) found no significant differences between right, mixed and left handed groups' spatial ability or between verbal-spatial discrepancy for a large (n = 823), heterogeneous subject sample. Referring to the discrepancy between their results and those of Levy (1969) and Miller (1971) who did find a spatial deficit in left handers, Newcombe and Ratcliffe suggested that "the demonstration of a verbal-performance discrepancy in small selected samples does not warrant a broad generalization about the performance [spatial] skills of left handers in the normal population, although it may apply to selected groups at the extreme ends of the ability scale" (Newcombe and Ratcliffe, 1973, p. 401).

The basis of a spatial deficit in small, selected groups of left handers will remain obscure, and therefore difficult to replicate, until a model of hemispheric specialization which can account for variation in lateralization has been more fully developed and validated.

References

Annett, M. A model of the inheritance of handedness and cerebral dominance. Nature, 1964, 204, 59-60.

Annett, M. The binomial distribution of right, mixed and left handedness. Quarterly Journal of Experimental Psychology, 1967, 19, 327-333.

Annett, M. Classification of hand preference by association analysis. British Journal of Psychology, 1970, 61(3), 303-321.

Annett, M. The distribution of manual asymmetry. British Journal of Psychology, 1972, 63, 343-358.

Annett, M. Hand preference and the laterality of cerebral speech. Cortex, 1975, XI(4), 305-328.

Annett, M., Hudson, P. T. W., & Turner, A. The reliability of differences between the hands in motor skill. Neuropsychologia, 1974, 12(4), 527-532.

Barnsley, R. H., & Rabinovitch, M. S. Handedness: proficiency versus stated preference. Perceptual and Motor skill, 1970, 30, 343-362.

Beaumont, J. G. Handedness and hemisphere function. In S. J. Dimond and J. G. Beaumont (Eds.), Hemisphere Function in the Human Brain. London: Elek Science, 1974.

Benton, A. L. The problem of cerebral dominance. Canadian Psychologist, 1965, 6a(4), 332-348.

Benton, A. L. Right-left Discrimination and Finger Localization. New York: Harper, 1959.

Benton, A. L., Meyers, R., & Polder, G. J. Some aspects of handedness. Psychiat. Neurol., Basel, 1962, 144, 321-327.

Berman, A. The problem of assessing cerebral dominance and its relationship to intelligence. Cortex, 1971, 7, 372-386.

Bocca, E., Calearo, C., Cassinari, V., & Migliavacca, F. Testing 'cortical' hearing in temporal lobe tumors. Acta Oto-Laryngology, 1955, 45, 289-304.

Bogen, J. E., & Gazzaniga, M. S. Cerebral commissurotomy in man: Minor hemisphere dominance for certain visuo-spatial functions. Journal of Neurosurgery, 1965, 23, 394-399.

Bowers, D., & Heilman, M. Material specific hemispherical arousal. Neuropsychologia, 1976, 14, 123-127.

Briggs, G. G., & Nebes, R. D. Patterns of hand preference in a student population. Cortex, 1976, XI, 230-238.

Bryden, M. P. Tachistoscopic recognition, handedness and cerebral dominance. Neuropsychologia, 1965, 3, 1-8.

Bryden, M. P. Left-right differences in tachistoscopic recognition: Directional scanning or cerebral dominance? Perceptual and Motor Skills, 1966, 23, 1127-1134.

Bryden, M. P., & Rainer, C. A. Left-right differences in tachistoscopic recognition. Journal of Experimental Psychology, 1963, 66, 568-571.

Cohen, G. Hemispheric differences in a letter classification task. Perception and Psychophysics, 1972, 11, 139-142.

Conrad, K. Veber aphasishe Sprachtseoruugen bei hironverletzten Linkshaendren. Nervenarzt, 1949, 20, 148-154. Cited by O. L. Zangwill, Cerebral Dominance and its Relation to Psychological Function. London: Oliver and Boyd, 1960, p. 5.

Crawford, J. E., & Crawford, D. M. Crawford Small Parts Dexterity Test Manual. New York: The Psychological Corporation, 1956.

Cronbach, L. J. Essentials of Psychological Testing, Third Edition. New York: Harper and Row, Publishers, Inc., 1970.

Curry, F. K. W., & Rutherford, D. R. Recognition and recall of dichotically presented verbal stimuli by right- and left-handed persons. Neuropsychologia, 1967, 5, 119-126.

Curry, F. K. W. A comparison of left-handed and right-handed subjects on verbal and non-verbal dichotic listening tasks. Cortex, 1967, 3, 343-352.

Dee, H. L. Auditory asymmetry and strength of manual preference. _Cortex_, 1971, _7_, 236-245.

Dimond, S. J. Hemisphere function and word registration. _Journal of Experimental Psychology_, 1971, _87_, 183-186.

Dimond, S. J. _The Double Brain_. London: Churchill-Livingstone, 1972.

Dimond, S. J., & Beaumont, J. G. Experimental studies of hemisphere function in the human brain. In S. J. Dimond and J. G. Beaumont (Eds.), _Hemisphere Function in the Human Brain_. London: Elek Science, 1974.

Ettlinger, G., Jackson, C. V., & Zangwill, O. L. Cerebral dominance in sinistrals. _Brain_, 1956, _79_, 569-588.

Fleishman, E. A. Dimensional analysis of movement reactions. _Journal of Experimental Psychology_, 1958, _55_, 438-453.

Fleishman, E. A., & Ellison, G. D. A factor analysis of fine manipulative tests. _Journal of Applied Psychology_, 1962, _46_(2), 96-105.

Fleishman, E. A., & Hempel, W. E., Jr. A factor analysis of dexterity tests. _Personnel Psychology_, 1954, _7_, 15-32.

Gazzaniga, M. Cerebral dominance viewed as a decision system. In S. J. Dimond and J. G. Beaumong (Eds.), _Hemisphere Function in the Human Brain_. London: Elek Science, 1974.

Geffen, G., Bradshaw, J. L., & Wallace, G. Interhemispheric effects on reaction time to verbal and nonverbal stimuli. _Journal of Experimental Psychology_, 1971, _87_, 415-422.

Geschwind, N., & Levitsky, W. Human brain. Left right asymmetries in temporal speech region. _Science_, 1968, _161_, 186-187.

Gibson, A. R., Filbey, R., & Gazzaniga, M. S. Hemisphere differences as reflected by reaction time. _Fed. Proc._, 1970, _29_, 658.

Gilbert, C. Strength of left-handedness and facial recognition ability. _Cortex_, 1973, _9_, 145-151.

Harcum, E. R. Effects of symmetry on the perception of tachistoscopic patterns. American Journal of Psychology, 1964, 77, 600-606.

Harcum, E. R. & Finkel, M. E. Explanation of Mishkin and Forgay's result as a directional reading conflict. Canadian Journal of Psychology, 1963, 17, 224-234.

Harcum, E. R. & Jones, M. L. Letter-recognition within words flashed left and right of fixation. Science, 1962, 138, 444-445.

Hardyck, C. and Petrinovich, L. F. Left handedness. Psychological Bulletin, 1977, 84(3), 385-404.

Hecaen, H. Aphasic, apraxic and agnosic syndromes in right and left hemisphere lesions. In P. J. Vinken & G. W. Bruyn (Eds.), Handbook of Clinical Neurology, (Vol. 4). Amsterdam: North Holland Publishing Co., 1973, pp. 291-311.

Hecaen, H. & Piercy, M. Paroxysmal dysphasia and the problem of cerebral dominance. Journal of Neurol. Neurosurg. Psychiat., 1956, 19, 194-201.

Hecaen, H., & Sauget, J. Cerebral dominance in left handed subjects. Cortex, 1971, 7, 19-48.

Hempel, W. E., Jr. & Fleishman, E. A. A factor analysis of physical proficiency and manipulatice skill. Journal of Applied Psychology, 1955, 39, 12-16.

Howes, D., & Boller, F. Simple reaction time: Evidence for focal impairment from lesions of the right hemisphere. Brain, 1975, 98(II), 317-332.

Kerlinger, F. N., & Pedhazur, E. J. Multiple Regression in Behavioral Research. New York: Holt, Rinehart & Winston, Inc., 1973.

Kershner, J. R. Ocular-manual laterality and dual hemispheric specialization. Cortex, 1974, 10, 293-302.

Kimura, D. Cerebral dominance and the perception of verbal stimuli. Canadian Journal of Psychology, 1961, 15, 166-171 (b).

Kimura, D. Some effects of temporal-lobe damage on auditory perception. Canadian Journal of Psychology, 1961, 15, 156-165 (a).

Kimura, D. Left-right differences in the perception of melodies. Quarterly Journal of Experimental Psychology, 1964, 16, 355-358.

Kimura, D. Dual functional asymmetry of the brain in visual perception. Neuropsychologia, 1966, 4, 275-285.

Kimura, D. Functional asymmetry of the brain in dichotic listening. Cortex, 1967, 3, 103-178.

Kimura, D., & Durnford, M. Normal studies on the function of the right hemisphere in human vision. In S. J. Dimond & J. G. Beaumont (Eds.), Hemisphere Function in the Human Brain. London: Elek Science, 1974.

Knox, A. W., & Boone, D. R. Auditory laterality and tested handedness. Cortex, 1970, 6, 164-173.

Lake, D. A., & Bryden, M. P. Handedness and sex differences in hemispheric asymmetry. Brain and Language, 1976, 3(2), 266-282.

Levy, J. Psychobiological implications of bilateral asymmetry. In S. J. Dimond & J. G. Beaumont (Eds.), Hemisphere Function in the Human Brain. London: Elek Science, 1974.

Levy, J., & Trevarthen, C. Hemispheric specialization tested by simultaneous rivalry for mental associations.

Levy, J., Trevarthen, C., & Sperry, R. W. Perception of bilateral chimeric figures following hemispheric deconnection. Brain, 1972, 95, 61-78.

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

Luria, A. R. Higher Cortical Functions in Man. New York: Basic Books, 1966.

Matarazzo, J. O. Wechsler's Measurement and Appraisal of Adult Intelligence. Baltimore: The Williams and Wilkins Co., 1972.

McCrae, P. L., Branch, C. L., & Milner, B. The occipital locus and cerebral dominance. Neurology, 1968, 18, 95-98.

McFie, J., Piercy, M. F., & Zangwill, O. L. Visual-spatial agnosia associated with lesions of the right hemisphere. Brain, 1950, 73, 167-190.

McGlone, J., & Davidson, W. The relation between cerebral speech laterality and spatial ability with special reference to sex and hand preference. Neuropsychologia, 1973, 11, 105-113.

McGlone, J., & Kertesz, A. Sex differences in cerebral processing of visuospatial tasks. Cortex, 1973, 9, 313-320.

Miller, E. Handedness and the pattern of human ability. British Journal of Psychology, 1971, 6, 111-112.

Milner, B., Branch, C., & Rasmussen, T. Evidence for bilateral speech representation in some non-right handers. Trans. Amer. Neurol. Ass., 1966, 91, 306-308.

Nachshon, I., & Carmon, A. Hand preference in sequential and spatial discrimination tasks. Cortex, 1975, XI, 123-143.

Natale, M. Perception of nonlinguistic auditory rhythms by the speech hemisphere. Brain and Language, 1977, 4, 32-44.

Nebes, R. D. Handedness and the perception of part-whole relationships. Cortex, 1971, 7, 350-356.

Nebes, R. D. Superiority of the minor hemisphere in commissurotomizes more for the perception of part-whole relations. Cortex, 1971, 7, 333-349.

Newcombe, F., & Ratcliffe, G. Handedness, speech lateralization and ability. Neuropsychologia, 1973, 11, 399-407.

Nie, N. H., Hull, C. H., Jendins, J. G., Steinbrenner, K., and Bent, D. H. Statistical Package for the Social Sciences, Second Edition. New York: McGraw-Hill Book Co., 1975.

Nunnally, J. C. Introduction to Psychological Measurement. New York: McGraw-Hill Book Co., 1970.

Oldfield, R. C. The assessment and analysis of handedness: The Edinburgh Inventory. Neuropsychologia, 1971, 9, 97-113.

Olson, M. Laterality differences in tachistoscopic word recognition in young normal and delayed readers. Neuropsychologia, 1973, 11(3), 393-351.

Orbach, J. Retinal locus as a factor in recognition of visually perceived words. American Journal of Psychology, 1953, 65, 555-562.

Orlando, C. Relationships between language laterality and handedness in eight and ten-year old boys. Unpublished doctoral dissertation. University of Connecticut, 1971.

Paterson, A., & Zangwill, D. L. Disorders of visual space perception associated with lesions of the right cerebral hemisphere. Brain, 1944, 67, 331-358.

Provins, K. A., & Cunliffe, P. The reliability of some motor performance tests of handedness. Neuropsychologia, 1972, 10, 199-206.

Rosenweig, M. R. Representations of the two ears at the auditory cortex. American Journal of Physiology, 1951, 167, 147-158.

Russell, W. R., & Espir, M. L. E. Traumatic Aphasia. London: Oxford University Press, 1961.

Satz, Paul. Laterality effects in dichotic listening. Nature, 1968, 218, 277-278.

Satz, P. Laterality tests: An inferential problem. Unpublished manuscript, 1975.

Satz, P., Achenbach, K., & Fennell, E. Correlations between assessed manual laterality and predicted speech laterality in a normal population. Neuropsychologia, 1967, 5, 295-310.

Satz, P., Achenbach, K., Pattishall, E., & Fennell, E. Order of report, ear asymmetry and handedness in dichotic listening. Cortex, 1965, 1, 377-396.

Schell, B., & Satz, P. "Nonverbal" visual half-field perception and hemispheric asymmetry. Proceedings 78th Annual Convention, APA, 1970, part 1, 187-188.

Searleman, A. A review of right hemisphere linguistic capabilities. Psychological Bulletin, 1977, 84(3), 503-528.

Semmes, J. Hemispheric specialization: A possible clue to mechanism. Neuropsychologia, 1968, 6, 11-26.

Shankweiler, D. Effects of temporal lobe lesions on recognition of dichotically presented melodies. Journal of Comparative and Physiological Psychology, 1966, 62, 115-119.

Shankweiler, D., & Studdert-Kennedy, M. A continuum of lateralization for speech perception. Brain and Language, 1975, 2(2), 212-225.

Spellacy, F. J. Lateral preferences in the identification of patterned stimuli. Journal of the Acoustical Society of America, 1970, 47(2), 574-578.

Sperry, R. W.; Gazzaniga, S., & Bogen, J. E. Interhemispheric relationships: the neocortical commisures; syndromes of hemispheric disconnection. In P. J. Vinken & G. W. Bruym (Eds.), Handbook of Clinical Neurology (Vol. 4). Amsterdam: North Holland Publishing Co., 1973, pp. 273-290.

Studdert-Kennedy, M., & Shankweiler, D. Hemispheric specialization for speech perception. The Journal of the Acoustical Society of America, 1970, 48(2), 579-593.

Subirana, A. Handedness and cerebral dominance. In P. J. Vinken and G. W. Bruym (Eds), Handbook of Clinical Neurology (Vol. 4). Amsterdam: North Holland Publishing Co., 1973, pp. 248-272.

Teng, E. L.; Yang, P. L. K.; & Chang, P. T. Handedness in a Chinese population: Biological, social and pathological factors. Science, 1977, 193, 1148-1150.

Terrace, H. The effects of retinal locus and attention on the perception of words. Journal of Experimental Psychology, 1959, 58, 382-385.

Thompson, A. L., & Marsh, J., Jr. Probability sampling of manual asymmetry. Neuropsychologia, 1976, 14, 217-223.

Tunturi, A. R. A study of the pathway from the medial geniculate body to the acoustic cortex in the dog. American Journal of Physiology, 1946, 147, 311-319.

Wada, J. A new method for the determination of the side of cerebral speech dominance. A preliminary report on the intracarotid injection of sodium amytal in man. Medical Biology, 1949, No. 14, p. 221.

Wechsler, D. Manual for the Wechsler Adult Intelligence Scale. New York: The Psychological Corporation, 1955.

White, M. J. Laterality differences in perception: a review. Psychological Bulletin, 1969, 72, 387-405.

Witelson, S. F., & Pollie, W. Left hemisphere specialization for language in the newborn: neuroanatomical evidence of asymmetry. Brain, 1973, 96, 641-646.

Wyke, J., & Ettlinger, G. Efficiency of recognition in the left and right visual fields. Archives of Neurology, 1961, 5, 659-665.

Zangwill, O. Cerebral Dominance and its Relation to Psychological Function. London: Oliver and Boyd, 1960.

Zurif, E. B., & Bryden, M. P. Familial handedness and left-right differences in auditory and visual perception. Neuropsychologia, 1969, 7, 179-187.

Appendix A

Stimuli for the Dichotic Listening Test

1.	pack	tent	cat	port	tea	cow
2.	fame	sum	bond	fur	sale	bee
3.	duck	ship	gas	deck	shoe	gun
4.	vine	zone	mob	vane	zoo	meal
5.	nose	pride	track	name	plate	trail
6.	coast	flight	sake	corn	fleet	sunk
7.	bowl	damp	good	bell	deed	game
8.	shine	vent	zest	sheep	vast	zeal
9.	mass	nine	pin	mill	nail	pace
10.	tin	cloth	faith	torn	clock	fresh
11.	spit	belt	night	speak	bark	need
12.	shell	guard	volt	shore	guest	vault
13.	there	mad	nick	though	map	note
14.	pig	teeth	crust	pal	tongue	cream
15.	fault	sand	brain	flag	send	blown
16.	ditch	glow	shirt	dawn	give	shift
17.	view	this	mouth	vim	then	mink
18.	noon	pork	tan	noun	pan	top
19.	cord	fit	stamp	coop	fog	style
20.	bank	noise	glove	birth	neck	grain
21.	sheet	voice	than	shame	verb	that
22.	mine	nice	cord	male	nudge	coop

Appendix B

As an instrument for the measurement of verbal and spatial abilities, the WAIS (Wechsler, 1955) has several advantages. It is well standardized and reliable, and factor analysis studies have demonstrated the Verbal and Performance factors to be robust. Studies carried out with brain damaged patients have shown that the Performance IQ is depressed with right hemisphere damage and the Verbal IQ is depressed with left hemisphere damage, lending support for the use of the WAIS to compare tasks which are normally controlled by the right or the left hemisphere.

Other tests than the WAIS yielding verbal and nonverbal IQ's may provide more "pure" measures of verbal and spatial processing ability but are not without drawbacks: e.g., Guilford's tests while based on factor analysis and designed as "pure" tests tend to show higher correlations between tests measuring dissimilar abilities than between tests measuring similar abilities (Cronbach, 1970). The California Test of Mental Maturity provides verbal and nonverbal IQ's but according to Cronbach (1970) there is little evidence to indicate the practical significance of differences between the two IQ's. The Primary Mental Abilities Tests, which developed out of Thurstone's factor analytic work, includes tests of factors (Verbal Comprehension and Verbal Fluency) which might be used as measures of verbal ability, and a test of Spatial Orientation which might be used as a test of spatial ability, but reliablity is low for some tests (e.g., Word Fluency: $r = .72$) and correlations between tests representing different factors are unsatisfactorily high (Nunnally, 1970). While other tests of intellectual, or cognitive, functioning which yield separate scores for verbal and spatial abilities are available, the WAIS is superior in terms of reliability, subtest intercorrelations and standardization.

Since short forms of the WAIS, which may include two or more subtests, generally correlate at .90 or above with full WAIS IQ scores (Matarazzo, 1972) four WAIS subtests were considered sufficient for the purposes of this study. The tests of verbal ability, Vocabulary and Similarities, are highly reliable ($r = .95$ and $r = .86$, respectively) and correlate well with the Verbal IQ score ($r = .86$ and $r = .80$). The spatial tests, Block Design and Object Assembly, are reliable ($r = .84$ and $r = .70$) and correlate well with the Performance IQ ($r = .83$ and $r = .80$).

Appendix C

To test handedness - cognitive abilities hypotheses, handedness has been defined by Manual Skill difference scores (MS). MS can be treated as a continuous variable or partitioned to form a discrete variable of two or more levels. Partitioning a continuous variable in order to achieve a factorial design is problematic for the following reasons: a) Partitioning a continuous variable results in loss of variance and therefore a lower probability of significant results; b) Partitioning MS will inevitably result in unequal *n*'s; c) Because females commonly score lower on spatial tests than males, the Sex effect has to be controlled for. The result of b) and c) is a factorial design with unequal *n*'s.

If MS is not partitioned but retained as a continuous variable, the problem of interpreting the results of an unequal *n*'s factorial analysis is avoided. Since multiple regression will handle both categorical and continuous variables and interactions between them, this method was used to test hypotheses three and four. The steps of this procedure are listed below.

a) A multiple regression analysis tests the overall effect of the variables MS, Sex, and the MS x Sex interaction on spatial ability (or the verbal-spatial disparity). The resulting squared multiple correlation is the total percentage of variance accounted for by the relationship between the independent variables and the dependent variable. The squared multiple correlation is tested for significance by the following *F* ratio:

$$F = \frac{R^2_{SA.S,MS,SMS})/K}{(1 - R^2_{SA.S,MS,SMP})/(N-k-1)}$$

where *R*^{2} is the squared multiple correlation coefficient, *SA* is the criterion or dependent variable, *S* is the Sex variable, *MS* is the MS variable and *SMS* is the Sex by MS interaction. *N* is the total number of subjects and *k* the total number of predictors, or independent variables.

If the *F* value is not significant the analysis is terminated here. If the overall percentage of variance accounted for is significant, the next step is a test of the Sex by MS interaction.

b) A second regression analysis is performed, omitting the interaction variable. The difference between the two *R*^{2} values represents the interaction effect and is tested by the following *F* ratio:

$$F = \frac{(R^2_{SA.S,MS,SMS} - R^2_{SA.S,MS})/(k_1-k_2)}{(1 - R^2_{SA.S,MS,SMS})/(N-k-1)}$$

The interaction represents differences between Males and Females in the slopes of the MS - Spatial Ability regression lines. If the interaction is significant, separate regression equations are necessary for Males and Females. If the interaction is not significant, the effect of the continuous variable, MS is tested.

c) The MS effect is tested by performing a regression of Sex on Spatial Ability and subtracting the $\underline{R}^2$ value from the $\underline{R}^2$ for the multiple regression which includes both Sex and MS. The resulting $\underline{R}^2$ represents the effect of MS with the Sex effect partialled out. That is, variance in Spatial Ability that is shared by Sex and MS is removed. The $\underline{R}^2$ is tested by the following $\underline{F}$ ratio:

$$F = \frac{(R^2_{SA.S,MS} - R^2_{SA.S})/(k_1-k_2)}{(1 - R^2_{SA.S,MS})/(N-k-1)}$$

d) The final test is a test of differences in the intercepts, or the elevation of the MS - Spatial Ability regression lines for Males and Females. The Sex effect is tested by performing a regression of MS on Spatial Ability and subtracting the $\underline{R}^2$ value from the $\underline{R}^2$ for the multiple regression of Sex and MS on Spatial Ability. The resulting $\underline{R}^2$ is tested by the $\underline{F}$ ratio:

$$F = \frac{(R^2_{SA.S,MP} - R^2_{SA.MP})/(k_1-k_2)}{(1 - R^2_{SA.S,MP})/(N-k-1)}$$

In summary, this series of regression analyses yields the overall percentage of variance accounted for, the percentage of variance accounted for by the Sex by MS interaction, and the percentage of variance accounted for by the Sex and MS effects. Each effect can be tested for significance by the appropriate $\underline{F}$ ratio, as illustrated (Kurlinger and

Pedhazur, 1973; Nie, Hull, Jenkins, Steinbrenner, and Bent, 1975).

Appendix D

Glossary of Terms and Abbreviations

agnosia - inability to attach meaning to sensory impressions.

aphasia - a disorder of speech which may occur as an inability to understand speech and/or an inability to use speech.

apraxia - the inability to manipulate or to deal intelligently with objects.

cognitive abilities - the term is used to refer jointly to: verbal reasoning ability which is generally under the control of the left hemisphere and visuospatial reasoning ability which is generally under the control of the right hemisphere.

EA - subjects' ear advantage on the dichotic listening test computed via the formula: $R-L/\sqrt{R+L\,[2T-(R+L)]}$

hemispheric dominance - traditionally, the term has referred to the greater control of the left, or major, hemisphere for language processing--and, by inference, all cognitive processing. The right, or minor, hemisphere is now known to play a controlling role in visuospatial perception and appears to be essential to spatial reasoning ability.

hemispheric lateralization - also refers to unilateral hemispheric control of functions such as speech, manual skill and visuospatial processing but implies variation in degree of asymmetrical control.

hemispheric specialization - the mechanism proposed by Semmes (1968) and adopted by Shankweiler and Studdert-Kennedy (1974) to underlie the greater control of one hemisphere for behaviors requiring fine sensorimotor control, such as manual skills and speech.

MS - the term refers collectively to the subjects' right minus left hand scores on five manual skill tests computed via the formula: $MS = R-L/\sqrt{R+L}$ where R = right hand score and L = left hand score.

SC - subjects' self-classification as right or left handed.

SL - strongly lateralized - unilateral left hemisphere control of speech and manual skill (see WL).

VHF - visual half-field. Stimuli can be presented tachistoscopically separately to the right VHF, which projects to the left hemisphere, or to the left VHF, which projects to the right hemisphere.

WL - weakly lateralized - refers to a lesser degree of unilateral left hemisphere control of manual skills and speech, or a tendency toward bilateral hemispheric control of these processes.

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Title of Thesis

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