Bilateral Cerebral Activation in Relation to Verbal and Spatial Task Performance, Sex and Handedness

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by

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ABSTRACT

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Katherine J. Schultz

The existing literature on cerebral hemispheric activation focuses primarily on the asymmetric role of the left and right hemispheres in verbal and spatial task performance. However, a number of authors have suggested that for certain subject groups, bilateral hemispheric activation is associated with verbal or spatial processing. The conceptualizations of bilaterality posited by Buffery and Gray, Annett and Levy are considered in the present study. Each of these authors speculates that bilateral cerebral activation is most likely to occur in specific sex and handedness groups. Further, these authors each posit that bilaterality is associated with specific levels or patterns of task performance.

The present study evaluates bilateral cerebral activation by assessing changes from baseline electroencephalographic (EEG) alpha duration concomitant with verbal and spatial task performance, and by comparing left to right hemisphere alpha ratios during verbal and spatial performance. Male and female undergraduates who exhibit either strong right preferences in handedness, footedness, eyedness and earedness and complete reported familial dextrality, or who have mixed, left and right, peripheral laterality preferences served as subjects. On the basis of EEG alpha criteria, three subject groups were identified for each task and method of analysis. These groups were (a) bilateral cerebral activation, (b) left hemisphere activation, and (c) right hemisphere

activation. Task performance on synonym and circle matching tasks was assessed by the number of problems answered correctly and by response latencies.

Discriminant analyses in which laterality was defined as a task concomitant change from baseline activation provided virtually no support for prevailing conceptualizations of bilaterality. However, those analyses which defined laterality in terms of activation ratios provided strong support for the concepts advanced by Annett and moderate support for those of Levy and Buffery and Gray.

Overall, the results emphasize the importance of peripheral laterality, verbal and spatial performance and sex in the discrimination of cerebral laterality groups. Further, a strong link between verbal, but not spatial, laterality and both verbal and spatial performance was found. Finally, the disparate findings of the analyses suggest that subject sex and peripheral laterality determine the specific cerebral activation patterns found during task performance.

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CHAPTER I

REVIEW OF THE LITERATURE

It is generally acknowledged that the left and right cerebral hemispheres differ in cognitive processing capabilities, with the left hemisphere being more proficient in verbal processing, the right in spatial. While left hemisphere proficiencies can alternately be described as linguistic, verbal, logical and analytic, those of the right hemisphere can be labelled visuospatial, nonverbal, preverbal and synthetic (Thompson, 1975). However, this clear division of competencies may in fact be restricted to a minority of individuals; although a great deal of evidence, gathered by a variety of techniques, does support an asymmetric role for the cerebral hemispheres in cognitive processing, the universality and importance of these functional asymmetries has yet to be fully established.

That functional differences existed between the two grossly, anatomically similar cerebral hemispheres was known at least as early as 3000 B.C. (Cadwallader, Semrau and Cadwallader, 1971) but it was not until the last century that detailed study of this asymmetry was begun. By the 1860's, observations of patients with unilateral brain disease by Dax, Broca, Wernicke and others had indicated a major role for the left hemisphere in speech processing, particularly for right-handed individuals (Young, 1970). This assertion was subsequently expanded from dominance of the left side of the brain for speech and skilled movement to prepotence of this hemisphere for most cognitive processes. Although Jackson (1958) warned in 1876 that the right cerebral hemisphere could play a special role in visual ideation, this possibility was generally disregarded until the Second World War, when patients with well-localized brain lesions were available for systematic study and the role of the right hemisphere in spatial ideation was revealed (Luria, 1980).

Asymmetric roles for the cerebral hemispheres in cognitive processing have been further confirmed by the surgical approaches of Penfield, Sperry, and their colleagues (Gazzaniga & Sperry, 1967; Penfield, 1975; Penfield & Roberts, 1959; Sperry, 1974; Sperry, Gazzaniga & Bogen, 1969). Penfield mapped cortical function during surgical removal of scarred brain tissue implicated in focal epileptic seizures by applying a threshold electrical current to the exposed cortex of conscious, locally anesthetized patients. Stimulation of the dominant language controlling hemisphere produced either spontaneous vocalization upon stimulation in the region of Broca's area, or cessation of ongoing vocalization during stimulation of Wernicke's area. Further, Penfield (1975) reported that in the 522 patients studied, the left hemisphere was generally dominant.

Sperry's (1974) work with commissurotomized individuals, in whom the corpus callosum, the major fiber tract joining the two cerebral hemispheres, had been severed, provides striking additional information on cerebral asymmetry for spatial and language processing. Restricting sensory input and motor output to only one hemisphere, Sperry clearly demonstrated the contrasting specializations of the two sides of the brain. When sensory input was confined to the left hemisphere, patients were able to name and decribe the input but were unable to manually identify it with the right hand. Conversely, when the input was confined to the right hemisphere it could only by identified manually, but not verbally. Further, when disparate stimuli were presented to the two isolated cerebral hemispheres and a verbal response required, left hemisphere input was identified. If however, a manual response were required, stimuli presented to the right hemisphere were reported (Gazzaniga & Sperry, 1967). The right hemisphere's role in spatial processing was further supported by examination of the manual performance of commissurotomized patients on tasks involving matching or reproducing spatial patterns. Such tasks were performed in a superior manner by the left hand, which is controlled primarily by the motor center of the right hemisphere, and were not performed at all by the right hand (Bogen & Gazzaniga, 1965). While lesion and surgical intervention studies document the direction of functional brain asymmetry, tachistoscopic and dichotic listening studies with neurologically intact subjects have further articulated the concept of function lateralization.

In a standard tachistoscopic procedure an individual is required to fixate visually on a point straight ahead while a stimulus is flashed briefly to the left or right of that point (Springer, 1977). Since the stimulus is presented just off midline, thus falling on the nasal portion of one retina and the temporal portion of the other, visual information is presented to only one cerebral hemisphere. Brief stimulus exposure precludes saccadic eye movements and the shifting of the retinal image into both hemispheres.

Although there is no simple auditory equivalent of the tachistoscopic presentation procedure, as the eighth nerve projects to both the contralateral and ipsilateral auditory cortex, the dichotic listening procedure (Kimura, 1961) does permit initial input lateralization. In this technique, two different messages are presented simultaneously, one to each ear. Following such presentation, the material from one ear is reported more accurately. This reporting bias is interpreted as resulting from suppression of the ipsilateral auditory pathway when such conditions of competition exist. Thus, subjects' reports would represent only the input of the contralateral pathway, and the stimuli accurately reported would be those presented to the ear contralateral to the dominant hemisphere.

Both tachistoscopic and dichotic listening techniques document, for normal individuals, the same directions of lateralization that have been found for persons in the lesion and surgical intervention studies. Once again, the left hemisphere is found to process verbal information while the right deals with spatial data. Thus, for example, the left hemisphere has been found to be more efficient in reporting letters (Bryden, 1973), determining initial letters of an object name (Klatzky & Atkinson, 1971), recognizing nonsense syllables (Kimura, 1973) and processing nonsense words when they are presented within phrase structures (Zurif & Mendelsohn, 1972), while the right hemisphere has been found to be more proficient in facial recognition (Rizzolatti, Umilta & Berlucchi, 1971), recognition of melodies (Kimura, 1964), and matching on the basis of physical characteristics (Gibson, Dimon, & Gazzaniga, 1972).

These techniques have also been used to provide evidence for functional asymmetry in neonates and infants. Nagafuchi (1970) has documented right-ear language superiority in children as young as three years, while Entus (1977) has used a modified dichotic technique to support right-ear language superiority in infants with an average age of 50 days but this result was not replicable (Vargha-Khadem & Corballis, 1979). However, the examination of evoked potentials has also provided evidence of functional asymmetry in infants. Molfese and his colleagues (Molfese, Freeman & Palermo, 1975) have found that when speech sounds are presented to infants from one week to ten months of age, nine of the ten infants studied generated left hemisphere evoked potentials of greater amplitude. Such potentials would be indicative of greater left hemisphere involvement in processing of speech sounds. Thus, a large body of research has documented the existence of functional cerebral laterality and the ubiquity of this functional asymmetry has been further reinforced by reports of anatomical asymmetries in brain regions important for speech and language.

Geschwind and Levitsky (1968) reported that in a sample of 100 adult brains examined post-mortem, the temporal plane was larger in the left hemisphere for 65%, larger in the right hemisphere for 11% and not different in 24% of the sample. These findings have subsequently been confirmed in studies of over 200 additional brains. Seventy percent of the brains in these combined samples exhibited asymmetry characterized by a larger left temporal plane (Wada, Clark & Hamm, 1975). Similar asymmetry has also been documented in fetal and infant brains. Chi, Dooling and Giles (1977) report that in 207 brains aged from ten to forty-four weeks post-conception, the left temporal plane was longer in 54% while the right temporal plane was longer in 18% and no difference was found in 28% of the brains examined. Wada et al (1975) also found that of 100 fetal brains examined (mean age of 48 weeks post-conception), the left temporal plane was longer in fifty-six percent, while the right plane was longer in twelve percent, and there was no notable difference in thirty-two percent. Further evidence of anatomical asymmetry has been reported by Ratcliff, Dila, Taylor and Milner (1980). The posterior Sylvian branches of the middle cerebral artery were examined on the carotid angiograms of 59 patients in whom language lateralization had been established in sodium amytal studies. These vessels were found to be asymmetric in patients with left hemisphere speech representation but little evidence of asymmetry was found in patients with language localized bilaterality or in the right hemisphere.

Although much evidence supports functional cerebral lateralization, cognitive processing asymmetry is also believed to be moderated by other factors. Kinsbourne (1970) has suggested that the basic pattern of lateralization, established as the result of numerous physiological and environmental factors, may be exaggerated or obscured by shifts of attention between the hemispheres. That is, when the left hemisphere is activated, its superiority in processing of linguistic material becomes more marked, but its processing advantage diminishes if the right hemisphere is also activated. Conversely, right hemisphere activation would enhance spatial processing while concurrent left hemisphere activation would disrupt right hemisphere spatial processing. Investigations of this hypothesis have attempted to activate the hemispheres selectively using motor responses, sensory input and memory loads. The conclusions drawn from this research do not lend strong support to Kinsbourne's hypothesis (Allard & Bryden, 1979; Boles, 1979; Cohen, 1975; Springer &

Deutsch, 1981). Stronger evidence exists for the moderating influences of handedness and sex on cerebral asymmetry.

The importance of handedness and sex to the functional organization of the cerebral hemispheres has long been of interest to researchers. The early work of Bouilland, Broca (cited in Young, 1970) and Jackson (1958) discussed the relation of the "language" hemisphere to handedness, noting the high frequency with which control for both language and handedness was located in the left cerebral hemisphere. Clinical evidence has continued to suggest that cerebral dominance for language functions is reliably related to handedness. Approximately 97% of right-handed dysphasics have left hemisphere lesions or trauma (Rasmussen & Milner, 1975; Zangwill, 1967), thus strongly linking dextrality with left hemisphere language dominance. However, for nonright-handed individuals, the pattern of cerebral dominance is much less clear. For example, Rasmussen and Milner (1975) report that of 112 left-handers for whom speech dominance was established using sodium amytal injections to the carotid artery (Wada, 1949), 70% had left hemisphere, 15% right hemisphere and 15% bilateral speech representation. This result clearly indicates that a much more complex relation between handedness and cerebral language dominance exists for left - than for right-handers. In an analogous manner, complicated patterns of cerebral functional representation have emerged in relation to the sex of the subject.

Clinical studies reveal differences in functional laterality for males and females. For example, McGlone (1977), following a systematic examination of the relation between sex and functional asymmetry in right-handed adults with strictly unilateral brain lesions, reported that the incidence of aphasia following left hemisphere lesion was three times as great in males as in females. Further, when aphasics were removed from the sample, only males with left hemisphere damage, when compared to males with right hemisphere damage, showed the expected pattern of depressed verbal intelligence and verbal memory loss. No such significant differences emerged, however, when females with left and right hemisphere lesions were compared. Such results suggest that males are more likely than females to be strongly left hemisphere dominant for speech functions and that some lesser degree of left hemisphere language dominance, perhaps even bilateral dominance, may be typical for women. Similarly, when spatial abilities are examined, performance decrements are greater for males than for females following right hemisphere lesion (Bogen, 1969; Lansdell, 1968a,b; McGlone & Kertesz, 1973).

When synthesized, such findings on handedness and sex support the generally acknowledged role of the left hemisphere in language and the right hemisphere in spatial processing, but primarily only for right-handers and/or males. Further, the findings are not straightforward for non-right-handers and females. Consequently, a number of hypotheses have been advanced, positing alternate patterns of functional lateralization and the existence of bilaterality for these subjects groups.

Bilaterality

Conceptualizations of bilaterality propose that, for certain individuals, under certain conditions, both cerebral hemispheres are involved in cognitive processing. Varying propositions of bilaterality have been independently advanced by Buffery and Gray (1972), Annett (1964; 1967; 1972; 1978) and Levy (1969; 1974).

Buffery and Gray. The Buffery and Gray (1972) conceptualization of lateralization and performance is derived primarily from the experimental investigations of Buffery, who first hypothesized (1970) that the lateralization of cerebral dominance for language occurs earlier in human females than in males, and from the work of Gray (1971), describing general sex differences in the emotional and cognitive behaviour of mammals. These works, in conjunction with a series of studies by Buffery (1970, 1971a, 1971b, 1971c), resulted in the formation of a conceptualization of functional asymmetry.

The research base for these concepts consists primarily of two series of experiments, one on verbal and one on spatial performance, reported by Buffery in the early 1970's (1970, 1971a, 1971b, 1971c). In the studies of verbal performance, concurrent visual and auditory verbal stimuli were presented to subjects whose task was to identify these words as the same or different. The visual stimuli were tachistoscopically presented binocularly to the right or left visual half-fields and the auditory stimuli were presented to the right or the left ear. The subjects in this investigation were 48 right-handed children, matched in IQ and socio-economic status. There were eight boys and eight girls at each of three age levels; five, six and seven years. Buffery reports that accuracy was greatest when the auditory stimulus was presented to the left hemisphere and the visual stimulus presented to the right hemisphere. The next highest level of accuracy occurred when both simuli were presented to the left hemisphere. The third highest accuracy was obtained when the auditory simulus was presented to the right hemisphere and the visual stimulus to the left hemisphere. Finally, subjects were least accurate when both stimuli were presented to the right hemisphere. These accuracy differences, however, were statistically significant only between the most and the least accurate conditions. Buffery and Gray further observed that this pattern of significant verbal results was more marked in girls than in boys, occurring in girls at all age levels but occurring in boys only at age seven.

Spatial functioning (Buffery, 1970; 1971c) was studied in 160 right-handed children, twenty boys and twenty girls at each of four age levels: three through four years, five through six years, seven through eight years, and nine through ten years. Each child was asked to draw, simultaneously a square with one hand and a circle with the other, with eyes closed. The task was then repeated so each child drew each figure with the dominant and non-dominant hand. The drawings of the squares were subsequently scored for the degree of deviation of the actual square from an ideal square constructed in relation to the first line drawn of the actual square. The majority of girls at all ages exhibited a non-preferred, left-hand superiority for drawing well proportioned squares. It was only at seven years, however, that boys changed from a preferred, right-hand superiority to a non-preferred, left-hand superiority. Additionally, girls from three to seven years of age exhibited a greater degree of right-hand preference than did boys in these age groups. Finally, for both sexes, the degree of non-preferred, left-hand superiority over the preferred right-hand increased with the degree of right-hand preference, which itself increased with age.

Taken together, these studies led Buffery and Gray to postulate that the originally bilateral neural activity which mediates linguistic skill lateralizes progressively over the early years, generally to the left cerebral hemisphere. This hemisphere contains a relatively dormant but structurally predisposed speech perception mechanism which exists to subserve language functions. Further, this proposed speech perception mechanism is hypothesized to be more developed in the female brain than in the male brain in children of the same age. This early development allows the lateralization of language to occur earlier and to progress more quickly in girls than in boys. As a result of this early lateralization, the non-dominant, usually right, hemisphere of the female will be freer to subserve non-verbal functions than is the non-dominant hemisphere of the male. This pattern of lateralization would further be linked to performance differences.

In discussing performance, Buffery and Gray suggest that sex differences in the lateralization of cerebral dominance for linguistic skill may contribute to the general finding of a female superiority in verbal tasks and a male superiority in spatial tasks. Linguistic skill, with its need for quick associations and serial ordering, would, according to this conceptualization demand fast and intricate neural mechanisms. Such mechanisms could benefit from being subserved by specific structures with a clearly lateralized and localized cerebral representation and this is apparently more likely in the female than male brain. Spatial skill, however, which is usually exercised in a three dimensional world, would benefit from a more bilateral cerebral representation. Thus, the authors speculate, a consequence of the less well-lateralized cerebral representation of language in the male brain might be a more bilateral cerebral representation of spatial skill than can be achieved in the female brain.

In summary, this conceptualization of laterality proposes a high degree of language lateralization and resultant good verbal performance for females, and a high degree of spatial bilateralization and resultant good spatial performance for males.

Annett. A second conceptualization of bilaterality relates this pattern of cerebral activation to performance and handedness rather than to sex. Annett (1967, 1972, 1978) postulates a two-factor (genetic and environmental) basis for handedness and cerebral laterality. She suggests (Annett, 1964) that human handedness is determined by two alleles, one, D, which manifests right-handedness and the second, R, which manifests left-handedness. D is usually dominant and R is usually recessive, but there is partial penetrance of R in heterozygotic individuals, making them less strongly right-handed than homozygotic individuals. Annett further postulated that cerebral dominance for language is closely linked with handedness, so that dominant homozygotes are consistant right-handers, with speech more highly developed in the left hemisphere, while recessive homozygotes are consistent left-handers, with speech mainly in the right hemisphere. However, in the absence of homozygosity, there is less inherited bias toward right-handedness and the second factor, environmental influence, subsequently establishes handedness. For heterozygous individuals, speech will be represented in both the left and the right hemispheres and handedness will be mixed.

As a consequence of this lack of cerebral specialization, mixed-handers perform less well on language tasks than do right-handers.

Annett's subsequent work has been primarily concerned with validating her genetic model through the assessment of the degree of handedness and unimanual skill evidenced in both children and adults (Annett, 1967; 1972; 1978). However, Annett (1964) does address spatial performance in relation to children with unilateral epileptic foci and mixed hand preferences. She suggests that such children tend to have verbal functions localized in the impaired hemisphere so that the biologically more crucial skills or orientation in space can be developed in the opposite, normal hemisphere. Such a pattern of development could account for the greater verbal, compared to spatial, impairment found in these children following hemispherectomy.

Miller (1971) has extrapolated from Annett's proposals to mixed-handed adults, predicting that mixed-handers would exhibit better visuo-spatial than verbal functioning. Further, he hypothesizes that the spatial performance of mixed-handers would be on a par with that of consistent right- or left-handers, but verbal functioning would be impaired in mixed-handers, relative to other handedness groups. This mixed-handed performance pattern would result from competition for the neurological substrates which underlie these behaviours. However, spatial functions would take precedence and be unimpaired in mixed-handers, while verbal functions for this group would be limited.

<u>Levy</u>. A third conceptualization linking bilaterality to subject characteristics and performance has been proposed by Levy (1969; 1974; Levy & Gur, 1980). This view of the relation between laterality and

performance has evolved from studies of both normal and commissurotomized individuals. Levy (1969, 1974) reports right hemisphere involvement in spatial processing following a study of the performance of six split-brain patients on a modified version of the Space Relations Subtest of the Differential Aptitude Test (Bennett, Seashore, and Wesman, 1947). In this task subjects were required to match a three-dimensional block with an unfolded two-dimensional representation of that form. The block was examined out of sight using one hand and the subject subsequently pointed with the same hand to the block's matching pattern. Of six patients studied, three with right hemisphere damage were unable to perform the task. Two of the remaining three subjects performed at a level greater than chance when using the left hand, right hemisphere, but not when using the right hand, left hemisphere. The third patient performed at a level above chance with both hands, but was vastly superior using the left. This pattern of performance established a clear role for the right hemisphere in spatial processing.

The relation of verbal and spatial performance to handedness in normal subjects was investigated using 10 left-handed and 15 right-handed graduate science students at the California Institute of Technology (Levy, 1969). Performance was assessed using the Wechsler Adult Intelligence Scale. Dextrals and sinistrals did not differ in Verbal performance, but the left-handers scored significantly lower on the Performance scale than did the right-handers. Additionally, sinistrals performed significantly more poorly on the Performance scale than they did on the Verbal scale, but no such difference was found for dextrals.

In a third study leading to the formulation of Levy's hypothesis

(Levy & Reid, 1976), language dominance was evaluated using two tachistoscopic tasks for 48 subjects, 24 right-handers and 24 left-handers. These subjects were also classified as having either a normal or an inverted writing posture. In a normal writing posture, the hand is held below the line of writing and the pencil pointed toward the top of the page, while in an inverted posture, the hand is held above the line of writing and the pencil pointed toward the bottom of the page. Regardless of handedness, the tachistoscopic studies revealed that all subjects with a normal writing posture had language dominance in the hemisphere contralateral to the writing hand. Further, this study revealed a sex difference in lateralization. Sixty-six percent of the male, but only 31% of the female sinistrals exhibited an inverted writing posture. Thus, right hemisphere language dominance was more frequent in female left-handers than in male. Levy's conceptualization of bilaterality is based on these lines of evidence as well as on Gur's finding (cited in Levy & Gur, 1980) linking eyedness and performance. Gur reports that among right-handed males, those who are right-eyed manifest a strong right visual field superiority for verbal material and a strong left field superiority for spatial material, whereas, those who are lefteyed, though having left field spatial superiority, show no significant asymmetry for verbal stimuli.

Thus, research on which Levy's premises were based has thus shown that the right hemisphere is frequently involved in spatial functions (Levy 1969; 1974), that left-handers, when compared to right-handers, perform less well on spatial tasks, that left-handed males perform less well on spatial tasks than they do on verbal tasks (Levy 1969); that left-handed females, compared to left-handed males, have a greater incidence of right hemisphere language localization (Levy & Reid, 1976); and that right-handed, right-eyed males have language and spatial functions localized in the left and right hemispheres, respectively, while right-handed left-eyed males have spatial function localized in the right hemisphere but exhibit verbal bilaterality (Levy & Gur, 1980). Levy (Levy & Gur, 1980) then considered these findings in conjunction with two additional sources of information. The first is the literature on sex differences in cognitive functioning. This literature (Harris, 1975; Maccoby & Jacklin, 1974) supports relative male superiority in visuospatial functioning and female superiority in verbal functioning. The second is additional work by Reid (cited in Levy & Gur, 1980) in which she reports that in 5- to 8-year old children with left hemisphere language, boys showed superior performance on a spatial task but not on a verbal task, whereas girls exhibited the reverse performance pattern. In children with right hemisphere language, boys displayed superiority on the verbal task, but not on the spatial task, while girls displayed superiority on the spatial task but not on the verbal. Additionally, girls with left hemisphere language performed better on a standardized test of verbal function than on one of spatial function, while boys had the opposite profile. Thus, a reverse pattern of sex-related differences was seen in children with right hemisphere language.

Finally, in considering these findings, Levy derives a number of hypotheses concerning the relation between sex, bilateral cerebral organization and performance. First, she suggests that bilateral representation of one function should produce incomplete specialization of the hemisphere mainly responsible for the other function. This laterality pattern will lead to high ability in the bilateralized function and low ability in the other. Given such a relation between performance and laterality, levels of performance are then indicative of laterality patterns. If this is true, and given the literature on sex differences in cognitive functioning and Levy's (1969) study of handedness and task performance, then, verbal functions would be bilaterally represented in females and perhaps left handers while spatial functions would be bilateralized in males and right handers. However, given the results of Reid, these laterality patterns would occur only when the main language hemisphere was the left. The reverse pattern of performance and laterality would occur when the main language hemisphere was the right. Levy further predicts, based on Gur's results, that eye dominance should act as a moderating variable in all patterns of brain laterality. When eye dominance is contralateral to the language hemisphere, the predicted associations should be most strongly manifested. However, when an ipsilateral relationship occurs, overall performance would be reduced and the predicted effects attenuated.

The three conceptualizations presented above all address the relation between bilateral cerebral representation of cognitive functions and task performance and handedness and/or sex. These relations can be summarized as follows:

1. Buffery and Gray: Bilateral spatial representation enhances spatial performance and exists in males, while lateralized language representation enhances verbal performance and exists in females.

2. Annett: Bilateral language representation diminishes language performance and exists in mixed-handers.

3. Levy: Bilateral spatial requirements enhances spatial performance, diminishes verbal performance and generally exists in right handers and males with left hemisphere language and right eye dominance. Bilateral language representation enhances language performance, diminishes spatial performance, and generally exists in left handers and females, but may also exist in right handed, left eyed males.

In order to evaluate these proposed relations, it is necessary to establish whether functional laterality or bilaterality exists, to evaluate spatial and language performance and to analyze these factors in relation to variations in handedness and sex. Much of the work relevant to these propositions has used tachistoscopic or dichotic listening techniques which evaluate verbal and/or spatial performance following lateralized task input and infer lateral or bilateral cerebral involvement on the basis of differences in performance. Even stronger support for lateralized or bilateral cerebral involvement can be obtained, however, using electrophysiological techniques.

EEG Techniques for Evaluation of Functional Asymmetry

Electrophysiological techniques provide a means of assessing hemisphere involvement in cognitive processing. In this approach, a cognitive task is presented and scalp-monitored electroencephalographic (EEG) activity is recorded during performance of this task. Such techniques have three major advantages over those which rely on lateralized sensory input. First, EEG activity can be monitored during ongoing task performance, since the presentation of task simuli is not time restricted, and thus, one may assess hemispheric involvement during relatively normal cognitive functioning. Second, these techniques measure hemispheric activity directly. Scalp recorded EEG activity reflects changes in the electrical potential of the underlying cerebrum (Frost, 1976), and these changes in potential reflect alterations in levels of awareness, mental activity and sensory-motor responsiveness (Shagass, 1972). Third, the use of EEG analysis allows for concurrent measurement of hemispheric activity and task performance, thus more directly examining this relation.

In order to measure lateral EEG activation during normal cognition, electrodes are positioned over homologous left and right hemispheric sites, referenced to a common, equidistant site, and the EEG activity is recorded. Electrode positioning generally follows the standard placement sites outlined in the International 10-20 System (Jasper, 1958). The recorded electrophysiological activity is subsequently evaluated for left, right asymmetries by examining interhemispheric frequency, amplitude or power differences in the total range of EEG or in selected frequency ranges (Shagass, 1972). The alpha frequency range (8 to 14 Hz) is commonly examined in such studies.

Alpha rhythms are a dominant phenomenon in cortical EEG, occurring during relaxed waking throughout the neocortex (Thatcher & John, 1977). It is generally suggested that through a complex system of feedback loops the thalamus functions as the pacemaker (Andersen & Andersson, 1968) or master synchronizer (Thatcher & John, 1977) of such rhythmic cortical activity. Further, Pribram (1971) has speculated that a cortical excitability cycle is associated with the waxing and waning phases of the rhythmic alpha waves, such that during resting alpha EEG of 10

Hz., alternating periods of maximum and minimum excitability would each occur only ten times a second. This pattern of cortical arousal differs from the almost continuous excitability that would be present during desynchronized EEG and could reflect a scanning mechanism.

The alpha rhythm has been found to be reduced or desynchronized during attentive mental activity (Marsh, 1978) and so is frequently examined in studies of cerebral involvement in cognitive processing. Lateral hemispheric involvement in task performance is generally inferred from reduced levels of alpha activity in the active, dominant, hemisphere as compared to the levels in the inactive, nondominant, hemisphere. Bilateral involvement would be reflected in a lessening of alpha activity in both hemispheres.

Butler, Crute and Glass (1977) have demonstrated that the analysis of EEG activation during task performance validly reflects cerebral dominance. In a study of 41 neurological patients, the hemisphere controlling language was initially established using either the sodium amytal test, or through an evaluation of behavioral deficits following lesion. Thirty-four individuals were found to be left hemisphere dominant for speech while seven were right dominant. Subsequently, it was determined that occipital EEG alpha power decreased over the dominant hemisphere during an analytic task, mental arithmetic, for all subjects.

The reliability of such EEG activity analysis has also been recently demonstrated in two separate studies. Amochaev and Salomy (1979) presented four cognitive tasks to six subjects on three separate occasions and found that five of the six subjects showed stable intrasubject alpha band suppression in the left hemisphere during verbal, analytic task performance and in the right hemisphere during visuospatial task completion. This was particularly true when the homologous hemispheric parietal recording electrodes (P_3 and P_4) were referenced to either the ear lobes (A_1 and A_2) or to the midline (C_3 and C_4), rather than to the vertex (C_z). Similarly, test-retest reliability was found by Ehrlichman and Weiner (1979) for an EEG alpha measure in a study of eleven subjects who each performed four verbal and four spatial tasks, while both the percentage of time in alpha and integrated alpha were measured. Significant reliability was found only for the integrated alpha measure, which takes both signal frequency and amplitude into account. This measure was found reliable both within and between subjects and was related to cognitive task demands in the expected direction. Although EEG activity analysis is a valid and reliable measure of laterality, a number of procedural constraints must be observed in order to ensure accurate assessment of task-related asymmetries.

The possibility of resting EEG asymmetry must be taken into account when assessing task-related changes. Many early investigators (e.g. Rancy, 1939; Strauss, Liberson & Meltzer, 1943) reported the presence of a greater amount of alpha activity in the right hemisphere during resting, non-task baselines. More recent investigations have also confirmed that during such non-task conditions, alpha activity is rarely symmetric in either amplitude or in phase (Remond, Leseure, Joseph, Rieger & Lairy, 1969). Indeed, Furst (1976) has demonstrated that the ratios of right to left hemispheric activity measured during non-task baseline periods are correlated with spatial task performance ($r = .51$) with nearly the same strength as is the ratio of activity recorded during actual task performance (r = .55). Ray, Newcombe, Semon and Cole (1981) have also reported such baseline and task correlations. Thus, it appears that subjects enter the test situation with varying degrees of activation in the right and left hemispheres and that these variations are related to cognitive task performance. However, it must be noted that resting EEG asymmetry is not unanimously reported (Butler & Glass, 1974). Although the existence of non-task EEG asymmetry has not been universally documented, the possibility of such asymmetry systematically biasing EEG activity assessed during task performance must be eliminated. For this reason Donchin, Kutas and McCarthy (1977) suggest that EEG activity recorded during task performance be compared to a subject's resting baseline EEG when evaluating asymmetry in task-induced activation changes.

It has also been suggested that the difficulty of the task may complicate the interpretation of EEG activation patterns. Galin, Johnstone and Herron (1978) reported that alpha power ratios increased as task difficulty increased, regardless of whether difficulty was assessed by performance or by subjective ratings. Further, this study found that for some subjects, the significant alpha power increase occurred only in the left or only in the right hemisphere, while for other subjects the increase was bilateral. Yet, conversely, both Dumas and Morgan (1975) and McLeod and Peacock (1977) have examined EEG activation in relation to task difficulty and found no relation. Thus, although the reports are not unanimous, the issue of task difficulty must be considered when interpreting functional laterality.

Two further methodological issues have been raised in connection with EEG analysis of functional laterality. First, Donchin et al (1977) have cautioned against the presentation of only ratio data when reporting relative hemispheric EEG activity since it is not possible to determine whether EEG changes reported in this fashion are due to modification of the numerator, the denominator or both. Thus, the nature of task related changes in EEG activation would be obscured.

Second, the possibility that requiring a motor response may bias hemispheric activation has been raised by Gevins, Zeitlin, Doyle, Yingling, Schaffer, Callaway and Yeager (1979). A performance measure is necessary to ensure a subject's participation in the requisite task during EEG recording and to enable cognitive processing to be assessed; but it is possible that such motor activity may influence hemispheric activation. However, in response to this issue, Butler (1980) reports preliminary findings which indicate that task-induced EEG asymmetries occur when there is no requirement for overt manual output and further, that when such unimanual output requirement is introduced, the asymmetry is unaffected.

Thus, within certain constraints, analysis of EEG activity provides a valid, sensitive and reliable means of assessing lateral cerebral involvement during task performance and as such, can be used to evaluate the extent of bilateral cerebral involvement in cognitive processing.

EEG Evidence of Functional Asymmetry

A number of studies have shown that the amount of alpha activity in one hemisphere relative to the other is task related. Morgan, McDonald and MacDonald (1971) found more alpha activity in the left versus the right hemisphere during performance of a spatial task, and more right hemisphere alpha activity during performance of verbal or analytic tasks. This finding was replicated by Morgan, MacDonald and Hilgard (1974) and similar findings have been reported by a number of other researchers as well. For example, Doyle, Ornstein and Galin (1974) analyzed differences in temporal and parietal EEG activity recorded during the performance of language, arithmetic, spatial and music tasks and found that both whole band EEG and, more strongly, alpha EEG power ratios reliably reflected the expected hemispheric involvement. Butler and Glass (1974) found similar task dependent EEG changes. Alpha EEG was found to be evenly distributed between the hemispheres when subjects were relaxed but was suppressed in the left hemisphere during the performance of mental arithmetic. Dumas and Morgan (1975) found that performance of left and right lateralized tasks was accompanied by alpha suppression in the hemisphere dominant for any particular task. Further, in an approach related to analysis of EEG changes during task performance, Furst (1976) examined ratios of integrated alpha activity during imaginal manipulation of visually presented forms and found that subjects with lower right/left (R/L) alpha ratios, that is, high right hemisphere activation, solved spatial problems more rapidly than did other subjects.

Thus, using alpha EEG analyses it has been possible to document asymmetries in cerebral hemispheric activation as a function of task performance. The range of tasks which has resulted in these differences is similar to those used in clinical studies and include tasks which activate the left-hemisphere, such as solving arithmetic problems (Butler & Glass, 1974) and writing a letter (Doyle et al, 1974), and tasks which activate the right hemisphere, such as recognition of faces, the Nebes (1971) arc-circle matching test (Dumas & Morgan, 1975), listening to music, and tonal memory (Doyle et al, 1974). A detailed examination of the tasks associated with significant differences in right and left hemisphere EEG activation has been completed by Ornstein and his colleagues (Ornstein, Johnstone, Herron, Swencionis, 1980) and has shown that all of the spatial tasks employed in that study (the Nebes arc-circle matching and circle-circle matching tests, a paper form board test, a picture completion task, and the mental rotation of objects) activate the right hemisphere. However, the mental rotation task was found to also activate the left hemisphere. Further, although all tasks did activate the right hemisphere, when the amounts of right hemisphere activity were compared to the left hemisphere activity associated with a verbal, synonym matching task, only the Nebes circle-circle matching task induced right hemisphere activity which was consistently and significantly greater than that in the left hemisphere. This result may be a function of the lack of verbal labels and analytic strategies applicable to a task which consists of identifying circles of the same size. Further, this finding implies that bilateral EEG activation may be due to confounded task demands. That is, a task labelled verbal or spatial may in fact require both modes of cognitive processing. If this were true, then bilateral EEG activation would reflect the confounded verbal and spatial demands of the task, not cerebral predispositions for bilateral involvement in verbal or spatial processing. This must be considered when interpreting results.

In summary, the preceding studies indicate that language tasks do activate the left cerebral hemisphere while spatial tasks activate the right cerebral hemisphere, as evidenced by EEG analysis. Further, these differences are significant when spatial tasks which allow little, if any, verbal mediation are compared to verbal tasks. EEG activity analysis can thus be used to assess bilaterality, allowing it to be studied in relation to subject handedness, subject sex and task performance.

Handedness and Functional Asymmetry

The relation between handedness and spatial and language task performance has been examined using a variety of techniques. Miller (1971) studied performance in 23 mixed-handers (individuals who were equally likely to use either their left or right hands) and 29 right-handers. These two groups performed virtually identically on the verbal test but right handers performed significantly better than mixed-handers on the spatial task. Similarly, Levy (1969) reports that while there was no difference between the W.A.I.S. Verbal scores of left- and right-handers, the left-handers did have significantly lower Performance scores than did right-handers. Both of these studies lend some support to Levy's hypothesis if mixed- and left-handers are considered to have bilateral language representation. They do not, however, provide support for Annett's notion of bilaterality and function.

The relation between handedness and EEG activity has also been examined, but the results are even less robust than those examining handedness and performance. Glanville and Antonitis (1955), using occipital electrode placements, found no difference in either the proportion or amplitude of resting EEG alpha activity in normal subjects for whom handedness was ascertained by questionnaire. Similarly, Provins and Cunliffe (1972) compared EEG activity in left- and right-handers and found no consistent differences between resting left and right parietal recordings in either alpha EEG or total EEG activity. However, they did report that when only right hemisphere activity was compared between right- and left-handers, the right-handed group exhibited more alpha activity. In a similar vein, Smyk and Darwaj (1972) in a study of right-, left-, and mixed-handed individuals found that EEG amplitude was frequently lower over the hemisphere which controlled the dominant hand.

Herron (1980) has more directly studied the relation between handedness and lateralized cognitive processing by assessing EEG activity during spatial and verbal task performance in right-, left-, and mixed-handers. Here, right- and left-handers differed significantly in lateralized EEG activation only during a verbal task which required them to write facts from memory. Right-handers were reported to have significantly less left hemisphere alpha, that is, more left hemisphere involvement during performance of this task, while left-handers presented the reversed pattern of activation. Further, when the difference scores for left and right hemisphere EEG activation ratios obtained during speaking and during block manipulation were analyzed, right-handers had significantly higher difference scores than did left-handers. This result is interpreted by Herron as evidence for strong left hemisphere participation in speaking and strong right hemisphere participation in block manipulation in right-handers and as a reverse pattern of activation for left-handers. The EEG ratios of mixed-handers were found to be lower than those of right- and left-handers, and thus in this group more right hemisphere activity occurred across tasks. When the tasks were individually examined, mixed-handers showed significantly lower right to left (R/L) ratios during singing than both left- and right-handers, and during speaking, when compared to righthanders. On the basis of these results, Herron suggests that there is more continuous right hemisphere engagement in mixed-handers than in either right- or left-handers. However, because Herron reports only ratio data, the validity of this suggestion cannot be adequately evaluated. The information supplied does not allow direct hemispheric comparisons to be made, and thus a comparatively lower ratio could be due to decreased right hemisphere activity or increased left hemisphere activity. Herron's work as well as that of Provins and Cunliffe (1972) and Smyk and Darwaj (1972) does however, suggest that handedness is reflected in different patterns of hemispheric activation during baseline and during task performance. Further, Herron reports bilaterality only in mixed-handers, but since she does not examine task performance, the relation between handedness and performance can not be examined.

However, it should be noted that handedness is only one of several indicators of lateral preference. Although handedness is frequently treated as a simple, unidimensional phenomenon, there is little support for such an assumption. Handedness is complicated by the related phenomena of preferential foot, eye and ear use; and these factors in turn may influence the relation between handedness and lateralized cognitive processing. In all aspects of peripheral laterality (e.g. handedness, footedness, eyedness, earedness), there is a bias towards dextrality, but this right bias is not necessarily consistent for any individual. For example, Porac and Coren (1978) assessed lateral preference for hand, foot, eye and ear use in 171 subjects and found that 87% were right-handed, 80% right-footed, 69% right-eared, but only 56% right-eyed. Thus, no more than 56% of their subjects could have been congruent for all aspects of peripheral laterality. Similar results were obtained by Schultz (unpublished data) in an assessment of peripheral laterality in 274 university students. Seventy-eight percent of these individuals were found to be right-handed, yet only 57% were both right-handed and -footed, while just 42% were right-handed, -footed and -eyed. Further, in a factor analytic study of peripheral laterality (Porac, Coren, Steiger & Duncan, 1980) in which hand, foot, eye and ear use were assessed in 962 individuals between the ages of ten and 75 years, three independent factors representing limb, eye and ear preference emerged. These results add further weight to the suggestion that peripheral laterality is a multidimensional process rather than a unitary phemomenon. Thus, if handedness is related to cerebral laterality, it is possible that footedness, eyedness and/or earedness are also involved.

The complexity of handedness is further compounded by the existence of a familial component in lateral preference. Porac and Coren (1979) assessed lateral use of hand, foot, eye and ear in 701 subjects who were members of 207 families. Significant correlations were found within families between mother and offspring for handedness and between mother and son for earedness, thus suggesting some familial influence on peripheral laterality. The effects of varying individual and familial patterns of peripheral laterality on asymmetric hemispheric involvement in cognitive processing have not been widely evaluated, but some evidence suggests that these variables do affect functional cerebral asymmetry. McKeever, Van Deventer and Suberi (1973) used a visual half-field letter masking task to assess performance differences in left-handers and in right-handers with and without familial sinistrality. They found that right-handers without familial left-handedness differed significantly from the other two subject groups, displaying significant right visual field, left hemisphere, superiority on the masking task. This result suggests that the relation between handedness and cognitive laterality can be complicated by other aspects of peripheral laterality. Kraft (1981) has also reported a relation between familial handedness and lateral specialization using dichotic tests. In a study of 80 right-handed boys, age six to twelve years, he found that subjects with familial sinistrality had an attenuated right side advantage for verbal and non-verbal stimuli and decreased non-verbal accuracy compared to the familially dextral subjects. Thus, if one were to accept sinistrals and dextrals with familial sinistrality as having bilateral dominance, then these results would support Annett's hypothesis that bilateral language representation exists in non-right-handers and hinders verbal and spatial performance.

In summary, the studies examining peripheral and cerebral laterality support the proposal that right-handers are well lateralized, with left hemisphere dominance for language and right hemisphere dominance for spatial processing. Hemispheric bilaterality was supported for mixed-handers by analysis of EEG activity (Herron, 1980) and by examination of spatial performance deficits (Levy, 1969; Miller, (1971).

Further, being left-handed or right-handed with familial sinistrality was associated with performance decrements on a language task presented to the left hemisphere, thus offering some support for Annett's hypothesis. However, none of these results unequivocally support the predictions of the models relating bilaterality to handedness and performance. Further, in order to evaluate these models fully, the relation of sex to lateral hemispheric activation during task performance must also be considered.

Sex and Functional Asymmetry

The relation of sex to asymmetric hemispheric involvement in task performance is supported both indirectly by the sex difference literature on abilities and more directly by the clinical literature evaluating hemispheric functioning. The abilities believed lateralized within separate cerebral hemispheres are in fact those in which males and females consistently differ in performance. Females in general display higher levels of ability than males on verbal tasks and, after adolescence, males routinely score higher than females on spatial tasks (Maccoby & Jacklin, 1974; Sherman, 1971). Clinical studies reveal further differences in functional laterality. Studies of performance decrements following brain trauma reveal that males are more likely than females to be left hemisphere dominant for language and right hemisphere dominant for spatial abilities, while females are more likely to have bilateral dominance for such skills (McGlone, 1980). However, dichotic and tachistoscopic studies fail to offer any clear consensus on the relation between sex and lateral functioning. Numerous studies support (e.g. Bradshaw & Gates, 1978; Ehrlichman, 1971; Marshall & Holmes, 1974) and oppose (e.g. Hannay & Boyer, 1978; McKeever & Van Deventer, 1977) the conclusions drawn from the clinical studies.

When EEG recordings of brain activity are used to investigate sex differences in lateralized cognitive processing, a pattern similar to that reported in the clinical literature is substantiated. Tucker (1976) examined sex differences in hemispheric specialization, studying 20 male and 19 female right-handed subjects during the performance of visuospatial tasks which required either analytic or synthetic processing. Alpha EEG power analysis indicated that for males, the right hemisphere was more involved in synthetic, spatial processing, while for females, there was no such specialization, thus supporting the hypothesis of bilateral spatial representation in females. Similarly, Ray, Morrell, Frediani and Tucker (1976) examined sex differences in lateralization by assessing hemispheric EEG power ratios during the performance of tasks chosen to approximate normal cognitive activities. These tasks included addition, counting, listening to music and visualizing scenes. Temporal EEG activity differed significantly, in the expected direction, between these spatial and language tasks for males, but did not differ for females. This result also supports the notion of functional bilaterality in females. Corresponding results were reported as well by Trotman and Hammond (1979) and Ray, Newcombe, Semon and Cole (1981). Trotman and Hammond recorded bilateral EEG during the performance of three verbal and three spatial tasks, and found differences in hemispheric activity only for males. Ray and his colleagues examined the relation of EEG asymmetry to spatial performance in high and low spatial ability males and females. High spatial ability males had relatively greater right hemisphere activity associated with successful spatial performance while the reverse relation was found for low spatial ability males. For both high and low spatial ability females, there was no consistent pattern of relationships. Further findings congruent with functional bilaterality in females were also reported by Butler (1980) and Wogan, Kaplan, Moore and Epro (1979). However, Moore (1979) reported no significant sex differences in EEG activity recorded during listening to prose and listening to music, tasks which did result in the expected left and right hemisphere activation patterns. Thus, there is strong, if not unanimous, support for bilateral spatial and verbal representation in females and lateralized representation in males. Such findings lend some support to Levy's hypothesis and are contrary to that of Buffery and Gray. However, task performance was not evaluated in these studies, so predictions concerning bilaterality and performance can not be evaluated.

Other studies have examined the relation of both peripheral laterality and sex to functional laterality and the outcomes of these investigations are also directly relevant to the conceptualizations of bilaterality being considered.

Peripheral laterality, Sex and Functional Asymmetry

Many of the studies which evaluate the relation between handedness, sex and functional laterality do so by evaluating differences in task performance. Such studies, while not assessing the presence of bilaterality, do evaluate the predicted relations between sex, handedness and performance. Other studies examine performance when information is presented to only one cerebral hemisphere and on the basis of this performance, infer cerebral laterality. Such studies also assess aspects of the predicted relations between handedness, sex and performance. Still other studies monitor hemispheric activity during cognitive processing and evaluate relative activity levels in relation to sex and peripheral laterality. Such studies more directly measure the presence of bilaterality.

Studies which assess performance differences have found both handedness and sex to be influential. Newcombe and Ratcliff (1973) examined WAIS Verbal and Performance scores for 409 men and 414 women who had been classified as right-, left-, or mixed-handed on the basis of questionnaire responses. Males scored significantly higher than did females on both Verbal and Performance scales but handedness had no significant effect. In a further investigation, the performance of a left-handed group of 15 men and 11 women was compared with that of 26 right-handers matched for age, sex, social class, years of schooling and place of residence. Again, no significant handedness effects were found.

Similarly, Johnson and Harley (1980) assessed verbal and spatial performance in left-, right- and mixed-handed males and females using a short form of the WAIS and in contrast to the findings presented above, found that both handedness and sex had significant effects on performance. Females, compared to males, were found to score significantly lower overall and left-handers scored significantly higher than dextrals and mixed-handers in synonym identification and significantly lower in spatial thinking. These reports suggesting that males perform better on spatial tasks than do females lend some support to the proposals of both Buffery and Gray and of Levy, but once again fail to assess cerebral dominance.

Kocel (1977) also looked at sex and handedness in relation to performance but found significant interaction effects only. She administered both verbal and spatial tests to 3251 subjects for whom handedness and familial handedness had been determined. There were no significant differences in scores between the left- and right-handed group, nor did the presence of familial sinistrality affect performance. However, when subject sex was also considered, a different pattern of results emerged. The presence of familial sinistrality in right-handed males was associated with lower spatial ability, while in females it accompanied better spatial performance. If familial sinistrality is indicative of bilateral dominance, then this result is in direct opposition to the proposals of all three bilaterality models. Further, Kocel found that dextral males showed lower spatial ability than sinistral males, while right-handed females showed higher spatial abilities than left-handed females. This finding also counters the proposal of Buffery and Gray, if in fact right-handed males are well lateralized.

Other studies have examined the effects of sex and handedness on functional laterality using tachistoscopic and dichotic techniques, inferring hemispheric dominance on the basis of superior performance on tasks presented to only one hemisphere. Milstein, Small, Malloy and Small (1979) examined the ability of right- and left-handed males and females to solve simple multiplication problems which were visually presented to one cerebral hemisphere while competing stimuli were presented to the other hemisphere. Over all conditions, females and dextrals made significantly more correct responses than did males or sinistrals respectively. This finding supports in part, the predictions of Levy for females but is contrary to her predictions for dextrals. However, Piazza (1980) found that regardless of handedness, males exhibited a strong left hemisphere advantage for processing dichotically presented language stimuli and that only right-handed females showed significant right hemisphere specialization for processing both melodies and environmental sounds. This result is not predicted by any of the models.

The relation between sex, handedness and performance was also explored in a series of studies by McGlone and Davidson (1973) which assessed variations in spatial ability in male and female left- and right-handers. Verbal and spatial hemispheric dominance were first inferred on the basis of performance on a dichotic word test and a tachistoscopic dot enumeration test, respectively. Then performance on two visuospatial tasks was evaluated in relation to lateral dominance, sex and handedness. Overall, males performed significantly better on the visuospatial tasks than females. Further, females with inferred right hemisphere language dominance performed significantly more poorly on these spatial tasks than did males with either left or right hemisphere language dominance or females with left hemisphere language dominance. In addition, left-handers with right hemisphere language dominance performed significantly less well on these spatial tasks than did subjects with all other combination of handedness and verbal dominance. Overall, spatial performance decrements were greatest for those individuals with reversed dominance, that is, with left hemisphere spatial and right hemisphere verbal dominance. These results link poor spatial performance to reversed functional lateralization rather than to bilateralization as proposed by Levy.

Studies which use anlayses of EEG activity to establish functional dominance and thus can evaluate bilaterality and its effects have also examined task performance in relation to subject sex and handedness. Davidson, Schwartz, Pugash and Bromfield (1976) examined sex differences in EEG asymmetry in right-handed subjects, for whom familial sinistrality had been determined. They reported that only females without familial sinistrality exhibited significantly more left hemisphere EEG activation when speaking lyrics than when whistling the melody of a song. Further, only this group exhibited significant right hemisphere activation during the self-generation of feelings ranging from anger to relaxation. These results indicate dextral females with no history of familial sinistrality are left hemisphere dominant for language and right hemisphere dominant for affect, and do not conform with Levy's hypothesis of bilateral language dominance in females. The findings of Herron (1980) discussed earlier, are also relevant here. In her study of EEG activity during task performance, Herron reported a reversed pattern of activation in sinistral subjects. This pattern of higher right hemisphere activation during verbal tasks and higher left hemisphere activation during spatial tasks was further found to be more pronounced in female than male left-handers. This reversal of laterality as a function of sex and handedness is not in accord with the predictions of any of the hypotheses outlined.

Galin, Ornstein, Herron and Johnstone (1982) have also examined hemispheric specialization in relation to sex and handedness. Using 90 normal adults, fifteen males and fifteen females in each of three handedness categories (right, left and mixed), they found both sex and handedness effects on alpha EEG asymmetry present during language, musical and spatial tasks. Right-handers exhibited significant differences in alpha ratios between tasks, with the highest right/left log ratios present during language performance. Further, within the language tasks, the alpha ratios differed significantly, with writing associated with the greatest asymmetry, followed by speaking, reading and listening. Non-right-handers showed less task-dependent asymmetry and the handedness groups differed significantly on only two tasks, listening and singing. Left-handers had significantly higher alpha power than right-handers for both tasks and than mixed-handers on listening. Reversal of the expected right-handed pattern of task related alpha asymmetry was found for 10% of the right-handers and for 36% of the non-right-handers. This reversal was particularly prevalent in left-handed females, with 46% exhibiting reversed asymmetry and thus suggesting a sex difference for non-right-handers. However, no sex differences in EEG measures were found among right-handers on any task. Although performance was not assessed, these EEG findings suggest that mixed- and left-handers are less lateralized than right-handers and so provide some support for Annett's and Levy's hypotheses concerning laterality.

No conceptualization of cerebral bilaterality received clear support from the literature which addresses these hypotheses. Some support and negation can be found for the ideas presented by each Buffery and Gray, Annett and Levy within the studies which relate sex and/or peripheral laterality to cerebral dominance and task performance. Much of the equivocation in the conclusions drawn from this research is the result of a deficiency of direct examinations of the bilaterality proposals. If bilaterality is to be evaluated, it is necessary to assess activity levels in each cerebral hemisphere during task performance and to evaluate these levels in relation to each other and to the activity levels present during non-task conditions. Additionally, performance must be evaluated. Further, the tasks employed must activate only the language dominant hemisphere or only the spatial, dominant hemisphere in well lateralized individuals. Finally, these measures must be examined in both males and females with various patterns of peripheral laterality.

The purpose of this study was to investigate the relation of bilateral cerebral hemispheric activation to spatial and verbal task performance in males and females with different patterns of peripheral laterality and to relate these findings to the conceptualizations of bilaterality outlined above. In order to assess these relations equal numbers of males and females served as subjects. Further, half of the subjects of each sex were peripherally right-dominant, with no history of familial sinistrality, while the remaining subjects were peripherally mixed-dominant. Since mixed-dominant subjects have been found to exhibit bilateral hemispheric activation during task performance (Herron, 1980), they were anticipated to be central to the investigation of the relation between bilateral cerebral activation, task performance, peripheral laterality and sex.

Discriminant analysis was used to investigate these relations. On the basis of patterns of cerebral activation, subjects were classified as bilaterally active, left hemisphere active or right hemisphere active. Subsequently, variables relating to sex, peripheral laterality and performance were entered as potential discriminators and evaluated for their ability to differentiate the laterality groups. The subjects who exhibited bilateral activity during verbal task performance would be discriminable from those who did not by poorer verbal performance and mixed-handedness, according to Annett's hypotheses, or by better verbal performance, poorer spatial performance, left-handedness and being female, according to Levy's hypotheses. Buffery and Gray would posit that subjects who exhibited left hemisphere activity during verbal performance would be discriminated from those who did not by better verbal performance and being females. The predictions concerned with spatial laterality would further suggest that the individuals who exhibited bilateral activation during spatial processing would be discriminable from those who did not by better spatial performance and being male, according to Buffery and Gray, or by better spatial performance, poorer verbal performance being right-handed and being male, according to Levy.

CHAPTER II

Method

Subjects

The sample consisted of 40 subjects, 20 males and 20 females, selected as right-lateralized or mixed-lateralized by their responses to a questionnaire on unilateral activites (modified after Oldfield, 1971). All right-lateralized subjects reported complete familial hand dextrality while the mixed-lateralized subjects reported both left- and right-handed family members. For the mixed-lateralized subjects, the mean familial dextrality was 76.5% (SD = 32.6). Of the mixed-lateralized subjects 4 were right-handed and 6 were left-handed males and 4 were right-handed and 6 were left-handed females. Thus, four groups of ten subjects each were used. The mean subjects age was 19.9 years (SD = 3.1) and there were no significant differences in age between males and females or between laterality groups.

All subjects were recruited from Introductory and second year psychology courses. The individuals who participated in the study were native English speakers with normal or corrected to normal vision, totally negative neurological histories and no current use of any medication or recreational drug known to influence the EEG.

Subject Selection

The forty subjects were selected after screening 955 students. These individuals were screened for lateralized hand, foot, eye and ear preference, as well as for familial dextrality and native language.

Seven hundred and seventy-five of the students screened reported English as their native language. Forty-six of these native English speakers met the additional criteria of being right-handed, - footed, -eyed and -eared, with complete reported familial dextrality. Of the 46 dextrals, 11 were male and 35 female. Twenty-eight of the native English speakers (3.7%) met the mixed laterality criteria of using both left and right hands to perform the criterion handedness tasks and of having a mixed pattern of foot, eye and ear dominance. Of the 28 mixed-laterality subjects, 15 were male and 13 were female. The specifics of laterality classification are descibed below.

These 74 people who met the original screening criteria were subsequently contacted by telephone, and an individual session for additional screening was scheduled. Subjects were selected randomly from each group list until ten subjects from that group had met the selection criteria. If the established laterality criteria were met, the EEG recording also was completed during this session. One subject (right-lateralized, female) was not able to be reached at the telephone number she had provided during original screening and thus, did not participate in further study. Another three subjects (1 mixed-lateralized female, 1 right-lateralized female, 1 mixed-lateralized male) were rejected for failing to meet the additional laterality screening criteria and one subject (right-lateralized female) was excluded because of excessive EEG artifact. For the 40 subjects who successfully met all laterality and screening criteria, EEG was then recorded following the procedure outlined below.

Determination of Laterality

Handedness, footedness, eyedness and earedness were initially determined using a modified version of the Edinburgh Handedness Questionnaire (Oldfield, 1971) (see Appendix A). On this questionnaire, subjects indicated the hand used in each of 10 activities: writing, drawing, throwing, cutting with scissors, brushing teeth, using a knife with a fork, using a spoon, upper hand on a broom, holding a match to strike it, and holding the lid of a box when opening it. In addition, each subject indicated the foot used to kick a ball and step on a bug; the eye used to look through a telescope and peep through a key hole; and the ear used to listen to a radio with an ear plug and to listen in on a conversation going on behind a closed door. The two questions on earedness were not part of the original Edinburgh Questionnaire, but were drawn from a laterality survey employed by Coren and Porac (1978).

Subjects responded to the 16 questions comprising the laterality survey by indicating their degree of lateral Preference on a five-point scale, where "1" designated extreme left preference, "5" designated extreme right preference and "3" designated no preference. Subjects were categorized as right-lateralized when all 16 preferences were rated at levels 4 or 5 and as mixed-lateralized when the ratio of the number of left to right hand preferences (calculated by the formula, left-right/left + right) was between -0.6 and +0.6, and when the ratings on the six foot, eye and ear preference items ranged between 2 and 4, with a mean greater than or equal to 2.5 and less than or equal to 3.5.

Familial handedness was assessed by having subjects indicate the hand most frequently used by each member of their biological family and then calculating the percent of the family that was right-handed. For an individual to qualify as right-lateralized criterion, 100% of family members had to have been reported as right-handed. No familial handedness restrictions were placed on the classification of mixed lateralized subjects. The mean familial dextrality for this group was 76.5% (SD = 32.6).

Subjects who met the original screening criteria for either group were subsequently re-screened prior to EEG recording. In this second screening, the modified Edinburgh Laterality Questionnaire was readministered and scored, using the criteria outlined above. In addition, each subject completed a number of behavioural measures of laterality. Each subject first completed the Tapley and Bryden (1980) hand preference test, in which the subject marks a dot in the centre of each of a series of circles. This task is done four times, alternating between the preferred and nonpreferred hand. In each trial, the subject is allowed 20 seconds in which to mark as many dots as possible. This task was later scored for the total number of dots made with each hand and a performance ratio calculated using the formula of right - left/right + left. The correlations between all measures of laterality are presented in Appendix B.

Following completion of the dot task, each subject was asked to throw a bean bag at a target on the wall, step on an "x" marked on the floor, look through a tube, and place a radio ear plug in one ear. Lateral preference for each of these tasks was recorded. Those completed with the right hand, foot, eye or ear were scored as two, while those completed with the left were scored one.

If the performance on the behavioural measures of laterality was in accord with the lateral preferences reported on the laterality questionnaire, the subject was included in the study and participated in the EEG recording sessions.

Session Procedure

All subjects who met the original screening criteria were contacted by telephone and asked to report to the laboratory at an individually scheduled time. All but two subjects, a mixed-lateralized male and a right-lateralized female, reported at the arranged time. These two subjects were again telephoned and a second session scheduled. Both subjects appeared for this second appointment.

When subjects reported to the laboratory, they were told that the purpose of the study was to examine brain activity during problem solving, and that in order to do this seven electrodes would be attached; one on the arm, one above and below the eyes, two on the back of the head, and one clipped to each ear. The experimenter emphasized that these were recording electrodes and that no shock would be administered. All subjects were then shown the recording equipment and the session room where the recording would take place. Sample verbal, spatial and control problems were then shown to all subjects and the response requirements explained. The experimenter emphasized that it was brain activity during problem solving that was of particular interest, not the correctness of a subject's answers. All subjects were told that the only tasks requirement was to attempt to solve the problems given and to supply what they believed was the best answer. Any questions the subject had were then answered. Following this introduction, subjects were asked to sign an informed consent statement if they were willing to participate in the study. No one refused to participate.

The additional laterality screening was then completed, electrodes attached, and the subject seated in the recording room. The tasks and method of responding were again explained, the lights were dimmed and the necessity of attending visually to the screen throughout the recording session emphasized. The experimenter then returned to the control room. All subsequent communication between the subject and experimenter was carried out via an intercom connecting the session and control rooms.

The recording session began with the presentation of a slide containing three "X"'s, one centred and the others 17.54 cm (6.91 in.) to the left and right of the center (approximately 3 degrees of visual angle). Subjects were asked to fixate on the centre "X" for 10 seconds and were then asked to look back and forth from the centre "X" to the right "X" ten times, then from the center to the left "X" ten times, and finally from the left to the right "X" ten times. This information was later used to eliminate recording periods which contained large eye movements, suggestive of inattention to the task.

Next, sample verbal, spatial and control problems were projected and the task and method of responding again explained. Any questions the subject had were answered. Once the subject was comfortable with the procedure, the actual task presentation of alternating baseline and problem phases began. No verbal interaction occurred between the subject and experimenter during the actual recording period, though the subject was monitored by means of the intercom and a one-way mirror.

After completion of the recording session, the electrodes were removed and subjects were debriefed.

Task Presentation and Response

Each subject completed a total of 64 problems arranged in four problem blocks: one block of 16 spatial problems, one block of 16 verbal problems and two blocks of 16 control problems each. Each block contained four problems to which "a", "b", "c", and "d" were the respective correct answers. The 16 problems were randomly ordered within each block and these orders were consistent for all subjects. The problem blocks were presented in four different orders, all of which alternated spatial and verbal blocks with control blocks. The four orders were: (1) verbal, control 1, spatial, control 2; (2) control 1, spatial, control 2, verbal; (3) spatial, control 1, verbal, control 2; and (4) control 1, verbal, control 2, spatial. Nine subjects received order 1, 10 received order 2, 12 received order 3 and 9 received order 4. Problem blocks were separated by a two-minute baseline phase and each session began and ended with such a baseline phase. Blank slides were projected during all five baseline phases.

All task problems were presented by slides shown on a rear-projection screen located 1.218 m (48 in.) in front of the subjects. The projected problem image was 32.7 cm (12.875 in.) by 6.54 cm (2.58 in.), subtending approximately 4.6 degrees of visual angle, when viewed from the subject's position. During slide presentation, the ambient light level at the subjects's position was approximately 21.53 lx (2 foot-candles).

Subjects answered the task problems by depressing one of four lettered response buttons with their preferred hand. The buttons, mounted on a 17.5 cm by 12.5 cm by 7.5 cm response box, were lettered "a', "b", "c", and "d" respectively, from left to right. The subject was instructed to press the button corresponding in letter to the response alternative chosen as correct. Each problem slide was projected for a maximum of 45 seconds. If a response were made prior to the end of the 45 second interval, the projector automatically advanced to the next slide. If no response were made, this advance took place at the end of the 45 second interval. A Leheigh Valley Act-Interact System was programmed to control slide advancement. This system also timed and recorded each subject's latency to respond to the nearest .01 second and recorded the response alternative selected. This information was printed after each problem by a Texas Instrument, Silent 700 Electronic Data Terminal. The Leheigh Valley system allowed four seconds for the latency to respond and response selection information to be printed. During this interval the subject saw a blank projection screen. Due to equipment failure, information on response alternative selection was not available for one subject (mixed-handed male).

Tasks

The EEG was recorded while each subject performed verbal, spatial, and control tasks. The spatial task consisted of a version of the Nebes Circle-Circle Matching Test (Nebes, 1971), which was modified to include four (rather than five) response alternatives for each problem. In this task, a target circle was presented and the respondent indicated which of four lettered alternate circles of varied diameter matched the target circle in size (see Figure 1). Circles of seven different diameters were used in the spatial problems. In the test situation, these circles varied from 1.17 in. (2.97 cm) to 1.87 in. (4.76 cm) in diameter, increasing in steps or 0.117 in. (0.297 cm). Each problem contained one target, one correct alternative and three incorrect alternative circles. The alternate circles varied form the target circle by at least plus or minus 0.117 in. (0.297 cm), but by no more than plus or minus 0.351 in. (0.891 cm). The spatial task thus involved visual stimulation, visual discrimination, visualization, comparison and recognition.

The verbal task consisted of synonym matching problems. In this task, a target word was presented and the respondent indicated which of four lettered alternate words matched the target word in meaning (see Figure 2). All words were between five and nine letters in length and, when presented, were equal to or greater than the diameter of the smallest circle and equal to or less than the diameter of the largest circle used in the spatial task. The verbal task thus involved visual stimulation, reading, verbal discrimination, comparison and recognition.

Sixteen spatial and sixteen verbal tasks were presented during EEG recording. These 32 problems were selected from a set of 29 spatial and 73 verbal problems, presented in a paper-and-pencil format to 47 first- and second-year psychology students. The 32 problems employed were selected from the problems to which between 60% and 89% of the individuals tested had responded correctly. Twelve of the verbal and spatial problems were exactly matched in difficulty. Two of the verbal

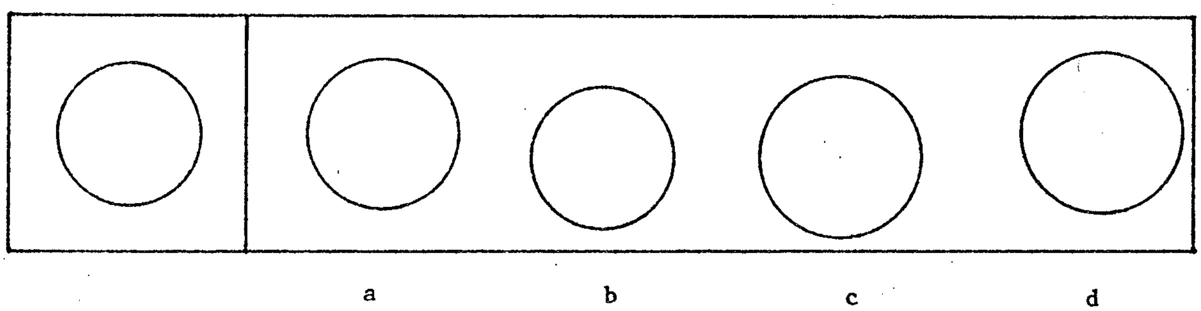

Figure 1. Example problem from the modified Nebes Circle-Circle Matching Test.

covenant	agreement	prayer	garden	debate
	a	b	c	d

Figure 2. Example synonym matching problem.

problems were 4% less difficult than their paired spatial problem, while another two verbal problems were 4% more difficult than their paired spatial problem. Once the sets of 16 spatial and 16 verbal problems had been selected, the response alternatives were arranged so that each problem set contained four problems to which each "a", "b", "c" and "d" was the correct answer.

In addition to the spatial and verbal problems, 32 control problems were employed. In these control tasks a single letter, corresponding to those used to letter the response alternatives in the spatial and verbal tasks, was presented in one of the four response letter positions (see Figure 3). Thus, for example, the letter "a" could appear in the space where "c" would have appeared had all four letters been presented. The respondent indicated the letter which had been presented. This task involved visual simulation and recognition, and was included as a means of determining the degree to which lateral hemispheric activation resulted from the sensory and motor, rather than the cognitive, demands of the spatial and verbal tasks.

EEG Recording

EEG activity was recorded using one left and one right hemisphere silver cup scalp electrode positioned at the respective International 10-20 System (Jasper, 1958) parietal positions, P3 and P4. Previous work has demonstrated strong task-dependent alpha EEG asymmetry at these locations, both when only this site is monitored (Davidson et al, 1976) and when this site is compared with other locations (Galin et al, 1978; Galin et al, 1983, Ornstein et al, 1980; Tucker, 1976). The scalp elec-

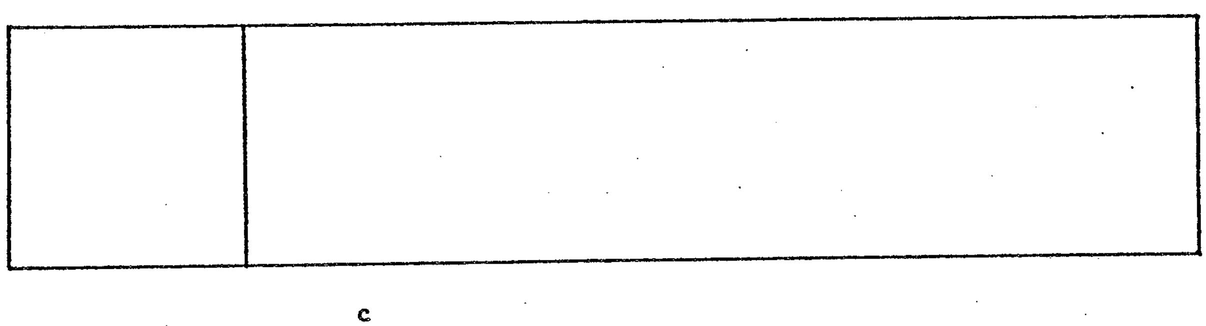

Figure 3. Example control problem.

trodes were each referenced to linked ear electrodes, and electrode impedance was less than 10 Kohm at each scalp location. A 16 mm silver cholide ground electrode was positioned on the medial forearm, and eye movements were monitored by two 11 mm silver cholide electrodes positioned on the lateral orbit, one slightly above the left eyebrow and the other directly below the corner of the right eye. Such positioning enabled detection of both vertical and horizontal movement (Stern, Ray & Davis, 1980).

Left and right parietal EEG activity was independently amplified using Grass model P511 EEG amplifiers and recorded by a Grass model 7 polygraph (chart speed 15 mm per second, 50 mV giving 1 cm pen deflection) and by a Hewlett-Packard model 3960 FM instrumentation recorder. Eye movement activity was amplified using a Grass model 7P511 amplifier and recorded on both the polygraph and FM tape. Both graph and tape marker channels were used to record task phase and problem presentation information for each subject. A continuous 12V signal was recorded during slide projection. No signal was present during slide changes.

Scoring of EEG Activity

After completion of EEG recording, the taped EEG activity was amplified to saturation by the Grass amplifier and the presence of alpha activity (9-13 Hz) was detected by a Colbourn model S75-15 alpha detector/filter. The duration of the alpha activity was then timed using a digital readout timer, accurate to .01 seconds. The minimum duration of detectable alpha activity was .05 seconds. A second digital timer was used to obtain a measure of the time between each problem or baseline slide change. Using the output of these two timers, a ratio of alpha time to total phase time was obtained for each problem and task phase. Additional measures of alpha activity were obtained by scoring the chart recording of EEG activity for average alpha amplitude and frequency. In order to obtain these measures, instances of alpha activity were isolated for each channel, and confirmed using the measures of alpha duration for each task. Once the alpha activity had been identified, the amplitude of alpha bursts of at least 0.33 seconds in duration were measured following the procedure outlined by Walter and Yeager (1956). In this amplitude measure, the peaks and the troughs of the alpha activity graph are joined by lines and the distance between the line connecting the peaks and the line connecting the troughs is measured every 0.2 seconds and averaged (see appendix C). Frequency was assessed by counting the number of alpha wave peaks within each alpha period for which amplitude was measured and calculating the average. The alpha amplitude and frequency measures were then averaged for each hemisphere, for each task and baseline phase. Frequency averages were rounded to the nearest whole number. Amplitude measurements were rounded to the nearest millimeter, i.e. 5mV. Finally, ratios were calculated for the amplitude and for the frequency measures using the formula left - right/left + right. These ratios were calculated for each baseline and problem phase.

Measures of the percent of phase or problem time spent in concurrent, left hemisphere only and right hemisphere only alpha EEG activity were also obtained from the chart recordings. The duration of each pattern of activity was measured and the percentage of concurrent, left only, or right only alpha time was calculated by dividing the appropriate alpha time figure by total alpha duration for the phase of interest and multiplying this result by one hundred.

Adjustment of the Variables

Six EEG variables and two performance variables were adjusted following a procedure outlined by Pedhazur (1981) prior to their use in subsequent analyses. The adjustment was performed to ensure that the contribution of the task variables to laterality group discrimination was independent of baseline, control task, or highly correlated variables and would thus reflect only task performance variation. The eight variables were each adjusted by regressing confounding variables on the variable of interest and then calculating residuals, that is, the difference between the actual level of the variable and its predicted level. Each residual variable thus calculated was therefore independent of its significantly correlated predictor variables.

Residuals were calculated for the percent of alpha time in which alpha activity was present in only the left hemisphere for each of the verbal and the spatial phases by using the percent of only left hemisphere alpha obtained during the first baseline and the mean only left hemisphere alpha percent obtained for the two control task phases as predictors in each regression analysis. Thus, the residual only left hemisphere alpha percents for both the verbal and the spatial tasks were independent of both the significantly correlated baseline and control task levels of this variable (see Table 1 and 2).

Table 1

Correlations of Baseline, Control Task and Verbal Task

Percent of Alpha Activity Restricted to the Left Hemisphere

	Baseline	Average Control Task	Verbal Task	Residual
Baseline	1.0			
Average Control Task	.3277*	1.0		
Verbal Task	.3875*	.6129**	1.0	
Residual	-.0000	-.0000	.7651*	1.0

N = 40

* $p < .05$

** $p < .01$

Table 2

Correlations of Baseline, Control Task and Spatial Task

Percent of Alpha Activity Restricted to the Left Hemisphere

	Baseline	Average Control Task	Spatial Task	Residual
Baseline	1.0			
Average Control Task	.3277*	1.0		
Spatial Task	.7057*	.5639**	1.0	
Residual	-.0000	-.0000	.6149*	1.0

N = 40

* $p < .05$

** $p < .01$

Residuals were similarly calculated for the percent of concurrent alpha time for both the verbal and the spatial tasks. In these analyses, residual calculations were performed, entering the first baseline and the mean control task levels of concurrent alpha time as predictors (see Table 3 and 4).

The final two EEG measures for which residuals were calculated were the verbal and spatial amplitude ratios. Here, the relevant task frequency ratios were entered as predictors, in order to remove the confounding effects of frequency on amplitude (see Table 5 and 6). The verbal and spatial amplitude residuals thus calculated were therefore independent of these frequency measures and provided a uniform means of assessing alpha activation.

Finally, residuals were calculated for the mean latency-to-respond measures for both the verbal and the spatial problems. In the calculation of these residuals, the mean latency-to-respond for the two control problem phases was entered as the predictor. The verbal latency-to-respond residual and the spatial latency-to-respond residuals were thus each independent of the control task latency-to-respond and therefore reflected aspects of task performance independent of letter recognition and button pressing (see Table 7 and 8).

The eight residual scores calculated by the procedures outlined above were subsequently used as discriminating variables. All of the residuals employed represent aspects of verbal or spatial performance which are independent of the initial, pre-task, baseline characteristics of the subject and/or of the control task performance of the subject. As such, they reflect only the influence of the verbal or the spatial

Table 3

Correlations of Baseline, Control Task and Verbal Task

Percent of Concurrent Alpha Activity

	Baseline	Average Control Task	Verbal Task	Residual
Baseline	1.0			
Average Control Task	.7117**	1.0		
Verbal Task	.7328**	.8589**	1.0	
Residual	-.0000	-.0000	.4820**	1.0

N = 40

* $p < .05$

** $p < .01$

Table 4

Correlations of Baseline, Control Task and Spatial Task

Percent of Concurrent Alpha Activity

	Baseline	Average Control Task	Spatial Task	Residual
Baseline	1.0			
Average Control Task	.7117**	1.0		
Spatial Task	.6847**	.9043**	1.0	
Residual	-.0000	-.0000	.4229**	1.0

N = 40

* $p < .05$

** $p < .01$

Table 5

Correlations of Verbal Frequency, Amplitude and Residual Measures

	Frequency	Amplitude	Residual
Frequency	1.0		
Amplitude	.9744**	1.0	
Residual	.0000	.2250*	1.0

N = 40

* $p < .163$

** $p < .01$

Table 6

Correlations of Spatial Frequency, Amplitude and Residual Measures

	Frequency	Amplitude	Residual
Frequency	1.0		
Amplitude	.9575**	1.0	
Residual	-.0000	.2884*	1.0

N = 40

* $p < .07$

** $p < .01$

Table 7

Correlations of Average Control Task, Verbal and Residual Latency-to-Respond Measures

	Average Control Task	Verbal Task	Residual
Average Control Task	1.0		
Verbal Task	.3190*	1.0	
Residual	-.0000	.9478**	1.0

N = 40

* $p < .05$

** $p < .01$

Table 8

Correlations of Average Control Task, Spatial and Residual Latency-to-Respond Measures

	Average Control Task	Spatial Task	Residual
Average Control Task	1.0		
Spatial Task	.4934**	1.0	
Residual	-.0000	.8672**	1.0

N = 40

* $p < .05$

** $p < .01$

task under examination. Thus, the calculation of residuals was done to eliminate the potential confounding effects of resting EEG asymmetry (Donchin et al, 1977; Furst, 1976; Rancy, 1939; Ray et al, 1981; Remond et al, 1969; Strauss et al, 1943) and motor responding (Gevins et al, 1979) on task EEG asymmetry. The transformations did not significantly alter the relation between the dependent and independent variables (see Appendix D).

Statistical Analyses

The presence of bilateral cerebral involvement in verbal and spatial task performance was investigated using stepwise discriminant analyses (SPSS; Hull & Nie, 1981), in which Wilk's lambda was the inclusion criterion statistic. In the first discriminant analysis, changes in EEG alpha activity duration during verbal performance were used to define the three laterality groups, while in the second discriminant analysis, changes in EEG alpha activity duration during spatial performance defined these three groups. In the third and fourth analyses, ratios of left to right hemisphere alpha activity during verbal or spatial performance defined the three groups. Subject characteristics, EEG features and performance measures were entered as potential discriminating variables in each of these analyses.

Cerebral involvement. Bilateral, left hemisphere and right hemisphere cerebral task involvement were defined for the first two analyses by task-contingent changes in the length of phase time spent in alpha EEG activity as follows.

If both left and right hemisphere alpha durations decreased from those found in the immediately preceding baseline phase concomitant with verbal or spatial task introduction, the subject was categorized as having bilateral cerebral involvement for that task. Eleven subjects on the verbal, and eleven subjects on the spatial tasks were thus categorized as bilateral. Six subjects were bilateral on both tasks.

If, contingent upon task introduction, left hemisphere alpha duration decreased relative to preceding baseline levels and right hemisphere alpha duration either increased or remained constant, the subject was classified as left hemisphere active for that task. There were 8 subjects who were thus classified as left hemisphere active on each the verbal and the spatial tasks. Three subjects were classified as left hemisphere active for both tasks.

If, contingent upon task introduction, right hemisphere alpha duration decreased relative to preceding baseline levels and there was either a concurrent increase or no change in left hemisphere alpha duration, the subject was categorized as right hemisphere active for that task. There were 4 subjects who were right hemisphere active on each the verbal and the spatial tasks. No subjects were classified as right hemisphere active for both tasks.

All remaining subjects were unclassified.

Definition of hemispheric involvement for the two remaining discriminant analyses were based on ratios of alpha activity present during verbal or spatial task performance. For both verbal and spatial tasks, these ratios were calculated by dividing the differences between left (LH) and right hemisphere (RH) alpha durations by the sum of left and right hemisphere alpha durations (LH-RH/LH+RH). Results for this ratio could range from +1.0 to -1.0 and highly positive ratios would result from high levels of LH and low levels of RH alpha activity while highly negative ratios would result from the inverse distribution of alpha activity. Thus, positive ratios would reflect greater RH arousal while negative ratios would reflect greater LH arousal.

Laterality group membership was determined by dividing the possible ratio range into thirds. Thus, those subject with ratios equal to or greater than +0.333 were defined as RH active, while subjects with ratios equal to or less than -0.333 were defined as LH active. Subjects with ratios between these extremes were classified as bilateral. Using these criteria, four subjects were categorized as having bilateral activity on the verbal task and three subjects were so categorized on the spatial task. Eleven subjects were LH active on the verbal task while seven were LH active on the spatial task. Finally, four subjects were RH active on the verbal task and five were RH active during the spatial task.

All remaining subjects were unclassified.

Discriminating variables. Three categories of discriminating variables were entered into the discriminant analyses: subject variables, EEG variables and performance variables. The items in the first category, subject variables, were sex and three laterality scores. The first two laterality scores were obtained by factor analyzing the responses of the original screening group of 775 native English speakers to the 16 items of the modified Edinburgh Laterality Questionnaire and to the questions on maternal and paternal handedness. Using a principle factors analysis and varimax rotation (BMDP; Frane & Jennrich, 1979), two factors were obtained. The first factor accounted for 6.057 percent of the variance and loaded strongly on all laterality items except the second eyedness, the second earedness and the parental handedness measures. The second factor accounted for 1.691 percent of the variance and loaded primarily on the eyedness and earedness items (see Table 9). The complete factor loadings are provided in Appendix E. The two factor scores for each of the 40 individuals participating in the EEG session constituted two of the laterality scores entered as discriminating variables. The third laterality measure entered as a potential discriminator was a behavioural laterality score obtained by summing each subject's scores on the five performance laterality measures administered prior to EEG recording. This measure thus consisted of the sum of the dot-task ratio, and the scores on the hand-, foot-, eye- and ear-use tasks performed by the subject.

Three EEG variables were also entered in both the verbal and the spatial discriminant analyses. These were the residual verbal or spatial percent of task-dependent alpha activity which occurred in the left hemisphere only, the residual verbal or spatial percent of concurrent alpha activity occurring during task performance and the residual verbal or spatial alpha amplitude ratio.

Finally, four performance measures were entered as potential discriminating variables. The first and second were the number of problems answered correctly on the verbal and spatial tasks, while the third and fourth were the residual latencies-to-respond for these tasks.

Thus, to analyze bilateral cerebral involvement in task performance, four discriminant analyses were performed, two for verbal and two

Table 9

Sorted,* Rotated Laterality Factor Loadings

Laterality Item	Factor 1	Factor 2
Hand (write)	0.876	0.0
Hand (spoon)	0.871	0.0
Hand (draw)	0.850	0.0
Hand (tooth brush)	0.823	0.0
Hand (scissors)	0.760	0.0
Hand (match)	0.750	0.0
Hand (throw)	0.745	0.0
Foot (kick ball)	0.615	0.0
Hand (box lid)	0.547	0.0
Eye (key hole)	0.0	0.903
Eye (telescope)	0.260	0.735
Foot (bug)	0.424	0.0
Hand (broom)	0.433	0.0
Hand (knife)	0.312	0.0
Ear (radio)	0.327	0.303
Ear (conversation)	0.0	0.345
Mother's handedness	0.0	0.0
Father's handedness	0.0	0.0
Variance explained	6.057	1.691

* (loadings less than 0.250 have been replaced by zero)

for spatial behavior. In each analysis there were three groups to be discriminated, bilateral, left hemisphere active and right hemisphere active. A total of 11 variables were entered as discriminators in each analysis.

A fifth stepwise discriminant analysis using Wilk's lambda as the inclusion criterion was performed to identify the EEG and performance variables which would discriminate between the four sex-by-peripheral laterality groups selected for study. The four groups to be discriminated were right-lateralized males, mixed-lateralized males, right-lateralized females, and mixed-lateralized females. The ten variables used as potential discriminators consisted of the performance measures of residual verbal and spatial latency-to-respond and number of verbal and spatial problems answered correctly, and the verbal and spatial EEG measures of residual concurrent alpha, residual left hemisphere only alpha, and residual alpha amplitude.

CHAPTER III

Results

Lateralized Change from Baseline: Verbal Performance

Three cerebral activation groups were defined, based on changes in the pattern of recorded EEG alpha activity. These groups were 1) bilaterally active, 2) left hemisphere active and 3) right hemisphere active. When EEG alpha activity levels during verbal task performance were compared to levels found in the immediately preceding baseline, 11 subjects exhibited bilateral decreases in alpha EEG activity and were classified as bilaterally active; 8 subjects had such decreases only in left hemisphere EEG alpha activity and were classified as left hemisphere active; and 4 subjects had such decreases only in right hemisphere EEG alpha activity and were classified as right hemisphere active. The sex and laterality characteristics of the members of these groups are presented in Table 10.

The discriminant analysis produced two canonical discriminant functions. Table 11 presents the results of the tests of signifiance of residual discrimination. The cerebral activation groups were significantly different ($P<.036$) before the derivation of any discriminant functions, and the first function derived was significant. After the derivation of the first discriminant function, the remaining group differences only approached significance ($P<0.192$) and thus, the second function derived only approached significance. The first function, therefore, contained more significant information about group differences and the second added only minimally more information. This pattern

Table 10

EEG Laterality Group Member Characteristics

Verbal Analysis

	Right-Lateralized		Mixed-Lateralized		Total
	Male	Female	Male	Female	
Bilateral	3	4	3	1	11
Left Hemisphere Active	1	2	3	2	8
Right Hemisphere Active	0	0	2	2	4

Table 11

Verbal EEG Laterality Group

Residual Discrimination and Test of Signifiance

Functions Derived	Wilk's Lambda	Chi-Squared	D.F.	Significance Level
0	0.3899	16.481	8	0.036*
1	0.7630	4.734	3	0.192

* P<.05

of discriminability was further reflected by the eigenvalues and canonical correlations which characterized the discriminant functions (see Table 12). Thus, as the territorial map further illustrates (see Figure 4), the group centroids were clearly separated on the first discriminant function and less well separated, but still distinct, on the second discriminant function. The coordinates of the group centroids are provided in Table 13.

Four variables contributed to the determination of the discriminant scores. These were the two laterality factor scores, the number of spatial problems answered correctly and the residual verbal EEG alpha amplitude measure. Examination of the standardized discriminant coefficients (see Table 14) revealed that the second laterality factor which reflected eyedness and earedness, and the number of correct spatial answers, contributed heavily to the calculation of the discriminant scores on function one, while the number of correct spatial answers, the residual EEG amplitude measure and the first, overall, laterality factor, contributed highly to the calculation of the discriminant scores on the second function.

However, because the contribution of a variable to the discriminant function can depend on its correlation with other variables, the total structure coefficients (see Table 15), that is, the simple bivariate correlations between each variable and the discriminant function, were also examined. These total structure coefficients indicated that eyedness and earedness and general laterality were most closely related to function one. The first of these variables was positively related, while the second was negatively related. Further, these coefficients

Table 12

Verbal EEG Laterality Group Discriminant Analysis

Eigenvalues and Measures of Importance

Discriminant Functions	Eigenvalue	Percent of Variance	Canonical Correlation
1	0.957	75.49	0.6992
2	0.311	24.51	0.4868

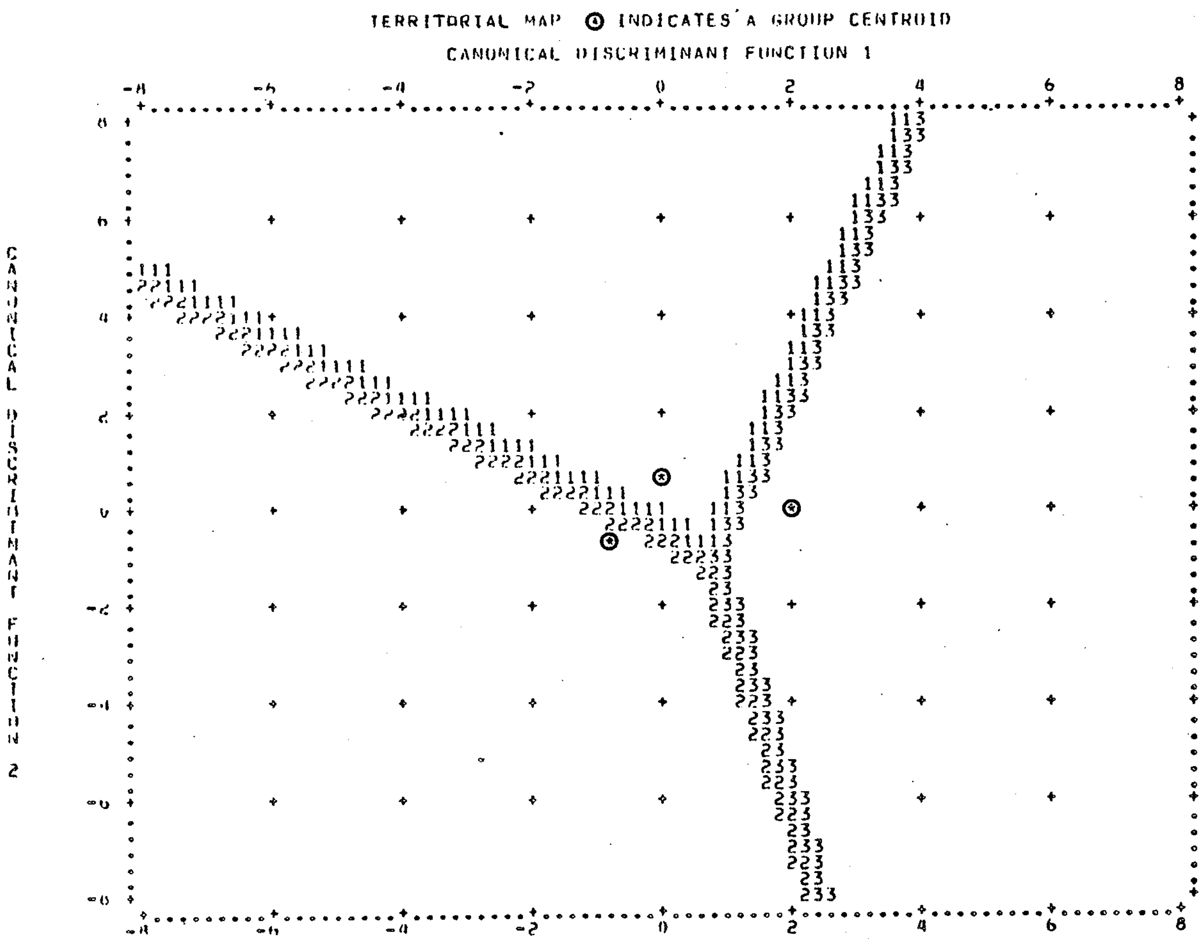

Figure 4. Territorial Map: verbal analysis.

Group centroid locations are plotted on discriminant functions 1 and 2, and the boundaries of each laterality group are demarcated. The distance between centroids indicates the degree of separation of the laterality groups.

Table 13

Coordinates of the Verbal EEG Laterality Group Centroids

Group	Function 1	Function 2
Bilateral	0.052	0.560
Left Active	-0.796	-0.733
Right Active	1.932	-0.099

Table 14

Standardized Canonical Discriminant Function Coefficients:

Verbal Analysis

Discriminator	Function 1	Function 2
Laterality Factor 1	-0.569	0.580
Laterality Factor 2	1.001	-0.142
Spatial Correct	0.865	-0.671
Residual Verbal EEG Amplitude	0.394	0.583

Table 15

Total Structure Coefficients:

Verbal Analysis

Variable	Function 1	Function 2
Laterality Factor 1	-0.491	0.546
Laterality Factor 2	0.606	0.061
Spatial Correct	0.116	0.554
Residual Verbal EEG Amplitude	-0.168	0.412

revealed that spatial performance, general laterality and residual amplitude were positively related to function two. Thus, the first and significant function discriminated on the basis of right-eyedness and -earedness and on the amount of non-right general laterality present. The second function discriminated on the basis of the number of spatial problems correctly answered, the degree of general right laterality and the residual verbal EEG alpha amplitude. The means and standard deviations for each cerebral activity group on these variables are presented in Table 16.

In summary, when the total structure coefficents and group centroids are considered for verbal performance, the bilateral subjects were generally right lateralized, right-eyed and -eared individuals, who solved most spatial problems correctly and had high residual EEG amplitude measures. The left hemisphere active subjects tended to be mixed lateralized, with mixed levels of eyedness and earedness. These people had the least spatial problems correct and had small residual EEG alpha amplitude measures. The right hemisphere active subjects were generally left lateralized with right eyedness and earedness. They performed midmost on the spatial task and had the smallest measures of residual amplitude.

The efficacy of the discriminant functions was tested by classifying known group members using the discriminant functions. The resultant classification matrix is presented in Table 17. Of the 23 cases for which group membership was known, 78.26% were correctly classified. The computation of tau, a statistic which reflects the proportional reduction in error, indicated that classification based on the discriminating variables made 67.6% fewer errors than would have been expected by

Table 16

EEG Laterality Group Means and Standard Deviations

on Discriminator Variables:

Verbal Analysis

Group	N	Laterality Factor 1	Laterality Factor 2	Spatial Correct	Residual Amplitude
Bilateral Activity	11	-0.097 SD = 1.209	0.600 SD = 0.732	13.546 SD = 1.293	0.480 SD = 1.640
Left Hemisphere Active	8	-0.443 SD = 1.284	0.041 SD = 1.282	12.375 SD =1.408	-0.010 SD = 0.654
Right Hemisphere Active	4	-1.454 SD = 0.654	1.302 SD = 0.669	13.333 SD = 2.082	-0.003 Sd = 0.506
Unclassified	17	-0.3021 SD = 1.235	0.5018 SD = 0.642	13.625 SD = 1.857	-0.311 SD = 0.452
Overall	40	-0.3891 SD = 1.200	0.517 SD = 0.830	13.316 SD = 1.636	-0.0000 SD = 0.987

Table 17

Classification Matrix

Verbal Analysis

Original Group	N of Cases	Predicted Group		
		Bilateral	Left Active	Right Active
Bilateral	11	9 (81.8%)	1 (9.1%)	1 (9.1%)
Left Active	8	1 (12.5%)	6 (75.0%)	1 (12.5%)
Right Active	4	1 (25.0%)	0 (0.0%)	3 (75.0%)

random assignment. Thus, the discriminant functions successfully discriminate the verbal performance cerebral activity groups.

Lateralized Change from Baseline: Spatial Performance

Three cerebral activation groups were also defined on the basis of changes in patterns of recorded EEG alpha activity during spatial performance. These groups were 1) bilaterality active, 2) left hemisphere active and 3) right hemisphere active. When EEG alpha levels during spatial task performance were compared to levels found in the immediately preceding baseline, 11 subjects exhibited bilateral decreases in alpha EEG activity and were classified as bilaterally active; 8 subjects had such decreases only in left hemisphere EEG alpha activity and were classified as left hemisphere active; and 4 subjects had such decreases only in right hemisphere EEG alpha activity and were classified as right hemisphere active. The sex and laterality characteristics of the members of these groups are presented in Table 18.

The discriminant analysis produced two canonical discriminant functions and Table 19 presents the results of the tests of significance of residual discrimination. The cerebral activation groups were significantly different ($P<.024$) before the derivation of any discriminant functions, and the first function derived was significant. After the derivation of the first discriminant function, the remaining group differences only approached signifiance ($P<0.114$) and thus, the second function derived only approached significance as well. Therefore, the first function contained more significant information about group differences and the second added only minimally more information. This pattern of discriminability was further reflected by the eigenvalues and

Table 18

EEG Laterality Group Member Characteristics

Spatial Analysis

	Right-Lateralized		Mixed-Lateralized		Total
	Male	Female	Male	Female	
Bilateral	5	3	2	1	11
Left Hemisphere Active	1	1	1	5	8
Right Hemisphere Active	2	0	2	0	4

Table 19

Spatial EEG Laterality Group

Residual Discrimination and Test of Signifiance

Functions Derived	Wilk's Lambda	Chi-Square	D.F.	Significance Level
0	0.318	20.633	10	0.024*
1	0.661	7.450	4	0.114

* P<.05

canonical correlations which characterized the discriminant functions (see Table 20). Thus, as the territorial map illustrates (see Figure 5), the group centroids were clearly separated on the first discriminant function and less well separated, but still distinct, on the second discriminant function. The coordinates of the group centroids are provided in Table 21.

Five variables contributed to the determination of the discriminant scores. These were sex, the first laterality factor score, residual spatial task latency-to-respond, residual spatial EEG alpha amplitude, and residual spatial percent concurrent alpha activity. Examination of the standardized discriminant coefficients (see Table 22) revealed that spatial latency-to-respond, sex and the factor score reflecting general laterality contributed most to the calculation of the discriminant scores on function one, while the measures of residual spatial task alpha amplitude, residual percent concurrent spatial alpha, and sex contributed heavily to the calaculation of the discriminant scores on the second function.

However, the total structure coefficients (see Table 23), that is, the correlations between each variable and the discriminating function, indicated that sex and residual spatial latency-to-respond were the variables most closely related to function one. The first of these variables was negatively related, while the second was positively related. Further, these coefficients revealed that the general laterality factor was most strongly and positively related to function two. Thus, the first, significant function discriminated primarily on the basis of sex and spatial latency-to-respond, while the second function

Table 20

Spatial EEG Laterality Group Discriminant Analysis

Eigenvalues and Measures of Importance

Discriminant Functions	Eigenvalue	Percent of Variance	Canonical Correlation
1	1.080	67.81	0.7206
2	0.513	32.19	0.5822

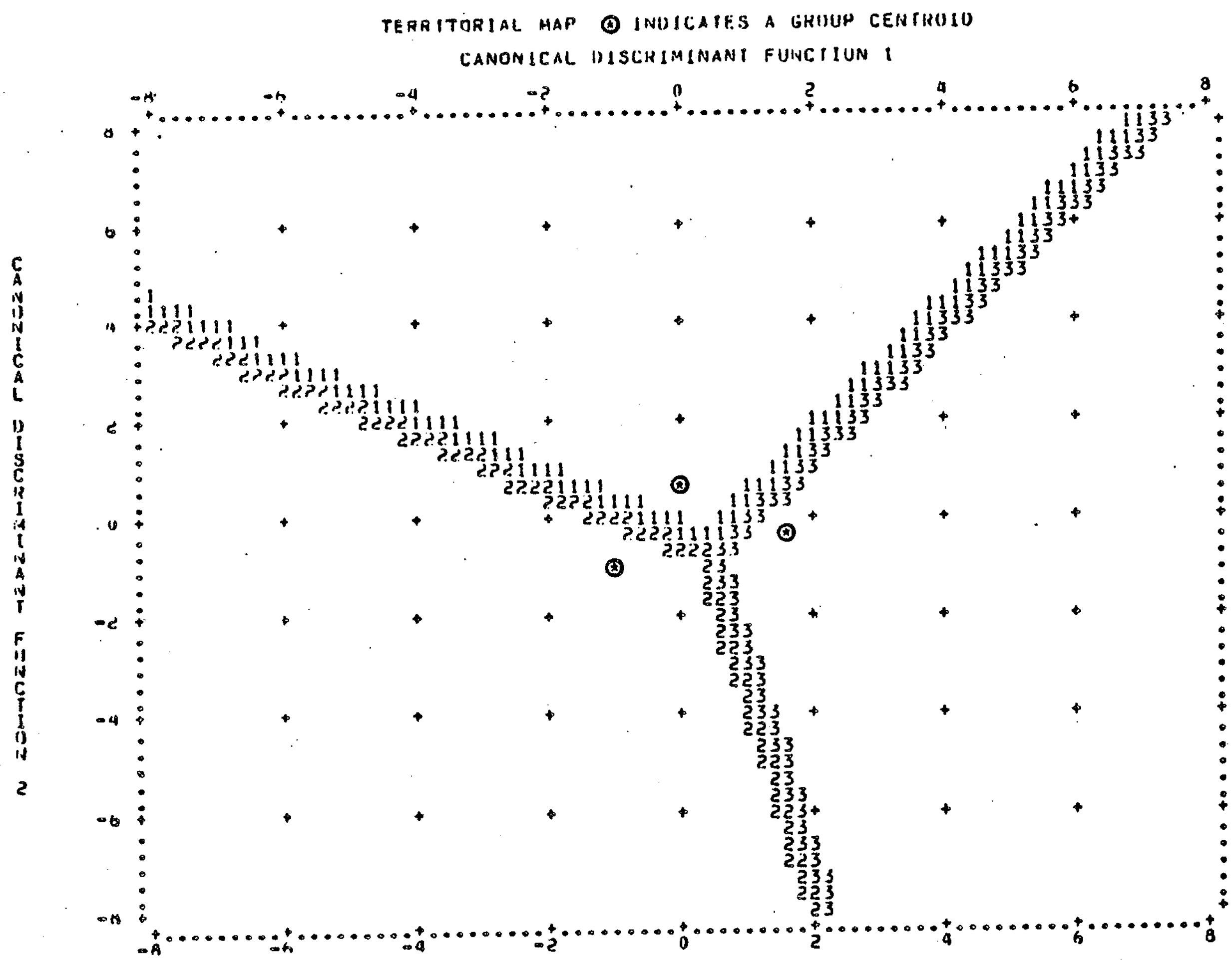

Figure 5. Territorial map: spatial analysis.

Group centroid locations are plotted on discriminant functions 1 and 2, and the boundaries of each laterality group are demarcated. The distance between centroids indicates the degree of separation of the laterality groups.

Table 21

Coordinates of the Spatial EEG Laterality Group Centroids

Group	Function 1	Function 2
Bilateral	0.094	0.809
Left Active	-0.927	-0.937
Right Active	1.595	-0.351

Table 22

Standardized Canonical Discriminant Function Coefficients:

Spatial Analysis

Discriminator	Function 1	Function 2
Sex	-0.575	0.622
Laterality Factor 1	-0.573	0.304
Residual Spatial Latency-to-Respond	0.706	-0.206
Residual Percent Concurrent Spatial Task Alpha	-0.299	0.831
Residual Spatial EEG Amplitude	-0.147	0.837

Table 23

Total Structure Coefficients:

Spatial Analysis

Variable	Function 1	Function 2
Sex	-0.633	-0.122
Laterality Factor 1	0.189	0.702
Residual Spatial Latency-to-respond	0.407	0.488
Residual Percent Concurrent Spatial Task Alpha	0.106	0.397
Residual Spatial EEG Amplitude	-0.351	0.493

discriminated largely on the degree of general laterality. The means and standard deviations for each cerebral activity group on all discriminating variables are presented in Table 24.

In summary, for spatial performance, the bilateral subjects tended to be males who responded moderately quickly to the spatial problems and who reported general right laterality preferences. These subjects also had a higher percentage of concurrent alpha activity and had alpha activity of greater amplitude than did the remaining subject groups. The left hemisphere subjects tended to be females who responded to the spatial problems quickly and had mixed general laterality preferences. Further, these subjects had little concurrent alpha activity and had alpha of low amplitude during spatial task performance. The right active subjects were males who responded more slowly to the spatial problems and who exhibited somewhat mixed laterality preferences. Additionally, these subjects had very little concurrent alpha during spatial task performance and had lower alpha amplitudes during spatial task performance than during the preceding baseline.

The efficacy of the discriminant functions was tested by classifying known group members using the discriminant functions. The resultant classification matrix is presented in Table 25. Of the 23 cases for which group membership was known 73.91% were correctly classified. The computation of tau, a statistic which reflects the proportional reduction in error, indicated that classification based on the discriminating variables made 65.5% fewer errors than would have been expected by random assignment. Thus, the discriminant functions do discriminate the cerebral activity groups.

Table 24

EEG Laterality Group Means and Standard Deviations

on Discriminator Variables:

Spatial Analysis

Group	Sex	Laterality Factor 1	Residual Spatial Latency-to-Respond	Percent Concurrent Spatial Alpha	Residual Spatial EEG Amplitude
Bilateral Activity (N=11)	1.364 SD=0.505	0.303 SD=0.834	0.177 SD=0.919	0.404 SD=1.413	0.759 SD=1.071
Left Hemisphere Active (N=8)	1.750 SD=0.463	-1.313 SD=1.427	-0.755 SD=0.378	-0.612 SD=1.323	0.181 SD=1.465
Right Hemisphere Active (N=4)	1.00 SD=0.000	-0.302 SD=1.258	0.209 SD=0.670	0.021 SD=0.0	-0.507 SD=0.0
Unclassified N=17)	1.588 SD=0.507	-0.423 SD=1.101	0.192 SD=1.159	0.022 SD=0.0	-0.461 SD=0.143
Overall (N=40)	1.500 SD=0.476	-0.389 SD=1.122	-0.000 SD=0.947	0.00 SD=0.946	-0.000 SD=0.987

Table 25

Classification Matrix

Spatial Analysis

Original Group	N of Cases	Predicted Group: Bilateral	Left Active	Right Active
Bilateral	11	8 (72.7%)	1 (9.1%)	2 (18.2%)
Left Active	8	2 (25.0%)	5 (62.5%)	1 (12.5%)
Right Active	4	0 (0.0%)	0 (0.0%)	4 (100.0%)

Hemisphere Ratios: Verbal Performance

Three cerebral activation groups were defined, based on EEG alpha activity ratios. These groups were 1) bilaterally active, 2) left hemisphere active and 3) right hemisphere active. When EEG alpha ratios for verbal task performance were computed, 4 subjects exhibited bilateral activation, 11 subjects were classified as left hemisphere active, and 4 subjects were classified as right hemisphere active. The sex and laterality groups of these subjects are presented in Table 26.

The discriminant analysis produced two canonical discriminant functions. Table 27 presents the results of the tests of signifiance of residual discrimination. The cerebral activation groups were significantly different ($P<.0002$) before the derivation of any discriminant functions, and the first function derived was significant. After the derivation of the first discriminant function, the remaining group differences only approached significance ($P<0.093$) and thus, the second function derived only approached significance. The first function, therefore, contained more significant information about group differences and the second added only minimally more information. This pattern of discriminability was further reflected by the eigenvalues and canonical correlations which characterized the discriminant functions (see Table 28). Further, the group centroids were clearly separated on the first discriminant function and less well separated, but still distinct, on the second discriminant function. The coordinates of the group centroids are provided in Table 29.

Seven variables contributed to the determination of the discriminant scores. These were the two laterality factor scores, the performance

Table 26

EEG Laterality Group Member Characteristics

Verbal Task Analysis

	Right-Lateralized		Mixed-Lateralized		Total
	Male	Female	Male	Female	
Bilateral	2	0	1	1	4
Left Hemisphere Active	4	3	1	3	11
Right Hemisphere Active	1	1	1	1	4

Table 27

Verbal Ratio Laterality Group

Residual Discrimination and Test of Signifiance

Functions Derived	Wilk's Lambda	Chi-Squared	D.F.	Significance Level
0	0.4583	40.077	14	0.0002*
1	0.4339	10.854	6	0.0930

* P<.01

Table 28

Verbal Ratio Laterality Group Discriminant Analysis

Eigenvalues and Measures of Importance

Discriminant Functions	Eigenvalue	Percent of Variance	Canonical Correlation
1	8.468	86.65	0.9457
2	1.305	13.35	0.7524

Table 29

Coordinates of the Verbal Ratio Laterality Group Centroids

Group	Function 1	Function 2
Bilateral	1.123	2.083
Left Active	-2.061	-0.546
Right Active	4.548	-0.580

laterality score, the residual spatial and verbal latency-to-respond scores, the residual left hemisphere verbal-task alpha and the residual verbal EEG alpha amplitude measure. Examination of the standardized discriminant coefficients (see Table 30) revealed that the performance laterality factor and the residual verbal latency-to-respond score, contributed heavily to the calculation of the discriminant scores on function one, while the residual spatial latency-to-respond and the two laterality factor scores contributed highly to the calculation of the discriminant scores on the second function.

However, because the contribution of a variable to the discriminant function can depend on its correlation with other variables, the total structure coefficients (see Table 31), that is, the simple bivariate correlations between each variable and the discriminant function, were also examined. These total structure coefficients indicated that residual left hemisphere alpha was positively and most closely related to function one. Further, laterality factor 2, residual spatial latency-to-respond and residual verbal amplitude were positively related to function two. Thus, the first and significant function discriminated on the basis of alpha distribution, while the second function discriminated on the basis of eyedness and earedness, spatial response time and alpha amplitude. The means and standard deviations for each cerebral activity group on these variables are presented in Table 32.

In summary, during verbal performance, the bilateral subjects were generally mixed lateralized, but right-eyed and -eared individuals, who answered both spatial and verbal problems slowly and had medium levels

Table 30

Standardized Canonical Discriminant Function Coefficients:

Verbal Task Analysis

Discriminator	Function 1	Function 2
Laterality Factor 1	-0.065	-1.181
Laterality Factor 2	1.889	1.118
Performance Laterality	-2.659	-0.136
Residual Spatial Latency-to-Respond	-1.791	1.225
Residual Verbal Latency-to-Respond	2.195	-0.656
Residual Left Hemisphere, Verbal Alpha	1.586	-0.038
Residual Verbal EEG Amplitude	0.115	0.677

Table 31

Total Structure Coefficients:

Verbal Task Analysis

Variable	Function 1	Function 2
Laterality Factor 1	-0.034	-0.247
Laterality Factor 2	-0.008	0.298
Performance Laterality	-0.018	0.194
Residual Spatial Latency-to-Respond	0.053	0.282
Residual Verbal Latency-to-Respond	0.140	0.202
Residual Left Hemisphere, Verbal Alpha	0.473	-0.023
Residual Verbal EEG Amplitude	0.016	0.277

Table 32

Verbal Task Laterality Group Means and Standard Deviations for Discriminator Variables:

Variable	Bilateral	Group Left Hemisphere Active	Right Hemisphere Active	Overall
N	4	11	4	40
Laterality Factor 1	0.687 SD = 1.633	0.074 SD = 0.973	0.011 SD = 0.848	-0.389 SD = 1.214
Laterality Factor 2	0.985 SD = 0.075	0.396 SD = 0.916	0.165 SD = 1.207	0.517 SD = 0.864
Performance Laterality	8.063 SD = 0.157	7.698 SD = 1.054	7.457 SD = 1.055	-7.383 SD = 1.132
Residual Spatial Latency-to-Respond	0.422 SD = 1.122	-0.356 SD = 0.736	-0.211 SD = 1.274	-0.000 SD = 0.987
Residual Verbal Latency-to-Respond	0.316 SD = 0.986	-0.478 SD = 0.518	0.178 SD = 1.377	-0.000 SD = 0.987
Residual Left Hemisphere Verbal Alpha	0.729 SD = 0.989	-0.468 SD = 0.714	1.918 SD = 0.654	-0.000 SD = 0.974
Residual Verbal EEG Amplitude	1.081 SD = 2.074	0.101 SD = 1.345	-0.014 SD = 0.532	-0.000 SD = 0.987

of LH alpha activity of moderate frequency and amplitude. The left hemisphere active subjects tended to be right lateralized. These people responded most quickly to both the verbal and the spatial problem and had little alpha activity in only the LH. Their alpha activity was more equally distributed between hemispheres. The right hemisphere active subjects were generally mixed lateralized with left eyedness and earedness. They responded moderately quickly on the verbal and spatial tasks and had more alpha in only the left hemisphere but had right hemisphere alpha of high amplitude and frequency.

The efficacy of the discriminant functions was tested by classifying known group members using the discriminant functions. The resultant classification matrix is presented in Table 33. Of the 21 cases for which group membership was known, 100% were correctly classified. The computation of *tau*, a statistic which reflects the proportional reduction in error, indicated that classification based on the discriminating variables made 100% fewer errors than would have been expected by random assignment. Thus, the discriminant functions do discriminate the verbal task cerebral activity groups.

Hemisphere Ratios: Spatial Performance

Three cerebral activation groups were also defined on the basis of EEG alpha ratio during spatial performance. These groups were 1) bilaterality active, 2) left hemisphere active and 3) right hemisphere active. When EEG alpha ratios for spatial task performance were computed, 3 subjects exhibited bilateral activation, while 7 subjects were left hemisphere active, and 5 subjects were right hemisphere

Table 33

Classification Matrix

Verbal Task Analysis

		Predicted Group		
Original Group	N of Cases	Bilateral	Left Active	Right Active
Bilateral	4	4 (100%)	0 (0%)	0 (0%)
Left Active	11	0 (0%)	11 (100%)	0 (0%)
Right Active	4	0 (0%)	0 (0.0%)	4 (100.0%)

active. The sex and laterality group membership of these subjects are presented in Table 34.

The discriminant analysis produced two canonical discriminant functions and Table 35 presents the results of the tests of significance of residual discrimination. The cerebral activation groups were significantly different ($P<.009$) before the derivation of any discriminant functions, and the first function derived was highly significant. After the derivation of the first discriminant function, the remaining group differences barely approached significance ($P<0.227$) and thus, the second function derived was not significant. Therefore, the first function contained more significant information about group differences and the second added only minimally more information. This pattern of discriminability was further reflected by the eigenvalues and canonical correlations which characterized the discriminant functions (see Table 36). Thus, the group centroids were clearly separated on both the first and second discriminant functions. The coordinates of the group centroids are provided in Table 37.

Six variables contributed to the determination of the discriminant scores. These were sex, the first and second laterality factor scores, the performance laterality measure, the residual verbal task latency-to-respond, and the residual left hemisphere alpha measure. Examination of the standardized discriminant coefficients (see Table 38) revealed that performance laterality and the laterality factor score reflecting eyedness and earedness contributed most to the calculation of the discriminant scores on function one, while the measures of residual verbal latency-to-respond and sex contributed strongly to the calculation of

Table 34

EEG Laterality Group Member Characteristics

Spatial Task Analysis

	Right-Lateralized		Mixed-Lateralized		Total
	Male	Female	Male	Female	
Bilateral	2	0	1	0	3
Left Hemisphere Active	2	1	2	2	7
Right Hemisphere Active	0	2	1	2	5

Table 35

Spatial Ratio Laterality Group

Residual Discrimination and Test of Signifiance

Functions Derived	Wilk's Lambda	Chi-Square	D.F.	Significance Level
0	0.061	26.510	12	0.009*
1	0.483	6.920	5	0.227

* P<.01

Table 36

Spatial Ratio Laterality Group Discriminant Analysis

Eigenvalues and Measures of Importance

Discriminant Functions	Eigenvalue	Percent of Variance	Canonical Correlation
1	8.862	86.49	0.934
2	1.072	13.51	0.719

Table 37

Coordinates of the Spatial Ratio Laterality Group Centroids

Group	Function 1	Function 2
Bilateral	-0.473	2.730
Left Active	-1.567	0.373
Right Active	2.477	-2.160

Table 38

Standardized Canonical Discriminant Function Coefficients:

Spatial Task Analysis

Discriminator	Function 1	Function 2
Sex	1.731	-0.760
Laterality Factor 1	0.771	-0.438
Laterality Factor 2	2.176	-0.398
Performance Laterality	-3.724	0.662
Residual Verbal Latency-to-Respond	0.532	0.882
Residual Spatial Left Hemisphere Alpha	0.899	0.413

the discriminant scores on the second function.

However, the total structure coefficients (see Table 39), that is, the correlations between each variable and the discriminating function, indicated that residual spatial left hemisphere alpha and sex were the variables most closely and positively related to function one. Further, these coefficients revealed that verbal latency-to-respond was most strongly and positively related to function two. Thus, the first, significant function discriminated primarily on the basis of alpha laterality and sex, while the second function discriminated largely on verbal reaction time. The means and standard deviations for each cerebral activity group on all discriminating variables are presented in Table 40.

In summary, for spatial performance, the bilateral subjects were right peripherally lateralized males who responded slowly to verbal problems and who had moderate amount of left hemisphere alpha. The left hemisphere active subjects were both males and females who were mixed lateralized and who responded to verbal problems quickly and had little left hemisphere alpha activity. The right active subjects were primarily females who were mixed lateralized, responded at a medium rate to verbal problems and had high levels of left hemisphere alpha.

The efficacy of the discriminant functions was tested by classifying known group members using the discriminant functions. The resultant classification matrix is presented in Table 41. Of the 15 cases for which group membership was known 100% were correctly classified. The computation of _tau_, a statistic which reflects the proportional reduction in error, indicated that classification based on the discriminating

Table 39

Total Structure Coefficients:

Spatial Task Analysis

Variable	Function 1	Function 2
Sex	0.238	-0.298
Laterality Factor 1	-0.020	-0.055
Laterality Factor 2	-0.045	0.261
Performance Laterality	-0.092	0.204
Residual Verbal Latency-to-Respond	0.080	0.724
Residual Spatial Left Hemisphere Alpha	0.351	0.310

Table 40

Spatial Task Laterality Group Means and Standard Deviations for Discriminator Variables

Variable	Bilateral	Group Left Hemisphere Active	Right Hemisphere Active	Overall
N	3	7	5	40
Sex	1.00 SD = 0.0	1.43 SD = 0.535	1.80 SD = 0.447	1.5 SD = 0.506
Laterality Factor 1	-0.162 SD = 1.543	-0.365 SD = 1.348	-0.415 SD = 1.181	-0.389 SD = 1.214
Laterality Factor 2	0.968 SD = 0.053	0.243 SD = 1.032	0.297 SD = 1.343	0.517 SD = 0.864
Performance Laterality	8.121 SD = 0.174	7.374 SD = 1.299	7.081 SD = 1.567	-7.383 SD = 1.132
Residual Verbal Latency-to-Respond	0.705 SD = 0.798	-0.708 SD = 0.149	0.204 SD = 1.308	-0.000 SD = 0.987
Residual Spatial Latency-to-Respond	0.221 SD = 0.314	-0.169 SD = 1.025	1.486 SD = 0.735	-0.000 SD = 0.987

Table 41

Classification Matrix

Spatial Task Analysis

		Predicted Group		
Original Group	N of Cases	Bilateral	Left Active	Right Active
Bilateral	3	3 (100%)	0 (0%)	0 (0%)
Left Active	7	0 (0%)	7 (100%)	0 (0%)
Right Active	5	0 (0%)	0 (0.0%)	5 (100.0%)

variables made 100% fewer errors than would have been expected by random assignment. Thus, the discriminant functions do discriminate the cerebral activity groups.

Sex and Laterality Groups

A third discriminant analysis was conducted to determine which of the potential discriminating variables could differentiate between the four sex-by-laterality groups chosen for study. Therefore, the four groups examined were 1) right-lateralized, male; 2) right-lateralized, female; 3) mixed-lateralized, male; and 4) mixed-lateralized, female. Ten variables were used as potential discriminators. These were both the verbal and spatial task measures of number correct, latency-to-respond, residual left hemisphere alpha, residual concurrent alpha, and residual amplitude.

Three discriminant functions were obtained in this analysis. Six variables had been entered as discriminators. These variables were the residual percent of concurrent spatial alpha EEG, the residual verbal EEG amplitude, the number of verbal problems answered correctly, the residual percent of left hemisphere verbal alpha EEG, the residual verbal latency-to respond, and the residual spatial lantecy-to-respond. However, none of the tests of residual discrimination was significant (see Table 41). The differences between the groups were not significant prior to the derivation of the first discriminant function ($P<0.156$) and the group differences became less pronounced as the functions were derived ($P<0.421$ and $P<0.735$, respectively). Therefore, this analysis was not pursued further.

Table 42

Residual Discrimination and Test of Significance:

Sex-by-Laterality Groups

Functions Derived	Wilk's Lambda	Chi-Squared	D.F.	Significance Level
0	0.473	23.978	18	0.156
1	0.727	10.224	10	0.421
2	0.939	2.005	4	0.735

In interpreting the results and evaluating the importance of variables to group discrimination, two factors were of primary importance. The first was the amount of variance accounted for by each discriminant function, while the second was the relative size of the total structure coefficients. Thus, variables with large total structure coefficients on discriminant functions accounting for the greatest amount of variance were interpreted as most important.

Before interpreting the results however, two points should be noted. First, a one-way analysis of variance revealed that the order in which the tasks were presented was not significantly related to any of the variables examined. Second, the verbal and spatial tasks employed were moderately difficult for all subject groups. The mean number of problems correct on the verbal task was 11.63 (72.7%, SD = 2.60) and the mean verbal task latency-to-respond was 9.44 seconds (SD = 3.60). When these scores were examined using a sex - by - laterality analysis of variance, neither measure differed significantly. The spatial task results were similar. The mean number of problems correct on the spatial task was 13.32 (83.3%, SD = 1.66) and the mean spatial latencyto-respond was 7.31 seconds (SD = 3.49). Again, neither of these measures differed significantly when analyzed using analysis of variance. For the control tasks 1 and 2, the mean number of problems correct were 15.95 (99.7%, SD = 0.25) and 15.95 (99.7%, SD = 0.23) respectively, while the respective mean latencies-to-respond were 1.94 seconds (SD = 0.09) and 1.82 seconds (SD = 0.09). Again, analysis of variance revealed no significant differences.

CHAPTER IV

Discussion

The conceptualizations of bilaterality proposed by Buffery and Gray (1972), Annett (1964; 1967; 1972; 1978) and Levy (1969; 1974) were only minimally supported by the results of the analyses which assessed laterality on the basis of changes from baseline, but received somewhat greater support from the analyses which assessed laterality during task performance.

Verbal Bilaterality

Task-Baseline Analysis. The results for verbal laterality, when laterality was determined by changes from baseline EEG activity, were the most disparate from the predictions advanced by Buffery and Gray, Annett and Levy. The hypotheses concerning patterns of cerebral activation advanced by the considerations of bilaterality reviewed, posited that individuals exhibiting bilateral cerebral activation during verbal task performance could be distinguished from those exhibiting lateral activation, in terms of verbal and spatial performance, handedness and sex. Individuals with bilateral cerebral activation would be poor verbal performers according to Annett, or good verbal and poor spatial performers according to Levy. Further, Annett posited that these individuals would be mixed-handed while Levy hypothesized that they would be left-handed. Further, according to Levy, the bilaterally active individuals would be female. Buffery and Gray additionally postulated that individuals who were left hemisphere active during verbal performance would exhibit good verbal performance and be females. None of these hypotheses was confirmed when the patterns of cerebral activation obtained concomitant with verbal performance were examined.

The variable most powerful in discriminating between verbal processing cerebral activation groups was the laterality factor score which strongly represented eyedness and earedness. The second most potent discriminator was the general peripheral laterality factor score, representing handedness, footedness, eyedness and earedness. The remaining discriminators were spatial performance and residual verbal performance EEG alpha amplitude. Of these variables, only spatial performance (Levy) and handedness (Levy, Annett) had been posited as related to patterns of cerebral EEG activity during verbal activity. However, none of the hypothesized patterns was observed.

Individuals who exhibited bilateral cerebral activation contingent upon verbal processing were generally right-eyed and -eared and, as well, were right-handed and -footed. Further, these subjects answered most spatial problems correctly and had high residual verbal task alpha EEG amplitude measures. Thus, these bilaterally active subjects were not the mixed-handed, poor verbal performers anticipated by Annett, nor the left-handed females with good verbal and poor spatial performance predicted by Levy, but rather were right lateralized males and females with good spatial performance and a particular pattern of task specific alpha EEG amplitude.

The lateralized subjects who exhibited only left hemisphere activity during verbal performance were peripherally mixed lateralized and poor spatial performers with medial measures of residual verbal task alpha EEG amplitude. These subjects thus, were not the females with good verbal performance anticipated by Buffery and Gray. The remaining lateralized subjects, who had only right hemisphere activity during verbal performance, were generally right-eyed and -eared, left-handed and -footed, with medium numbers of spatial problems answered correctly and low residual verbal task alpha EEG amplitude measures. No hypotheses had been advanced concerning the characteristics of this group.

The results of the analyses in this study, then, present a quite different set of characteristics as discriminators of the cerebral activation patterns found during verbal processing. It was not handedness, sex nor verbal performance but eyedness and earedness, peripheral laterality, spatial performance and alpha EEG amplitude characteristics that differentiated the cerebral activation groups. Foremost, these results support the importance of eyedness and earedness to verbal processing cerebral activation patterns. The factor score representing eyedness and earedness was the most powerful group discriminator. The importance of these aspects of peripheral laterality had been emphasized by Porac and Coren (1979) and this study extends this emphasis to studies which assess cerebral activation patterns. Previous studies of cerebral activity have generally assessed handedness without measuring other aspects of peripheral laterality (e.g. Galin et al, 1982; Herron, 1980). However, the study demonstrates that all aspects of peripheral laterality are important to patterns of verbal task cerebral activation. Further, the elements of peripheral laterality least often assessed were found to be most important.

Second, the results of the verbal analysis support the concept of an interdependence between verbal and spatial processing, an idea suggested by Levy's conceptualization of laterality. However, Levy's prediction that bilateral cerebral activation during verbal performance would be associated with poor spatial performance was not upheld. On the contrary, it was found that individuals bilateral during verbal performance answered the greatest proportion of spatial problems correctly. Further, subjects who were left hemisphere active answered the fewest spatial problems correctly, while those who were right hemisphere active performed between these two more extreme groups. These findings suggest that the involvement of both hemispheres in verbal processing facilitates the processing necessary for successful spatial task completion while the involvement of only the left hemisphere in verbal processing is detrimental to spatial performance. Acceptance of this hypothesis would necessitate adopting four assumptions about the relation between cognitive processing and the neural basis of that processing which are frequently implied in the laterality literature. First, it would have to be assumed that the amount of neural substrate available for verbal and spatial processing is limited. Second, it would have to be assumed that the distribution of one mode of processing restricted the distribution of the other. Third, it must be assumed that the cerebral hemispheres are "hard-wired" with respect to verbal and spatial processing. That is, when some portion of the cerebral hemispheres is devoted to verbal processing, it is, as a result of this dedication, unavailable for complete dedication to alternate modes of processing. Conversely, cerebral area would be devoted to spatial processing and subsequently unavailable for total dedication to alternate cognitive modes. Finally, it must be assumed that particular patterns of neural substrate dedication are associated with enhanced and diminished task performance. Once these assumptions had been made, the relation between verbal cerebral activation patterns and spatial performance could be explained by stating that the presence of neural substrate dedicated to verbal processing in both cerebral hemispheres resulted in, or resulted from, the pattern of spatial neural substrate dedication associated with enhanced spatial performance. However, the characteristics of this spatial substrate distribution can not be identified from the subjects studied here. Although the eleven subjects who were bilaterally active during verbal processing did not exhibit consistent patterns of hemispheric activation during spatial processing, the majority were also bilaterally active during spatial performance. Six subjects were bilaterally active, one subject was left hemisphere active and two subjects were right hemisphere active during spatial performance. The remaining two subjects were unclassified. Further, and more importantly, no pattern of cerebral activation during spatial activity was associated with more or fewer correctly answered spatial problems. Thus, although spatial performance and verbal lateral activation were found to be associated, the nature of this association does not appear to be the one frequently implied. However, it may be that evaluation of cerebral activation at other hemispheric locations would indicate such an association. On the other hand, it could also be that it is only the distribution of verbal neural substrate which is important to spatial performance, while the distribution of the neural basis of spatial processing has no effect on the efficacy of the processing.

One additional measure was important in the discrimination of the three verbal task cerebral activation groups. This was the residual verbal task alpha EEG amplitude ratio. In its residual form, the contribution of the verbal frequency ratio to this measure had been removed. Thus, this measure reflects only task-specific alpha amplitude, independent of alpha frequency. Higher residual ratios would be indicative of greater left hemisphere alpha amplitude while lower ratios would reflect greater right hemisphere alpha amplitude. If alpha frequency were low when amplitude was high, the ratio would become more extreme. The residual alpha amplitude measure contributed only minimally to the discrimination of the cerebral activity groups. However, the highest levels of residual amplitude were characteristic of individuals with bilateral activation, while the lowest levels were characteristic of those subjects who were right hemisphere active. Moderate residual amplitude measures were characteristic of the left hemisphere active subjects. Thus, although individuals in the bilateral groups had increased cerebral activation in both hemispheres contingent upon task performance, the ability of the residual amplitude measure to contribute to the discrimination between the groups suggests that bilaterals did not have equivalent hemispheric arousal during verbal task alpha. Rather, these subjects had somewhat greater right than left hemisphere activation during periods of low arousal, an asymmetric pattern similar to that found by earlier investigators (Rancy et al, 1943) and later reported by Remond et al (1969). Such differences offer some support to the concept of differential neural substrate dedication but again there is no clear link between activation and performance.

In summary, the results of the verbal task-minus-baseline activation discriminant analysis do not support the concepts of laterality offered in the hypotheses considered. Further, while not providing evidence of a straightforward link between the distribution of brain area dedicated to verbal processing and the efficacy of cognitive processing, these results do reiterate the link between the tasks under investigation and re-emphasize the importance of peripheral laterality to cerebral laterality. Similar concepts emerge from the spatial task-minus-baseline laterality analysis. However, as noted earlier, the discriminant analysis in which laterality was defined based on EEG activation during verbal performance provided greater support for conceptualizations of bilaterality being considered.

Task Analysis. The results for verbal laterality as assessed during task performance provided support for the Annett's contention that bilateral language representation would be associated with diminished verbal performance (long response latencies) and would exist in mixed handers. As well, these results supported Levy's proposition that language bilaterality would be associated with diminished spatial performance. However, verbal bilaterality was not accompanied by enhanced verbal performance, as Levy predicted, nor did right eye dominance have a clear moderating influence since both left hemisphere active and bilaterally active subjects were right eyed. Further, no support was found for Levy's hypothesis that verbal bilaterality would be found in females or left-handers. Rather, verbal bilaterality was found in mixed-handed and -footed individuals with right eye and ear dominance.

Additionally, when the lateralized groups were considered, Buffery and Gray's hypothesis that lateralized language would be associated with enhanced verbal performance was supported. Both the subjects with greater left hemisphere activation during verbal processing and, to a lesser extent, those with right hemisphere activation responded to verbal problems more quickly than did the bilateral subjects.

In general, the results of this analysis are in accord with the majority of language laterality studies. That is, left hemisphere activation during verbal processing was found in strongly right peripherally lateralized subjects, regardless of sex, and was associated with short response latencies on verbal problems. As well, this subject group had short response latencies on spatial problems and a relatively equal distribution of alpha frequency and amplitude. Subjects who were right hemisphere active during verbal performance were mixed handed and footed, with generally left eye and ear dominance. This hemisphere and peripheral laterality pattern was associated with moderate verbal and spatial response latencies and more left hemisphere alpha activity but higher amplitude in right hemisphere alpha.

Thus, when the EEG alpha activity present during verbal performance was considered in isolation from other periods of alpha activity, the subjects' peripheral laterality characteristics contributed heavily to the distinguishing of laterality groups. Further, these distinct cerebral and peripheral laterality groups had characteristic patterns of verbal and spatial performance. Any lateralized cerebral activation was associated with better verbal and spatial performance. The briefest response latencies for both verbal and spatial problems were found in the right peripherally lateralized, left hemisphere active subjects.

The longest latencies were found for the cerebral bilaterally active group, while the right hemisphere active subjects had response latencies which fell between these extremes. Thus, either left or right hemisphere involvement in verbal processing was associated with more efficient verbal and spatial responding. Bilateral verbal activation was accompanied by long response latencies on both problem types. Laterality was associated with more efficient processing, while bilaterality was accompanied by less efficient processing.

Spatial Bilaterality

Task-Baseline Analysis. The results for spatial laterality, when laterality was defined in terms of changes from baseline EEG activity, were also at variance with predictions of Buffery and Gray, Annett and Levy, but not to the degree of those found in the verbal task-baseline analysis. The conceptualizations of bilaterality advanced by Buffery and Gray, and by Levy each postulated that bilateral activation during spatial performance would be found in males and would be associated with good spatial performance. Levy further suggested that bilateral cerebral involvement in spatial performance would be linked to poor verbal performance. No hypotheses were advanced by these authors concerning lateralized cerebral activation during spatial performance. Nor did Annett address the issue of spatial laterality.

The variable most effective in discriminating these spatial processing cerebral activation groups was sex. Individuals with bilateral activation were generally male (64%), while all of the subjects with right hemisphere activation were male (100%) and subjects with left hemisphere activation were generally female (75%). This result provides some support for the hypotheses advanced by Buffery and Gray, and by Levy. Additionally, this finding supports the classic conceptualization of right hemisphere dominance for spatial processing in males advanced by Jackson (1958) and documented by Luria (1980), and indicates the importance of sex to patterns of spatial functioning. However, the second most potent discriminator, latency-to-respond, does not support the hypotheses advanced in the conceptualizations of bilaterality being considered.

The latency measure was a residual measure, independent of the response latencies found for the control tasks. This residual latency measure thus reflected the amount of time necessary to solve the spatial problem, independent of the time necessary to identify the letter of the selected response alternative and to press that response button. The shortest latency-to-respond, and therefore the best performance, was found for the left hemisphere active group while the longest latencies were characteristic of the right hemisphere active group. The bilateral subjects' response latencies generally fell between these two extremes, but were closer to those of the right hemisphere active than to those of the left hemisphere active group. These latency-to-respond differences can not be accounted for simply in terms of subject response hand and resultant hemisphere activation. According to the findings of an investigation of Kinsbourne's (1970) activation hypothesis completed by Cohen (1975), the shortest response latencies should be found in individuals for whom the hemisphere controlling the response hand had been activated by the cognitive task being performed. The reverse has occurred here.

The shortest response latencies were found for the left hemisphere active group, the group with the lowest representation of right-handed responders (38% compared to 75% in the right hemisphere active group and 91% in the bilateral group). However, the longest response latencies were found for the right-hemisphere active group, a group in which 75% of the respondents were right-handed and thus control of the response hand was in the hemisphere contralateral to the one activated by the task. But this small support of Cohen's expectations is greatly weakened by the long response latencies in the group in which both hemispheres were active during task performance. Thus, the activation hypothesis cannot account for the ability of the latency-to-respond measure to discriminate between the cerebral activation groups.

Three additional variables, about which no hypotheses had been advanced, also contributed to the discrimination of the activation groups. These were the laterality factor score which reflected all aspects of peripheral laterality, the residual percent of spatial task concurrent alpha, and the residual spatial task EEG amplitude ratio. The laterality factor scores of the three activity groups indicated that the bilaterally active subjects were generally right lateralized, while the left and right hemisphere active groups were generally mixed lateralized. This finding once again emphasizes the importance of peripheral laterality to patterns of cerebral activation, and further accentuates the weakness of studies in which it is overlooked.

When the amount of residual concurrent alpha was examined, bilateral subjects were found to have the highest levels, while the left hemisphere active group had the least concurrent alpha, with the right hemisphere active group was between these extremes. This spatial task measure of concurrent alpha was independent of the amounts of concurrent alpha present during the first baseline phase and during the two control task phases. Thus it reflects the degree to which the hemispheres are simultaneously uninvolved during spatial task performance. Individuals who were classified as having bilateral hemispheric involvement in task performance also had more bilateral hemispheric non-inolvement during task performance, reinforcing the idea that in these subjects the hemispheres are operating conjointly. This measure also indicated that those subjects who exhibited only left hemisphere activity contingent upon spatial task involvement were least likely to exhibit bilateral hemispheric inactivity during this task. This finding suggests that hemispheric activation was more constant in this subject group than in the other two groups. Perhaps this more continuous left hemisphere activation facilitated motor responding for both the left- and right-handed subjects, resulting in the short latency-to-respond scores characteristic of this cerebral activation group. However the converse of this pattern was not found. The bilaterally active group had the most concurrent inactivation, but did not have the longest latency-to-respond scores.

The final variable to discriminate between the laterality groups was the residual spatial task EEG amplitude ratio. As in the verbal analysis, this residual measure was independent of spatial task alpha frequency. Higher residual amplitude ratios would indicate greater left hemisphere alpha amplitude, while lower ratios would be characteristic of greater right hemisphere amplitude. The highest residual ratios were

were found for the bilaterally active group while the lowest were found for the right hemisphere active group. Those of the left hemisphere active group were midway between these groups. Thus, during inactivation, relatively higher levels of hemispheric activation were present for bilaterals in the left hemisphere and for right active subjects in the right hemisphere during spatial performance.

In summary, the spatial performance bilateral group did not consist of the predicted males with good spatial (Buffery & Gray; Levy) and poor verbal performance (Levy), but of males with medium levels spatial performance, who were generally right lateralized and who had high levels of congruent hemispheric inactivity but with somewhat higher alpha amplitude in the left than in the right hemisphere during spatial task alpha periods. Further, the results of the spatial task discriminant analysis reaffirm a strong link between sex and cerebral activation patterns during spatial performance but emphasize that the cerebral activation groups are best discriminated when information on latecy-to-respond, peripheral laterality, concurrent alpha levels and alpha amplitude are assessed in conjunction with sex. However, somewhat different relations emerge when only the laterality present during spatial task performance is considered.

Task Analysis. As outlined above, only Levy and Buffery and Gray addressed the issue of bilateral cerebral activation during spatial performance and neither of the authors specifically considered spatial laterality. The conceptualizations advanced by Levy received the greatest support from the results of the spatial task discriminant analysis, while these of Buffery and Gray received some, but less, conformation. Both conceptualizations of spatial bilaterality had suggested that it should be found in males and should be accompanied by enhanced spatial performance. Further, Levy speculated that spatial bilaterality would be associated with diminished verbal performance and should exist in right handers. This discriminant analysis revealed that spatial bilaterality existed only in males, thus confirming both Levy's and Buffery and Gray's propositions. It also showed that these individuals were right lateralized and relatively poor verbal task performers, further supporting Levy's hypotheses. However, spatial performance was not found to discriminate between the spatial laterality groups.

Thus, the spatial bilaterally cerebral active group consisted of right lateralized males with long verbal response latencies and a moderate amount of alpha activity restricted to the left hemisphere. The right hemisphere active group were primarily peripherally mixed lateralized females, with moderate verbal response latencies and a large amount of alpha activity limited to the left hemisphere. Finally, the left hemisphere active subjects were also mixed lateralized but this group contained almost equal numbers of males and females. This group also had the shortest verbal response latencies and the least alpha activity confined to the left hemisphere.

These results, while lending support to both Buffery and Gray and Levy are somewhat unanticipated. Most interesting from the point of view of the models under consideration was the lack of relation between spatial laterality and spatial performance. A possible explanation for this unanticipated result might be found in the spatial task employed. The Nebes circle-circle matching test was specifically selected because it had been found to activate the right hemisphere significantly more than the left hemisphere. This selective activation had not found for paper form board, picture completion or mental rotation tasks (Ornstein et al, 1980). Additional support for the uniqueness of this task was found in its lack of relation to WAIS measures of performance. Schultz and McIntyre (unpublished data) have found that performance on the circle-circle matching test, as measured by either response latency or number correct, was not significantly correlated with the WAIS measure of Performance IQ nor with any of the WAIS Performance subscales. Thus, the spatial task employed, while having been found to selectively activate the right hemisphere, does differ from those usually employed to assess spatial laterality and this difference could perhaps account for the lack of relation between spatial laterality and performance. That is, a task with characteristics that activate both the left and right hemisphere in subjects like those employed by Ornstein may be needed to obtain the hypothesized performance, bilaterality relation. Additionally, the lack of relation between spatial laterality and spatial performance may be a consequence of the task employed being efficiently handled by any undedicated cerebral area. Support for this idea can be found in the verbal task laterality analysis. In this analysis it was found that patterns of verbal laterality were related to spatial performance. If verbal task performance activated only the left or right hemisphere, spatial problems were answered quickly. If however, verbal performance activated both the left and the right hemisphere, spatial response latencies were long. Therefore, if the cerebral area involved in verbal processing was restricted, spatial performance was good, regardless of whether during spatial processing there was lateral or bilateral activation. If, however, the cerebral area involved in verbal processing was diffuse, then spatial processing was slow, again regardless of whether the cerebral area involved in spatial processing was lateralized or bilateral. Together, the two task analyses found that spatial performance was unrelated to spatial laterality but predictive of verbal laterality and that verbal performance was predictive of both verbal and spatial laterality. Further, for both types of tasks, lateral activation was associated with good verbal performance, while bilateral activation was related to poor verbal performance. This thus suggests that the spatial processing necessary for the circle matching task is secondary to and more easily accommodated than is the verbal processing necessary for synonym matching.

Finally, it should be noted that once again both sex and peripheral laterality were important for discriminating spatial cerebral activation groups while, of the subject characteristics, only peripheral laterality was important for verbal activation discrimination.

General Discussion and Conclusions

The most striking finding of this study was the discrepancy between the results derived with the two definitions of lateral activation. When patterns of hemispheric activation confined to task performance were examined, they were frequently those anticipated by Levy, Annett or Buffery and Gray or those expected based on traditional conceptualization of laterality. However, when laterality was assessed on the basis of changes from baseline cerebral activation concomitant with verbal or spatial processing, the results were both largely unanticipated and difficult to reconcile with existing views of laterality. In this method of assessment, baseline laterality was essentially removed from task laterality, leaving a remainder which was only idiosyncratically related to the anticipated or expected predictors. However, when laterality was assessed in the same subjects for the same tasks without removal of baseline activation, these uncommon relations were no longer present. Patterns of cerebral activation were then related to subject characteristics, task performance and alpha activity and occurred in anticipated or plausible ways. This strongly suggests that subjects were predisposed to specific cerebral lateral activation patterns for verbal and spatial processing. If so, then such predispositions would cause baseline activation but this influence would be removed if laterality were defined as deviations from baseline activation. However, if such predispositions are not removed but the cerebral activation accompanying verbal or spatial processing is added to these predispositions then, the resultant laterality patterns closely approximate those typically reported in the laterality literature. That such predispositions exist is further supported by the highly significant ($p<.0001$) correlations between the cerebral activation ratios found during the task performance, the original baseline, and the immediately pre-task baseline. The laterality factor reflecting handedness and footedness, the laterality factor associated with eyedness and earedness, and behavioural laterality were all subject characteristics which discriminated between verbal laterality groups and, with the addition of sex, between spatial laterality groups within both means of laterality assessment. Therefore, these factors could determine the predisposition to task specific cerebral activation patterns. However, such causal relations could only be confirmed within a manipulative methodology. Further, it is important to note that broad aspects of peripheral laterality, not just handedness, play a role in laterality predisposition.

In summary, this study investigated bilateral and lateral patterns of cerebral activation during verbal and spatial performance in peripherally right and mixed lateralized subjects. Very atypical results were obtained when laterality was defined as deviations from baseline levels of arousal. However, when laterality was defined by relative amounts of left and right hemisphere alpha activity present during task performance, full support was found for Annett's and partial support for Buffery and Gray's conceptualizations of verbal bilaterality, while general support was found for Levy's and Buffery and Gray's concepts of spatial bilaterality.

Together, the results suggest that peripheral laterality factors predispose an individual to certain cerebral activation patterns during verbal performance and, in conjunction with sex, to certain activation patterns during spatial performance.

The results further emphasize the importance of aspects of peripheral laterality beyond handedness and as well, suggest an interdependence between verbal laterality and verbal and spatial performance that does not extend to spatial laterality. However, further research must be done to explore the causal aspects of all of these relations.

References

Allard F., & Bryden, M. P. The effects of concurrent activity on hemispheric asymmetries. Cortex, 1979, 15, 5-17.

Amochaev, A., & Salamy, A. Stability of EEG laterality effects. Psychophysiology, 1979, 16, 242-246.

Andersen, P., & Andersson, S. A. Physiological basis of the alpha rhythm. New York: Appleton-Century-Crofts, 1968.

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

Annett, M. Genetic and nongenetic influences on handedness. Behavior Genetics, 1978, 8, 227-249.

Bennett, G. K., Seashore, H. G., & Wesman, A. G. Differential Aptitude Tests. New York: The Psychological Corporation, 1947.

Bogen, J.E. The other side of the brain II: An appositional mind. Bulletin of the Los Angeles Neurological Societies, 1969, 34, 135-162.

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

Boles D. B. Laterally biased attention with concurrent verbal load: Multiple failures to replicate. Neuropsychologia, 1979, 17, 353-361.

Bradshaw, J., & Gates, A. Visual field differences in verbal tasks: Effects of task familiarity and sex of subject. Brain and Language, 1978, 5, 166-187.

Bryden, M. Perceptual asymmetry in vision: Relation to handedness, eyedness and speech lateralization. Cortex, 1973, 9, 419-435.

Buffery, A. W. H. Sex differences in the development of hand preference, cerebral dominance for speech and cognitive skill. Bulletin of the British Psychological Society, 1970, 23, 233.

Buffery, A. W. H. An automated technique for the study of the development of cerebral mechanisms subserving linguistic skill. Proceedings of the Royal Society of Medicine, 1971a, 64, 919-922.

Buffery, A. W. H. Sex differences in the development of cognitive skills. Bulletin of the British Psychological Society, 1971b, 24, 242-243.

Buffery, A. W. H. Sex differences in the development of hemispheric asymmetry of function in the human brain. Brain Research, 1971c, 31, 364-365.

Buffery, A. W. H., & Gray, J. A. Sex differences in the development of spatial and linguistic skills. In C. Ounsted & D. C. Taylor (Eds.), Gender differences: Their ontogeny and significance. Edinburgh: Churchill Livingstone, 1972.

Butler, S. Sex differences in electrophysiological correlates of asymmetric cerebral function. The Behavioral and Brain Sciences, 1980, 3, 231-232.

Butler, S. R., Crute, J. E., & Glass, A. The reliability of alpha asymmetries for the assessment of cerebral dominance. Electroencephalography and Clinical Neurophysiology, 1977, 43(N5), 1 773.

Butler, S. R., & Glass, A. Asymmetrics in the electroencephalogram associated with cerebral dominance. Electroencephalography and Clinical Neurophysiology, 1974, 36, 481-491.

Cadwallader, T. C., Semrau, L. A., & Cadwallader, J. V. Early physiological psychology: Circa 3000 B.C. Proceedings of the Annual Convention, A.P.A., 1971, 6, 719-710.

Chi, J., Dooling, E., & Giles, F. Left-right asymmetries of the temporal speech areas of the human fetus. Archives of Neurology, 1977, 34, 346-348.

Cohen, G. Hemisphere differences in the effects of cuing in visual recognition tasks. Journal of Experimental Psychology: Human Perception and Performance, 1975, 1, 366-373.

Coren, S., & Porac, C. The validity and reliability of self-report items for the measurement of lateral preference. British Journal of Psychology, 1978, 69, 207-211.

Davidson, R. J., Schwartz, G. E., Pugash, E., & Bromfield, E. Sex differences in patterns of EEG asymmetry. Biological Psychology, 1976, 4, 119-138.

Donchin, E., Kutas, M., & McCarthy, G. Electrocortical indices of hemispheric utilization. In S. Harnad, R.W. Doty, L. Goldstein, J. Jaynes, & G. Krauthamer (Eds.), Lateralization in the nervous system. New York: Academic Press, 1977.

Doyle, J. C., Ornstein, R., & Galin, D. Lateral specialization of cognitive mode: II. EEG frequency analysis. Psychophysiology, 1974, 11(5), 567-577.

Dumas, R., & Morgan, A. EEG asymmetry as a function of occupation, task, and task difficulty. Neuropsychologia, 1975, 13, 219-228.

Ehrlichman, H. Hemispheric functioning and individual differences in cognitive abilities. Doctoral dissertation, New School for Social Research. University Microfilms, 1971, No. 72-27, 869.

Ehrlichman, H., & Weiner, M. S. Consistency of task-related EEG asymmetries. Psychophysiology, 1979, 16, 247-252.

Entus, A. K. Hemispheric asymmetry in processing of dichotically presented speech and nonspeech stimuli by infants. In S. J. Segalowitz and F. Gruber (Eds.), Language Development and Neurological Theory. New York: Academic Press, 1977.

Frane, J., & Jennrich, R. P4M: Factor analysis. In W. J. Dixon & M. B. Brown (Eds.) BMDP-79: Biomedical Computer Programs. Berkeley, CA: University of California Press, 1979.

Frost, J. D., Jr. Physiological bases of normal EEG rhythmns. In A. Remond (Ed.), Handbook of electroencephalography and clinical neurophysiology (Vol. 6A). Amsterdam: Elsevier Scientific Publishing Company, 1976.

Furst, C. J. EEG asymmetry and visuo-spatial performance. Nature, 1976, 260, 254-255.

Galin, D., Johnstone, J., & Herron, J. Effects of task difficulty on EEG measures of cerebral engagement. Neuropsychologia, 1978, 16, 461-472.

Galin, D., Ornstein, R., Herron, J., & Johnstone, J. Sex and handedness differences in EEG measures of hemispheric specialization. Brain and Language, 1982, 16, 19-55.

Gazzaniga, M. S., & Sperry, R. W. Language after section of the cerebral commissures. Brain, 1967, 90, 131-148.

Geschwind, N., & Levitsky, W. Human brain: Left-right asymmetries in temporal speech region. Science, 1968, 161, 186-187.

Gevins, A. S., Zeitlin, G. M., Doyle, J. C., Yingling, C. D., Schaffer, R. E., Callaway, E., & Yeager, C. L. Electroencephalogram correlates of higher cortical functions. Science, 1979, 203, 665-668.

Gibson, A., Dimond, S., & Gazzaniga, M. S. Left visual field superiority for word matching. Neuropsychologia, 1972, 10, 463-466.

Glanville, A. D., & Antonitis, J. J. The relationship between occipital alpha activity and laterality. Journal of Experimental Psychology, 1955, 49, 294-299.

Gray, J.A. Sex differences in emotional behaviour in mammals including man: Endocrine bases. Acta Psychologica, 1971, 34, 29-46.

Hannay, H., & Boyer, C. Sex differences in hemispheric asymmetry revisited. Perceptual and Motor Skills, 1978, 47, 317-321.

Harris, L. J. Sex differences in spatial ability: Possible environmental, genetic, and neurological factors. In M. Kinsbourne (Ed.) Hemispheric asymmetries of function. Springfield, Ill.: C. C. Thomas, 1975.

Herron J. Two hands, two brains, two sexes. In J. Herron (Ed.), Neuropsychology of left-handedness. New York: Academic Press, 1980.

Hull, J. G., & Nie, N. H. SPSS: Statistical package for the social sciences. New York: McGraw Hill, 1981.

Jackson, J. H. Case of large cerebral tumor without optic neuritis and left hemiplegia and imperception. In J. Taylor (Ed.), Selected writings of John Hughling Jackson, Vol. 2. New York: Basic Books, 1958.

Jasper, H. H. The ten-twenty electrode system of the international federation. Electroencephalography and Clinical Neurophysiology. 1958, 10, 371-375.

Johnson, O., & Harley, C. Handedness and sex differences in cognitive tests of brain laterality. Cortex, 1980, 16, 73-82.

Kimura, D. Dual functional asymmetry of the brain in visual perception. Neuropsychologia, 1961, 4, 275-25.

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

Kimura, D. The asymmetry of the human brain. Scientific American, 1973, 228, 70-78.

Kinsbourne, M. The cerebral basis of lateral asymmetries in attention. Acta Psychologia, 1970, 33, 193-201.

Klatzky, R., & Atkinson, R. C. Specialization of the cerebral hemispheres for information in short term memory. Perception and Psychophysics, 1971, 10, 335-338.

Kocel, K. M. Cognitive abilities: Handedness, familial sinistrality and sex. Annals of the New York Academy of Sciences, 1977, 299, 232-243.

Kraft, R.H. The relationship between right-handed children's assessed and familial handedness and lateral specialization. Neuropsychologia, 1981, 19, 697-705.

Landsdell, H. The use of factor scores from the Wechsler-Bellevue Scale of Intelligence in assessing patients with temporal lobe removals. Cortex, 1968a, 4, 257-268.

Landsdell, H. Effect of extent of temporal lobe ablations on two lateralized deficits. Physiology and Behavior, 1968b, 3, 271-273.

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

Levy, J. Psychobiological implications of bilateral asymmetry. In S. J. Dimond & J. G. Beaumont (Eds.), Hemispheric Function in the Human Brain. New York: Wiley, 1974.

Levy, J., & Gur, R.C. Individual differences in psychoneurological organization. In J. Herron (Ed.), Neuropsychology of left-handedness. New York: Academic Press, 1980.

Levy, J., & Reid, M. Variations in writing posture and cerebral organization. Science, 1976, 194, 337-339.

Luria, A. R. Higher cortical functions in man (2nd ed.). New York: Basic Books, 1980.

Maccoby, E. E., & Jacklin, C. N. The psychology of sex differences. Stanford, Calif.: Stanford University Press, 1974.

Marsh, G. R. Asymmetry of electrophysiological phenomena and its relation to behavior in humans. In M. Kinsbourne (Ed.), Asymmetrical function of the brain. Cambridge: Cambridge University Press, 1978.

Marshall, J. C., & Holmes, J. Sex, handedness and differential hemispheric specialization for components of word perception. International Research Communication System, 1974, 2, 1344.

McGlone, J. Sex differences in the cerebral organization of verbal functions in patients with unilateral brain lesions. Brain, 1977, 100, 775-793.

McGlone, J. Sex differences in human brain asymmetry: A critical survey. The Behavioral and Brain Sciences, 1980, 3, 215-227.

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.

McKeever, W. F., & Van Deventer, A. D. Visual and auditory language processing asymmetries: Influences of handedness, familial sinistrality and sex. Cortex, 1977, 13, 225-241.

McKeever, W.G., Van Deventer, A. D., & Suberi, M. Avowed, assessed, and familial handedness and differential hemispheric processing of brief sequential and nonsequential visual stimuli. Neuropsychologia, 1973, 11, 235-238.

McLeod, S. S., & Peacock, L. J. Task-related EEG asymmetry: Effects of age and ability. Psychophysiology, 1977, 14, 308-311.

Miller, E. Handedness and the pattern of human ability. British Journal of Psychology, 1971, 62, 111-112.

Milstein, V., Small, I. F., Malloy, F., & Small, J.G. Influence of sex and handedness on hemispheric functioning. Cortex, 1979, 16, 439-449.

Molfese, D. L., Freeman, R. B., Jr., & Palermo, D. S. The ontogeny of brain lateralization for speech and nonspeech stimuli. Brain and Language, 1975, 2, 356-368.

Moore, W. J., Jr. Alpha hemispheric asymmetry of males and females on verbal and non-verbal tasks: Some preliminary results. Cortex, 1979, 15, 321-326.

Morgan, A. H., MacDonald, H., & Hilgard, E. R. EEG alpha: Lateral asymmetry related to task and hypnotizability. Psychophysiology, 1974, 11, 275-282.

Morgan, A.H., McDonald, D. J., & MacDonald, H. Differences in bilateral alpha activity as a function of experimental task, with a note on lateral eye movements and hypnotizability. Neuropsychologia, 1971, 9, 459-469.

Nagafuchi, M. Development of dichotic and monaural hearing abilities in young children. Acta Otolaryngologica, 1970, 69, 409-414.

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

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

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

Ornstein, R., Johnstone, J., Herron, J., & Swencionis, C. Differential right hemisphere engagement in visuospatial tasks. Neuropsychologia, 1980, 18, 49-64.

Pedhazur, E. J. Multiple regression in behavioural research (2nd ed.). New York: Holt, Rinehart and Winston, 1981.

Penfield, W., & Roberts, L. Speech and brain mechanisms. Princeton: Princeton University Press, 1975.

Penfield, W., & Roberts, L. Speech and brain-mechanisms. Princeton: Princeton University Press, 1959.

Piazza, D. M. The influence of sex and handedness in the hemispheric specialization of verbal and non-verbal tasks. Neuropsychologia, 1980, 18, 163-176.

Porac, C., & Coren, S. The validity and reliability of self-report items for the measurement of lateral preference. British Journal of Psychology, 1978, 69, 207-211.

Porac, C., & Coren, S. Individual and familial patterns in four dimensions of lateral preference. Neuropsychologia,. 1979, 17, 543-548.

Porac, C., & Coren, S., Steiger, J. H., & Duncan, P. Human laterality: A multidimensional approach. Canadian Journal of Psychology, 1980, 34, 91-96.

Pribram, K. H. Languages of the brain. Englewood Cliffs, New Jersey: Prentice Hall, 1971.

Provins, K. A., & Cunliffe, P. The relationship between EEG activity and handedness. Cortex, 1972, 8, 136-146.

Rancy, E. T. Brain potentials and lateral dominance in identical twins. Journal of Experimental Psychology, 1939, 24, 21-39.

Rasmussen, T., & Milner, B. Clinical and surgical studies of the cerebral speech areas in man. In K. J. Zulch, O. Creutzfeldt, & G. C. Galbraith (Eds.), Cerebral localization. Berlin: Springer-Verlag, 1975.

Ratcliff, G., Dila, C., Taylor, L., & Milner, B. The morphological asymmetry of the hemispheres and cerebral dominance for speech: A possible relationship. Brain and Language, 1980, 11, 87-98.

Ray, W.J., Morell, M., Frediani, A.W., & Tucker, D. Sex differences and lateral specialization of hemispheric functioning. Neuropsychologia, 1976, 14, 391-394.

Ray, W. J., Newcombe, N., Semon, J., & Cole, P. M. Spatial abilities, sex differences and EEG functioning. Neuropsychologia, 1981, 19, 719-722.

Remond, A., Leseure, N., Joseph, J. P., Rieger, H., & Lairy, G. C. The alpha average. I. Methodology and description. Electroencephalography and Clinical Neurophysiology, 1969, 27, 364-372.

Rizzolatti, G., Umilta, C., & Berlucchi, G. Opposite superiorities of the right and left cerebral hemispheres in discriminative reaction time to physiognomical and alphabetical material. Brain, 1971, 94, 431-432.

Shagass, C. Electrical activity of the brain. In N.S. Greenfield & R.A. Sternback (Eds.), Handbook of psychophysiology. New York: Holt, Rinehart & Winston, Inc., 1972.

Sherman, J. On the psychology of women. Springfield, Ill.: Charles C. Thomas, 1971.

Smyk, K., & Darwaj, B. Dominance of one cerebral hemisphere in the electroencephalographic record. Acta Psycologica Polonica, 1972, 23, 359-367.

Sperry, R. W. Lateral specialization in the surgically separted hemispheres. In F. P. Schmitt & F. G. Worden (Eds.), _The neurosciences third study program_. Cambridge, Massachusetts: MIT Press, 1974.

Sperry, R. W., Gazzaniga, M. S., & Bogen, J. E. Interhemispheric relationships: The neocortical commissures: Syndromes of hemisphere disconnection. _Handbook of Clinical Neurology_, 1969, _4_, 273-290.

Spring, S. P. Tachistoscopic and dichotic listening investigations of laterality in normal human subjects. In S. Harnad, R.W. Doty, L. Goldstein, J. Jaynes, & G. Krauthamer (Eds.), _Lateralization in the nervous system_. New York: Academic Press, 1977.

Springer, S. P., & Deutsch, G. _Left brain, right brain_. San Francisco, California: W. H. Freeman and Company, 1981.

Stern, R. M., Ray, W.J., & Davis, C. M. _Psychophysiological Recording_. New York: Oxford University Press, 1980.

Strauss, H., Liberson, W.T., & Meltzer, T. Electroencephalographic studies: Bilateral differences in alpha activity in cases with and without cerebral pathology. _Journal of Mount Sinai Hospital_, 1943, _9_, 957-962.

Tapley, S.M., & Bryden, M. P. A group test to assess hand preference. Paper Presentation, Canadian Psychological Association Annual Meeting, Calgary, 1980.

Thatcher, R. W., & John, E. R. _Foundations of cognitive processess_. New York: John Wiley & Sons, 1977.

Thompson, R. F. Introduction to physiological psychology. New York: Harper & Row, 1975.

Trotman, S. C. A., & Hammond, G. R. Sex differences in task-dependent EEG asymmetries. Psychophysiology, 1979, 16, 429-431.

Tucker, D. M. Sex differences in hemispheric specialization for synthetic visuospatial functions. Neuropsychologia, 1976, 14, 447-451.

Vargha-Khadem, F. & Corballis, M.C. Cerebral asymmetry in infants. Brain and Language, 1979, 8, 1-9.

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. Igaku to Seibutsugaku, 1949, 14, 221-222.

Wada, J. A., Clark, R., & Hamm, A. Cerebral hemispheric asymmetry in humans. Archives of Neurology, 1975, 32, 239-246.

Walter, R. D., & Yeager, C. L. Visual imagery and electroencephalographic changes. Electroencephalography and Clinical Neurophysiology, 1956, 8, 193-197.

Wogan, M., Kaplan, C., Moore, S., & Epro. R. Sex differences and task effects in lateralization of EEG-alpha. International Journal of Neuroscience, 1979, 8, 219-223.

Young, R.M. Mind, brain and adaptation in the nineteenth century. Oxford: Clarendon Press, 1970.

Zangwill, O. L. Speech and the minor hemisphere. Acta Neurologica Psychiatric Belgium, 1967, 67, 1013-1020.

Zurif, E.G., & Mendelsohn, M. Hemispheric specialization for the perception of speech sounds: The influence of intonation and structure. Perception and Psychophysics, 1972, 11, 329-332.

APPENDIX A

LATERALITY QUESTIONNAIRE

Laterality Questionnaire

Please indicate your preferences for the use of your right or left hands, feet, eyes or ears in the following activities, using the following scale:

1 = very strong LEFT preference
2 = LEFT preference
3 = no preference (equally likely to use left or right)
4 = RIGHT preference
5 = very strong RIGHT preference

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

Please try to answer all the questions. Leave a blank only if you have no experience at all with the object or task. Answer the questions on this sheet by circling the appropriate number.

A. Which hand do you use for:

	LEFT					RIGHT
1. writing		1	2	3	4 5	
2. drawing		1	2	3	4 5	
3. throwing		1	2	3	4 5	
4. scissors		1	2	3	4 5	
5. toothbrush		1	2	3	4 5	
6. knife (with fork)		1	2	3	4 5	
7. spoon		1	2	3	4 5	
8. broom (upper hand)		1	2	3	4 5	
9. striking match (match)		1	2	3	4 5	
10. opening box (lid)		1	2	3	4 5	

B. Which foot do you use to:

11. kick a ball	1	2	3	4	5
12. step on a bug	1	2	3	4	5

C. Which eye do you use to:

13. look through a telescope	1 2 3 4 5
14. peep through a key hole	1 2 3 4 5

D. Which ear do you use to:

15. listen to a transistor radio with an ear plug	1 2 3 4 5
16. listen in on a conversation going on behind a closed door	1 2 3 4 5

On the scale below, please indicate the hand used most frequently by each member of your biological family.

1 = RIGHT hand
2 = LEFT hand
3 = uses both left and right with equal frequency
4 = do not know

If an alternative does not apply, please leave it blank.

	R	L	B	?
Mother	1	2	3	4
Father	1	2	3	4
Sister A	1	2	3	4
Sister B	1	2	3	4
Sister C	1	2	3	4
Sister D	1	2	3	4
Sister E	1	2	3	4
Sister F	1	2	3	4
Brother A	1	2	3	4
Brother B	1	2	3	4
Brother C	1	2	3	4
Brother D	1	2	3	4
Brother E	1	2	3	4
Brother F	1	2	3	4

APPENDIX B

LATERALITY CORRELATIONS

The Pearson Product Moment correlations were tested for significance using a one-tailed test.

ABBREVIATION KEY

Item	Abbreviation
Laterality Questionnaire: Screening Administration	
#1	WRITES
#2	DRAWS
#3	THROWS
#4	SCISSORS
#5	TOOTHS
#6	KNIFES
#7	SPOONS
#8	BROOMS
#9	MATCHES
#10	BOXS
#11	BALLS
#12	BUGS
#13	TELESCPS
#14	KEYHOLES
#15	RADIOS
#16	DOORS
familial handedness	FAMHANDS
Laterality Questionnaire: Session Administration	
#1	WRITE
#2	DRAW
#3	THROW
#4	SCISSOR
#5	TOOTH
#6	KNIFE
#7	SPOON
#8	BROOM
#9	MATCH
#10	BOX
#11	BALL
#12	BUG
#13	TELESCP
#14	KEYHOLE
#15	RADIO
#16	DOOR
maternal handedness	MOM
familial handedness	FAMHAND
Behavioural Measures	
handedness	BEANBAG
footedness	STEPX
eyedness	TUBE
earedness	PLUB
Hand Preference Test ratio (right - left/right + left)	DOTRATIO

P E A R S O N   C O R R E L A T I O N   C O E F F I C I E N T S

VARIABLE PAIR		VARIABLE PAIR		VARIABLE PAIR	
WRITES	1.0000	WRITES	0.1941	WRITES	0.5595
WITH	N(40)	WITH	N(40)	WITH	N(40)
DRAWS	SIG .000	THROWS	SIG .115	SCISSURS	SIG .000
WRITES	0.4106	WRITES	0.7357	WRITES	0.5212
WITH	N(40)	WITH	N(40)	WITH	N(40)
BROOMS	SIG .004	MATCHS	SIG .000	BOXS	SIG .000
WRITES	0.3718	WRITES	0.6763	WRITES	0.6289
WITH	N(40)	WITH	N(40)	WITH	N(40)
KEYHOLES	SIG .009	RADIOS	SIG .000	DOORS	SIG .000
WRITES	0.3137	WRITES	0.6060	WRITES	0.5995
WITH	N(40)	WITH	N(40)	WITH	N(40)
THROW	SIG .024	SCISSOR	SIG .000	TOOTH	SIG .000
WRITES	0.4353	WRITES	0.2978	WRITES	0.4317
WITH	N(40)	WITH	N(40)	WITH	N(40)
MATCH	SIG .002	BOX	SIG .031	BALL	SIG .003
WRITES	0.5842	WRITES	0.4709	WRITES	0.1049
WITH	N(40)	WITH	N(40)	WITH	N(40)
RADIO	SIG .000	DOOR	SIG .001	MOM	SIG .260
WRITES	0.3479	WRITES	0.3172	WRITES	0.9141
WITH	N(40)	WITH	N(40)	WITH	N(40)
TUBE	SIG .014	PLUG	SIG .023	OUTRATIO	SIG .000
DRAWS	0.3761	DRAWS	0.8073	DRAWS	0.4106
WITH	N(40)	WITH	N(40)	WITH	N(40)
KNIFES	SIG .008	SPOONS	SIG .000	BROOMS	SIG .004
WRITES	0.6970	WRITES	0.3761	WRITES	0.8073
WITH	N(40)	WITH	N(40)	WITH	N(40)
TOOTHS	SIG .000	KNIFES	SIG .008	SPOONS	SIG .000
WRITES	0.4859	WRITES	0.5477	WRITES	0.3227
WITH	N(40)	WITH	N(40)	WITH	N(40)
BALLS	SIG .001	BUGS	SIG .000	TELESCPS	SIG .021
WRITES	0.1808	WRITES	0.9810	WRITES	0.9884
WITH	N(40)	WITH	N(40)	WITH	N(40)
FAMHANDS	SIG .132	WRITE	SIG .000	DRAW	SIG .000
WRITES	0.1519	WRITES	0.7902	WRITES	0.3335
WITH	N(40)	WITH	N(40)	WITH	N(40)
KNIFE	SIG .175	SPOON	SIG .000	BROOM	SIG .018
WRITES	0.3914	WRITES	0.4881	WRITES	0.4788
WITH	N(40)	WITH	N(40)	WITH	N(40)
BUG	SIG .006	TELESCP	SIG .001	KEYHOLE	SIG .001

VARIABLE PAIR		VARIABLE PAIR		VARIABLE PAIR	
WRITES WITH FAMHAND	0.1716 N(40) SIG .145	WRITES WITH BEANBAG	0.2793 N(40) SIG .040	WRITES WITH STEPX	0.0268 N(40) SIG .435
DRAWS WITH THROWS	0.1941 N(40) SIG .115	DRAWS WITH SCISSORS	0.5595 N(40) SIG .000	DRAWS WITH TOOTHS	0.6970 N(40) SIG .000
DRAWS WITH MATCHS	0.7357 N(40) SIG .000	DRAWS WITH BOXS	0.5212 N(40) SIG .000	DRAWS WITH BALLS	0.4859 N(40) SIG .001
DRAWS WITH BUGS	0.5477 N(40) SIG .000	DRAWS WITH TELESCPS	0.3227 N(40) SIG .021	DRAWS WITH KEYHOLES	0.3718 N(40) SIG .009
DRAWS WITH WRITE	0.9810 N(40) SIG .000	DRAWS WITH DRAW	0.9884 N(40) SIG .000	DRAWS WITH THROW	0.3137 N(40) SIG .024
DRAWS WITH SPOON	0.7902 N(40) SIG .000	DRAWS WITH BROOM	0.3335 N(40) SIG .018	DRAWS WITH MATCH	0.4353 N(40) SIG .002
DRAWS WITH TELESCP	0.4881 N(40) SIG .001	DRAWS WITH KEYHOLE	0.4788 N(40) SIG .001	DRAWS WITH RADIO	0.5842 N(40) SIG .000
DRAWS WITH BEANBAG	0.2793 N(40) SIG .040	DRAWS WITH STEPX	0.0268 N(40) SIG .435	DRAWS WITH TUBE	0.3479 N(40) SIG .014
THROWS WITH TOOTHS	0.4431 N(40) SIG .002	THROWS WITH KNIFES	0.1948 N(40) SIG .114	THROWS WITH SPOONS	0.2180 N(40) SIG .088
THROWS WITH BALLS	0.5027 N(40) SIG .000	THROWS WITH BUGS	0.2318 N(40) SIG .075	THROWS WITH TELESCPS	0.3328 N(40) SIG .018
THROWS WITH FAMHANDS	0.4721 N(40) SIG .001	THROWS WITH WRITE	0.1965 N(40) SIG .112	THROWS WITH DRAW	0.2121 N(40) SIG .094
DRAWS WITH RADIOS	0.6763 N(40) SIG .000	DRAWS WITH DOORS	0.6289 N(40) SIG .000	DRAWS WITH FAMHANDS	0.1808 N(40) SIG .132
DRAWS WITH SCISSOR	0.6060 N(40) SIG .000	DRAWS WITH TOOTH	0.5995 N(40) SIG .000	DRAWS WITH KNIFE	0.1519 N(40) SIG .175

VARIABLE PAIR		VARIABLE PAIR		VARIABLE PAIR	
DRAWS WITH BOX	0.2978 N(40) SIG .031	DRAWS WITH BALL	0.4317 N(40) SIG .003	DRAWS WITH BUG	0.3914 N(40) SIG .006
DRAWS WITH DOOR	0.4709 N(40) SIG .001	DRAWS WITH MOM	0.1049 N(40) SIG .260	DRAWS WITH FAMHAND	0.1716 N(40) SIG .145
DRAWS WITH PLUG	0.3172 N(40) SIG .023	DRAWS WITH DOTRATIO	0.9141 N(40) SIG .000	THROWS WITH SCISSORS	0.1961 N(40) SIG .113
THROWS WITH BROOMS	0.3059 N(40) SIG .027	THROWS WITH MATCHS	0.4434 N(40) SIG .002	THROWS WITH BOXS	0.3033 N(40) SIG .029
THROWS WITH KEYHOLES	0.2992 N(40) SIG .030	THROWS WITH RADIOS	0.4476 N(40) SIG .002	THROWS WITH DOORS	0.5733 N(40) SIG .000
THROWS WITH THROW	0.7341 N(40) SIG .000	THROWS WITH SCISSOR	0.1153 N(40) SIG .239	THROWS WITH TOOTH	0.2669 N(40) SIG .048
THROWS WITH KNIFE	0.1154 N(40) SIG .239	THROWS WITH SPOON	0.2162 N(40) SIG .090	THROWS WITH BROOM	0.0783 N(40) SIG .316
THROWS WITH BUG	-0.0317 N(40) SIG .423	THROWS WITH TELESCP	0.2457 N(40) SIG .063	THROWS WITH KEYHOLE	0.2280 N(40) SIG .079
THROWS WITH FAMHAND	0.1724 N(40) SIG .144	THROWS WITH BEANBAG	0.8620 N(40) SIG .000	THROWS WITH STEPX	0.3391 N(40) SIG .016
SCISSORS WITH TOOTHS	0.5483 N(40) SIG .000	SCISSORS WITH KNIFES	0.3831 N(40) SIG .007	SCISSORS WITH SPOONS	0.5989 N(40) SIG .000
SCISSORS WITH BALLS	0.3705 N(40) SIG .009	SCISSORS WITH BUGS	0.5806 N(40) SIG .000	SCISSORS WITH TELESCPS	0.6002 N(40) SIG .000
SCISSORS WITH FAMHANDS	0.1452 N(40) SIG .186	SCISSORS WITH WRITE	0.5224 N(40) SIG .000	SCISSORS WITH DRAW	0.5400 N(40) SIG .000
SCISSORS WITH KNIFE	0.2826 N(40) SIG .039	SCISSORS WITH SPOON	0.5299 N(40) SIG .000	SCISSORS WITH BROOM	0.2091 N(40) SIG .098

VARIABLE PAIR		VARIABLE PAIR		VARIABLE PAIR	
SCISSORS WITH BUG	0.3578 N(40) SIG .012	SCISSORS WITH TELESCP	0.5137 N(40) SIG .000	SCISSORS WITH KEYHOLE	0.4954 N(40) SIG .001
THROWS WITH MATCH	0.4942 N(40) SIG .001	THROWS WITH BOX	0.1491 N(40) SIG .179	THROWS WITH BALL	0.2841 N(40) SIG .038
THROWS WITH RADIO	0.3899 N(40) SIG .006	THROWS WITH DOOR	0.3083 N(40) SIG .026	THROWS WITH MOM	0.1524 N(40) SIG .174
THROWS WITH TUBE	0.3035 N(40) SIG .028	THROWS WITH PLUG	0.3516 N(40) SIG .013	THROWS WITH DOTRATTO	0.2770 N(40) SIG .042
SCISSORS WITH BROOMS	0.4030 N(40) SIG .005	SCISSORS WITH MATCHS	0.6077 N(40) SIG .000	SCISSORS WITH BOXS	0.5360 N(40) SIG .000
SCISSORS WITH KEYHOLES	0.6385 N(40) SIG .000	SCISSORS WITH RADIOS	0.5774 N(40) SIG .000	SCISSORS WITH DOORS	0.4713 N(40) SIG .001
SCISSORS WITH THROW	0.1405 N(40) SIG .194	SCISSORS WITH SCISSOR	0.9344 N(40) SIG .000	SCISSORS WITH TOOTH	0.4024 N(40) SIG .005
SCISSORS WITH MATCH	0.4467 N(40) SIG .002	SCISSORS WITH BOX	0.3740 N(40) SIG .009	SCISSORS WITH BALL	0.4295 N(40) SIG .003
SCISSORS WITH RADIO	0.3628 N(40) SIG .011	SCISSORS WITH DOOR	0.4662 N(40) SIG .001	SCISSORS WITH MOM	0.1007 N(40) SIG .268
SCISSORS WITH FAMHAND	0.2395 N(40) SIG .068	SCISSORS WITH BEANBAG	0.0736 N(40) SIG .326	SCISSORS WITH STEPX	0.2920 N(40) SIG .034
TOOTHS WITH KNIFES	0.4738 N(40) SIG .001	TOOTHS WITH SPOONS	0.8329 N(40) SIG .000	TOOTHS WITH BROOMS	0.3829 N(40) SIG .007
TOOTHS WITH BUGS	0.4609 N(40) SIG .001	TOOTHS WITH TELESCPS	0.3073 N(40) SIG .027	TOOTHS WITH KEYHOLES	0.3500 N(40) SIG .013
TOOTHS WITH WRITE	0.6579 N(40) SIG .000	TOOTHS WITH DRAW	0.6833 N(40) SIG .000	TOOTHS WITH THROW	0.4842 N(40) SIG .001

VARIABLE PAIR		VARIABLE PAIR		VARIABLE PAIR	
TOOTHS WITH SPOON	0.8463 N(40) SIG .000	TOOTHS WITH BROOM	0.3681 N(40) SIG .010	TOOTHS WITH MATCH	0.5809 N(40) SIG .000
TOOTHS WITH TELESCP	0.3443 N(40) SIG .015	TOOTHS WITH KEYHOLE	0.3450 N(40) SIG .015	TOOTHS WITH RADIO	0.6949 N(40) SIG .000
TOOTHS WITH BEANBAG	0.3945 N(40) SIG .006	TOOTHS WITH STEPX	0.0699 N(40) SIG .334	TOOTHS WITH TUBE	0.2682 N(40) SIG .047
KNIFES WITH BROOMS	0.3023 N(40) SIG .029	KNIFES WITH MATCHS	0.2959 N(40) SIG .032	KNIFES WITH BOXS	0.4834 N(40) SIG .001
SCISSORS WITH TUBE	0.5242 N(40) SIG .000	SCISSORS WITH PLUG	0.3934 N(40) SIG .006	SCISSORS WITH DOTRATIO	0.6387 N(40) SIG .000
TOOTHS WITH MATCHS	0.6199 N(40) SIG .000	TOOTHS WITH BOXS	0.5017 N(40) SIG .000	TOOTHS WITH BALLS	0.3754 N(40) SIG .008
TOOTHS WITH RADIOS	0.7140 N(40) SIG .000	TOOTHS WITH DOORS	0.7246 N(40) SIG .000	TOOTHS WITH FAMHANDS	0.5710 N(40) SIG .000
TOOTHS WITH SCISSOR	0.5208 N(40) SIG .000	TOOTHS WITH TOOTH	0.7344 N(40) SIG .000	TOOTHS WITH KNIFE	0.3929 N(40) SIG .006
TOOTHS WITH BOX	0.0923 N(40) SIG .286	TOOTHS WITH BALL	0.2608 N(40) SIG .052	TOOTHS WITH BUG	0.1553 N(40) SIG .169
TOOTHS WITH DOOR	0.5618 N(40) SIG .000	TOOTHS WITH MOM	0.1401 N(40) SIG .194	TOOTHS WITH FAMHAND	0.3134 N(40) SIG .024
TOOTHS WITH PLUG	0.5943 N(40) SIG .000	TOOTHS WITH DOTRATIO	0.7234 N(40) SIG .000	KNIFES WITH SPOONS	0.5630 N(40) SIG .000
KNIFES WITH BALLS	0.2552 N(40) SIG .056	KNIFES WITH BUGS	0.6810 N(40) SIG .000	KNIFES WITH TELESCPS	0.5086 N(40) SIG .000
KNIFES WITH KEYHOLES	0.4923 N(40) SIG .001	KNIFES WITH RADIOS	0.5850 N(40) SIG .000	KNIFES WITH DOORS	0.4718 N(40) SIG .001

VARIABLE PAIR		VARIABLE PAIR		VARIABLE PAIR	
KNIFFS WITH THROW	0.1001 N(40) SIG .269	KNIFFS WITH SCISSOR	0.3731 N(40) SIG .009	KNIFFS WITH TOOTH	0.4173 N(40) SIG .004
KNIFFS WITH MATCH	0.0164 N(40) SIG .460	KNIFFS WITH BOX	0.1964 N(40) SIG .112	KNIFFS WITH BALL	0.1743 N(40) SIG .141
KNIFFS WITH RADIO	0.4876 N(40) SIG .001	KNIFFS WITH DOOR	0.4671 N(40) SIG .001	KNIFFS WITH MOM	0.0819 N(40) SIG .308
KNIFFS WITH TUBE	0.3961 N(40) SIG .006	KNIFFS WITH PLUG	0.6177 N(40) SIG .000	KNIFFS WITH POTRAITO	0.4744 N(40) SIG .001
SPOONS WITH BALLS	0.5033 N(40) SIG .000	SPOONS WITH BUGS	0.5551 N(40) SIG .000	SPOONS WITH TELESCPS	0.3556 N(40) SIG .012
SPOONS WITH FAMHANDS	0.3757 N(40) SIG .008	SPOONS WITH WRITE	0.7867 N(40) SIG .000	SPOONS WITH DRAW	0.7993 N(40) SIG .000
SPOONS WITH KNIFF	0.3231 N(40) SIG .021	SPOONS WITH SPOON	0.9295 N(40) SIG .000	SPOONS WITH BROOM	0.3448 N(40) SIG .015
KNIFES WITH FAMHANDS	0.2092 N(40) SIG .098	KNIFFS WITH WRITE	0.3543 N(40) SIG .012	KNIFES WITH DRAW	0.3699 N(40) SIG .009
KNIFES WITH KNIFF	0.2830 N(40) SIG .038	KNIFES WITH SPOON	0.5044 N(40) SIG .000	KNIFES WITH BROOM	0.1742 N(40) SIG .141
KNIFFS WITH BUG	0.3289 N(40) SIG .019	KNIFFS WITH TELESCP	0.4842 N(40) SIG .001	KNIFES WITH KEYHOLE	0.5056 N(40) SIG .000
KNIFFS WITH FAMHAND	0.1342 N(40) SIG .204	KNIFFS WITH BEANBAG	0.0708 N(40) SIG .332	KNIFFS WITH STEPX	0.1826 N(40) SIG .130
SPOONS WITH BROOMS	0.4033 N(40) SIG .005	SPOONS WITH MATCHS	0.7410 N(40) SIG .000	SPOONS WITH BOXS	0.5694 N(40) SIG .000
SPOONS WITH KEYHOLES	0.3853 N(40) SIG .007	SPOONS WITH RADIOS	0.8284 N(40) SIG .000	SPOONS WITH DOORS	0.6730 N(40) SIG .000

VARIABLE PAIR		VARIABLE PAIR		VARIABLE PAIR	
SPOONS WITH THROW	0.2615 N(40) SIG .052	SPOONS WITH SCISSUR	0.5949 N(40) SIG .000	SPOONS WITH TOOTH	0.6905 N(40) SIG .000
SPOONS WITH MATCH	0.4235 N(40) SIG .003	SPOONS WITH BOX,	0.1164 N(40) SIG .237	SPOONS WITH BALL	0.3814 N(40) SIG .008
SPOONS WITH BUG	0.2812 N(40) SIG .039	SPOONS WITH TELESCP	0.4834 N(40) SIG .001	SPOONS WITH KEYHOLE	0.4708 N(40) SIG .001
SPOONS WITH FAMHAND	0.2475 N(40) SIG .062	SPOONS WITH BEANBAG	0.1982 N(40) SIG .110	SPOONS WITH STEPY	-0.0304 N(40) SIG .426
BROOMS WITH MATCHS	0.4349 N(40) SIG .003	BROOMS WITH BOXS	0.6281 N(40) SIG .000	BROOMS WITH BALLS	0.3296 N(40) SIG .019
BROOMS WITH RADIOS	0.6004 N(40) SIG .000	BROOMS WITH DOORS	0.5101 N(40) SIG .000	BROOMS WITH FAMHANDS	0.1933 N(40) SIG .116
BROOMS WITH SCISSUR	0.3085 N(40) SIG .026	BROOMS WITH TOOTH	0.3253 N(40) SIG .020	BROOMS WITH KNIFE	0.2470 N(40) SIG .062
BROOMS WITH BOX	0.3517 N(40) SIG .013	BROOMS WITH BALL	0.0559 N(40) SIG .366	BROOMS WITH BUG	0.1651 N(40) SIG .154
BROOMS WITH DOOR	0.6172 N(40) SIG .000	BROOMS WITH MOM	0.0616 N(40) SIG .353	BROOMS WITH FAMHAND	0.1700 N(40) SIG .147
BROOMS WITH PLUG	0.3433 N(40) SIG .015	BROOMS WITH DOTRATTO	0.3510 N(40) SIG .013	MATCHS WITH BOXS	0.6743 N(40) SIG .000
SPOONS WITH RADIO	0.6215 N(40) SIG .000	SPOONS WITH DOOR	0.4955 N(40) SIG .001	SPOONS WITH MOM	0.1513 N(40) SIG .176
SPOONS WITH TUBE	0.3375 N(40) SIG .017	SPOONS WITH PLUG	0.5192 N(40) SIG .000	SPOONS WITH DOTRATTO	0.7780 N(40) SIG .000
BROOMS WITH BUGS	0.5129 N(40) SIG .000	BROOMS WITH TELESCPS	0.5600 N(40) SIG .000	BROOMS WITH KEYHOLES	0.5322 N(40) SIG .000

VARIABLE PAIR		VARIABLE PAIR		VARIABLE PAIR	
BROOMS WITH WRITE	0.3464 N(40) SIG .014	BROOMS WITH DRAW	0.3721 N(40) SIG .009	BROOMS WITH THROW	0.2162 N(40) SIG .090
BROOMS WITH SPOON	0.2665 N(40) SIG .048	BROOMS WITH BROOM	0.7332 N(40) SIG .000	BROOMS WITH MATCH	0.2234 N(40) SIG .083
BROOMS WITH TELESCP	0.3359 N(40) SIG .017	BROOMS WITH KEYHOLE	0.3198 N(40) SIG .022	BROOMS WITH RADIO	0.4762 N(40) SIG .001
BROOMS WITH BEANBAG	0.2010 N(40) SIG .107	BROOMS WITH STEPX	0.3166 N(40) SIG .023	BROOMS WITH TUBE	0.2178 N(40) SIG .089
MATCHS WITH BALLS	0.6821 N(40) SIG .000	MATCHS WITH BUGS	0.5295 N(40) SIG .000	MATCHS WITH TELESCPS	0.3420 N(40) SIG .015
MATCHS WITH FAMHANDS	0.3740 N(40) SIG .009	MATCHS WITH WRITE	0.6927 N(40) SIG .000	MATCHS WITH DRAW	0.7224 N(40) SIG .000
MATCHS WITH KNIFE	0.1890 N(40) SIG .121	MATCHS WITH SPOON	0.6667 N(40) SIG .000	MATCHS WITH BROOM	0.3477 N(40) SIG .014
MATCHS WITH BUG	0.4056 N(40) SIG .005	MATCHS WITH TELESCP	0.3598 N(40) SIG .011	MATCHS WITH KEYHOLE	0.3487 N(40) SIG .014
MATCHS WITH FAMHAND	0.3143 N(40) SIG .024	MATCHS WITH BEANBAG	0.3885 N(40) SIG .007	MATCHS WITH STEPX	0.2886 N(40) SIG .035
BOXS WITH BALLS	0.6363 N(40) SIG .000	BOXS WITH BUGS	0.7417 N(40) SIG .000	BOXS WITH TELESCPS	0.6140 N(40) SIG .000
BOXS WITH FAMHANDS	0.2809 N(40) SIG .040	BOXS WITH WRITE	0.4882 N(40) SIG .001	BOXS WITH DRAW	0.5195 N(40) SIG .000
BOXS WITH KNIFE	0.2392 N(40) SIG .069	BOXS WITH SPOON	0.4580 N(40) SIG .001	BOXS WITH BROOM	0.4280 N(40) SIG .003
BOXS WITH BUG	0.4394 N(40) SIG .002	BOXS WITH TELESCP	0.5681 N(40) SIG .000	BOXS WITH KEYHOLE	0.5527 N(40) SIG .000

VARIABLE PAIR		VARIABLE PAIR		VARIABLE PAIR	
MATCHS WITH KEYHOLES	0.3912 N(40) SIG .006	MATCHS WITH RADIOS	0.7419 N(40) SIG .000	MATCHS WITH DOORS	0.7725 N(40) SIG .000
MATCHS WITH THROW	0.3946 N(40) SIG .006	MATCHS WITH SCISSOR	0.5919 N(40) SIG .000	MATCHS WITH TOOTH	0.4046 N(40) SIG .005
MATCHS WITH MATCH	0.6819 N(40) SIG .000	MATCHS WITH BOX	0.3374 N(40) SIG .017	MATCHS WITH BALL	0.5058 N(40) SIG .000
MATCHS WITH RADIO	0.4326 N(40) SIG .003	MATCHS WITH DOOR	0.4010 N(40) SIG .005	MATCHS WITH MOM	0.1311 N(40) SIG .210
MATCHS WITH TUBE	0.3316 N(40) SIG .018	MATCHS WITH PLUG	0.3353 N(40) SIG .017	MATCHS WITH POTRAITO	0.7002 N(40) SIG .000
BOXS WITH KEYHOLES	0.6436 N(40) SIG .000	BOXS WITH RADIOS	0.7002 N(40) SIG .000	BOXS WITH DOORS	0.7384 N(40) SIG .000
BOXS WITH THROW	0.2445 N(40) SIG .064	BOXS WITH SCISSOR	0.5082 N(40) SIG .000	BOXS WITH TOOTH	0.4686 N(40) SIG .001
BOXS WITH MATCH	0.5435 N(40) SIG .000	BOXS WITH BOX	0.4114 N(40) SIG .004	BOXS WITH BALL	0.4151 N(40) SIG .004
BOXS WITH FAMHAND	0.3881 N(40) SIG .007	BOXS WITH BEANBAG	0.2386 N(40) SIG .069	BOXS WITH STEPX	0.4900 N(40) SIG .001
BALLS WITH BUGS	0.4047 N(40) SIG .005	BALLS WITH TELESCPS	0.4276 N(40) SIG .003	BALLS WITH KEYHOLES	0.4179 N(40) SIG .004
BALLS WITH WRITE	0.4810 N(40) SIG .001	BALLS WITH DRAW	0.4900 N(40) SIG .001	BALLS WITH THROW	0.3420 N(40) SIG .015
BALLS WITH SPOON	0.4295 N(40) SIG .003	BALLS WITH BROOM	0.0673 N(40) SIG .340	BALLS WITH MATCH	0.5253 N(40) SIG .000
BALLS WITH TELESCP	0.5754 N(40) SIG .000	BALLS WITH KEYHOLE	0.5306 N(40) SIG .000	BALLS WITH RADIO	0.4983 N(40) SIG .001

VARIABLE PAIR		VARIABLE PAIR		VARIABLE PAIR	
BALLS	0.4964	BALLS	0.3407	BALLS	0.5487
WITH	N(40)	WITH	N(40)	WITH	N(40)
BEANBAG	SIG .001	SIFPX	SIG .016	TUBE	SIG .000
BUGS	0.7417	BUGS	0.6695	BUGS	0.6722
WITH	N(40)	WITH	N(40)	WITH	N(40)
KEYHOLES	SIG .000	RADIOS	SIG .000	DOORS	SIG .000
BUGS	0.1834	BUGS	0.5655	BUGS	0.4736
WITH	N(40)	WITH	N(40)	WITH	N(40)
THROW	SIG .129	SCISSOR	SIG .000	TOOTH	SIG .001
BOXS	0.6320	BOXS	0.7634	BOXS	0.0080
WITH	N(40)	WITH	N(40)	WITH	N(40)
RADIO	SIG .000	DOOR	SIG .000	MOM	SIG .481
BOXS	0.5515	BOXS	0.5818	BOXS	0.5449
WITH	N(40)	WITH	N(40)	WITH	N(40)
TUBE	SIG .000	PLUG	SIG .000	OUTRATIO	SIG .000
BALLS	0.6122	BALLS	0.6696	BALLS	0.1626
WITH	N(40)	WITH	N(40)	WITH	N(40)
RADIOS	SIG .000	DOORS	SIG .000	FAMHANDS	SIG .158
BALLS	0.3609	BALLS	0.2856	BALLS	0.0387
WITH	N(40)	WITH	N(40)	WITH	N(40)
SCISSOR	SIG .011	TOOTH	SIG .037	KNIFE	SIG .406
BALLS	0.3549	BALLS	0.7190	BALLS	0.2647
WITH	N(40)	WITH	N(40)	WITH	N(40)
BOX	SIG .012	BALL	SIG .000	BUG	SIG .049
BALLS	0.4755	BALLS	0.1455	BALLS	0.1391
WITH	N(40)	WITH	N(40)	WITH	N(40)
DOOR	SIG .001	MOM	SIG .185	FAMHAND	SIG .196
BALLS	0.2919	BALLS	0.4313	BUGS	0.6962
WITH	N(40)	WITH	N(40)	WITH	N(40)
PLUG	SIG .034	OUTRATIO	SIG .003	TELESCPS	SIG .000
BUGS	0.2224	BUGS	0.4942	BUGS	0.5233
WITH	N(40)	WITH	N(40)	WITH	N(40)
FAMHANDS	SIG .084	WRTIE	SIG .001	DRAW	SIG .000
BUGS	0.3326	BUGS	0.5556	BUGS	0.4049
WITH	N(40)	WITH	N(40)	WITH	N(40)
MATCH	SIG .018	BOX	SIG .000	BALL	SIG .005
BUGS	0.5831	BUGS	0.6464	BUGS	0.1736
WITH	N(40)	WITH	N(40)	WITH	N(40)
RADIO	SIG .000	DOOR	SIG .000	MOM	SIG .142

VARIABLE PAIR		VARIABLE PAIR		VARIABLE PAIR	
BUGS	0.5934	BUGS	0.5116	BUGS	0.6061
WITH	N(40)	WITH	N(40)	WITH	N(40)
TUBE	SIG .000	PLUG	SIG .000	DOTRATIO	SIG .000
TELESCPS	0.1158	TELESCPS	0.2898	TELESCPS	0.3296
WITH	N(40)	WITH	N(40)	WITH	N(40)
FAMHANDS	SIG .238	WRITE	SIG .035	DRAW	SIG .019
TELESCPS	0.0097	TELESCPS	0.2454	TELESCPS	0.2887
WITH	N(40)	WITH	N(40)	WITH	N(40)
KNIFE	SIG .476	SPOON	SIG .064	BROOM	SIG .035
TELESCPS	0.2845	TELESCPS	0.7312	TELESCPS	0.7594
WITH	N(40)	WITH	N(40)	WITH	N(40)
BUG	SIG .038	TELESCP	SIG .000	KEYHOLE	SIG .000
TELESCPS	0.1836	TELESCPS	0.1668	TELESCPS	0.5826
WITH	N(40)	WITH	N(40)	WITH	N(40)
FAMHAND	SIG .128	BEANBAG	SIG .152	STEPX	SIG .000
KEYHOLES	0.5398	KEYHOLES	0.4833	KEYHOLES	0.1938
WITH	N(40)	WITH	N(40)	WITH	N(40)
RADIOS	SIG .000	DOORS	SIG .001	FAMHANDS	SIG .115
BUGS	0.2641	BUGS	0.4748	BUGS	0.4016
WITH	N(40)	WITH	N(40)	WITH	N(40)
KNIFE	SIG .050	SPOON	SIG .001	BROOM	SIG .005
BUGS	0.6529	BUGS	0.6459	BUGS	0.6505
WITH	N(40)	WITH	N(40)	WITH	N(40)
BUG	SIG .000	TELESCP	SIG .000	KEYHOLE	SIG .000
BUGS	0.1018	BUGS	0.0396	BUGS	0.4575
WITH	N(40)	WITH	N(40)	WITH	N(40)
FAMHAND	SIG .266	BEANBAG	SIG .404	STEPX	SIG .001
TELESCPS	0.9704	TELESCPS	0.5109	TELESCPS	0.4368
WITH	N(40)	WITH	N(40)	WITH	N(40)
KEYHOLES	SIG .000	RADIOS	SIG .000	DOORS	SIG .002
TELESCPS	0.1547	TELESCPS	0.5559	TELESCPS	0.2474
WITH	N(40)	WITH	N(40)	WITH	N(40)
THROW	SIG .170	SCISSOR	SIG .000	TOOTH	SIG .062
TELESCPS	0.2066	TELESCPS	0.4067	TELESCPS	0.3567
WITH	N(40)	WITH	N(40)	WITH	N(40)
MATCH	SIG .100	BOX	SIG .005	BALL	SIG .012
TELESCPS	0.4993	TELESCPS	0.6208	TELESCPS	0.1539
WITH	N(40)	WITH	N(40)	WITH	N(40)
RADIO	SIG .001	DOOR	SIG .000	MOM	SIG .172

VARIABLE PAIR		VARIABLE PAIR		VARIABLE PAIR	
TELESCPS	0.7007	TELESCPS	0.5548	TELESCPS	0.3706
WITH	N(40)	WITH	N(40)	WITH	N(40)
TUBE	SIG .000	PLUG	SIG .000	DOTRATIO	SIG .009
KEYHOLES	0.6219	KEYHOLES	0.3035	KEYHOLES	0.1015
WITH	N(40)	WITH	N(40)	WITH	N(40)
SCISSOR	SIG .000	TOOTH	SIG .028	KNIFE	SIG .267
KEYHOLES	0.4785	KEYHOLES	0.4357	KEYHOLES	0.3829
WITH	N(40)	WITH	N(40)	WITH	N(40)
BOX	SIG .001	BALL	SIG .002	BUG	SIG .007
KEYHOLES	0.6660	KEYHOLES	0.1009	KEYHOLES	0.2676
WITH	N(40)	WITH	N(40)	WITH	N(40)
DOOR	SIG .000	MOM	SIG .268	FAMHAND	SIG .048
KEYHOLES	0.5991	KEYHOLES	0.4373	RADIOS	0.8302
WITH	N(40)	WITH	N(40)	WITH	N(40)
PLUG	SIG .000	DOTRATIO	SIG .002	DOORS	SIG .000
RADIOS	0.3384	RADIOS	0.5486	RADIOS	0.6988
WITH	N(40)	WITH	N(40)	WITH	N(40)
THROW	SIG .016	SCISSOR	SIG .000	TOOTH	SIG .000
RADIOS	0.4577	RADIOS	0.1923	RADIOS	0.4480
WITH	N(40)	WITH	N(40)	WITH	N(40)
MATCH	SIG .001	BOX	SIG .117	BALL	SIG .002
RADIOS	0.6951	RADIOS	0.7140	RADIOS	0.2058
WITH	N(40)	WITH	N(40)	WITH	N(40)
RADIO	SIG .000	DOOR	SIG .000	MOM	SIG .101
RADIOS	0.4030	RADIOS	0.6038	RADIOS	0.6870
WITH	N(40)	WITH	N(40)	WITH	N(40)
TUBE	SIG .005	PLUG	SIG .000	DOTRATIO	SIG .000
KEYHOLES	0.3388	KEYHOLES	0.3769	KEYHOLES	0.1249
WITH	N(40)	WITH	N(40)	WITH	N(40)
WRITE	SIG .016	DRAW	SIG .008	THROW	SIG .221
KEYHOLES	0.3038	KEYHOLES	0.3429	KEYHOLES	0.3014
WITH	N(40)	WITH	N(40)	WITH	N(40)
SPOON	SIG .028	BROOM	SIG .015	MATCH	SIG .029
KEYHOLES	0.7898	KEYHOLES	0.8168	KEYHOLES	0.5508
WITH	N(40)	WITH	N(40)	WITH	N(40)
TELESCP	SIG .000	KEYHOLE	SIG .000	RADIO	SIG .000
KEYHOLES	0.1483	KEYHOLES	0.5485	KEYHOLES	0.7546
WITH	N(40)	WITH	N(40)	WITH	N(40)
BEANBAG	SIG .180	STEPX	SIG .000	TUBE	SIG .000

VARIABLE PAIR		VARIABLE PAIR		VARIABLE PAIR	
RADIOS WITH FAMHANDS	0.4024 N(40) SIG .005	RADIOS WITH WRITE	0.6508 N(40) SIG .000	RADIOS WITH DRAW	0.6597 N(40) SIG .000
RADIOS WITH KNIFE	0.3171 N(40) SIG .023	RADIOS WITH SPOON	0.7653 N(40) SIG .000	RADIOS WITH BROOM	0.4292 N(40) SIG .003
RADIOS WITH BUG	0.3832 N(40) SIG .007	RADIOS WITH TELESCP	0.5634 N(40) SIG .000	RADIOS WITH KEYHOLE	0.5307 N(40) SIG .000
RADIOS WITH FAMHAND	0.2800 N(40) SIG .040	RADIOS WITH BEANBAG	0.3966 N(40) SIG .006	RADIOS WITH STEPY	0.1015 N(40) SIG .267
DOORS WITH THROW	0.5402 N(40) SIG .000	DOORS WITH SCISSOR	0.4757 N(40) SIG .001	DOORS WITH TOOTH	0.5985 N(40) SIG .000
DOORS WITH MATCH	0.7322 N(40) SIG .000	DOORS WITH BOX	0.3657 N(40) SIG .010	DOORS WITH BALL	0.4962 N(40) SIG .001
DOORS WITH RADIO	0.6825 N(40) SIG .000	DOORS WITH DOOR	0.6926 N(40) SIG .000	DOORS WITH MOM	0.1079 N(40) SIG .254
DOORS WITH TUBE	0.3830 N(40) SIG .007	DOORS WITH PLUG	0.5562 N(40) SIG .000	DOORS WITH DOTRATIO	0.6432 N(40) SIG .000
FAMHANDS WITH SCISSOR	0.1185 N(40) SIG .233	FAMHANDS WITH TOOTH	0.3291 N(40) SIG .019	FAMHANDS WITH KNIFE	0.2863 N(40) SIG .037
FAMHANDS WITH BOX	0.0060 N(40) SIG .485	FAMHANDS WITH BALL	0.1394 N(40) SIG .195	FAMHANDS WITH BUG	0.1089 N(40) SIG .252
FAMHANDS WITH DOOR	0.2400 N(40) SIG .068	FAMHANDS WITH MOM	-0.1136 N(40) SIG .243	FAMHANDS WITH FAMHAND	0.3731 N(40) SIG .009
FAMHANDS WITH PLUG	0.3605 N(40) SIG .011	FAMHANDS WITH DOTRATIO	0.2219 N(40) SIG .084	WRITE WITH DRAW	0.9928 N(40) SIG .000
DOORS WITH FAMHANDS	0.4692 N(40) SIG .001	DOORS WITH WRITE	0.5889 N(40) SIG .000	DOORS WITH DRAW	0.6141 N(40) SIG .000

VARIABLE PAIR				VARIABLE PAIR				VARIABLE PAIR			
DOORS WITH KNIFE	0.3216	N(40)	SIG .022	DOORS WITH SPOON	0.6563	N(40)	SIG .000	DOORS WITH BROOM	0.3668	N(40)	SIG .010
DOORS WITH BUG	0.4624	N(40)	SIG .001	DOORS WITH TELESCP	0.4654	N(40)	SIG .001	DOORS WITH KEYHOLE	0.4617	N(40)	SIG .001
DOORS WITH FAMHAND	0.3448	N(40)	SIG .015	DOORS WITH BEANBAG	0.5261	N(40)	SIG .000	DOORS WITH STEPX	0.3158	N(40)	SIG .024
FAMHANDS WITH WRITE	0.1266	N(40)	SIG .218	FAMHANDS WITH DRAW	0.1844	N(40)	SIG .127	FAMHANDS WITH THROW	0.3691	N(40)	SIG .010
FAMHANDS WITH SPOON	0.4085	N(40)	SIG .004	FAMHANDS WITH BROOM	0.2707	N(40)	SIG .046	FAMHANDS WITH MATCH	0.5214	N(40)	SIG .000
FAMHANDS WITH TELESCP	0.1593	N(40)	SIG .163	FAMHANDS WITH KEYHOLE	0.1875	N(40)	SIG .123	FAMHANDS WITH RADIO	0.3899	N(40)	SIG .006
FAMHANDS WITH BEANBAG	0.4038	N(40)	SIG .005	FAMHANDS WITH STEPX	0.2912	N(40)	SIG .034	FAMHANDS WITH TUBE	0.1394	N(40)	SIG .195
WRITE WITH THROW	0.3384	N(40)	SIG .016	WRITE WITH SCISSOR	0.5978	N(40)	SIG .000	WRITE WITH TOOTH	0.6215	N(40)	SIG .000
WRITE WITH MATCH	0.4223	N(40)	SIG .003	WRITE WITH BOX	0.2929	N(40)	SIG .033	WRITE WITH BALL	0.4495	N(40)	SIG .002
WRITE WITH RADIO	0.5740	N(40)	SIG .000	WRITE WITH DOOR	0.4436	N(40)	SIG .002	WRITE WITH MUM	0.0362	N(40)	SIG .412
WRITE WITH TUBE	0.3792	N(40)	SIG .008	WRITE WITH PLUG	0.3165	N(40)	SIG .023	WRITE WITH DOTRATTO	0.9178	N(40)	SIG .000
DRAW WITH KNIFE	0.1717	N(40)	SIG .145	DRAW WITH SPOON	0.6005	N(40)	SIG .000	DRAW WITH BROOM	0.2949	N(40)	SIG .032
DRAW WITH BUG	0.3798	N(40)	SIG .008	DRAW WITH TELESCP	0.5196	N(40)	SIG .000	DRAW WITH KEYHOLE	0.5105	N(40)	SIG .000

VARIABLE PAIR		VARIABLE PAIR		VARIABLE PAIR	
DRAW WITH FAMHAND	0.2364 N(40) SIG .071	DRAW WITH BEANBAG	0.3163 N(40) SIG .023	DRAW WITH STEPX	0.0211 N(40) SIG .449
THROW WITH SCISSOR	0.0879 N(40) SIG .295	THROW WITH TOOTH	0.3393 N(40) SIG .016	THROW WITH KNIFE	0.1249 N(40) SIG .221
WRITE WITH KNIFE	0.1681 N(40) SIG .150	WRITE WITH SPOON	0.8046 N(40) SIG .000	WRITE WITH BROOM	0.2735 N(40) SIG .044
WRITE WITH BUG	0.3559 N(40) SIG .012	WRITE WITH TELESCP	0.5233 N(40) SIG .000	WRITE WITH KEYHOLE	0.5055 N(40) SIG .000
WRITE WITH FAMHAND	0.2324 N(40) SIG .074	WRITE WITH BEANBAG	0.3217 N(40) SIG .021	WRITE WITH STEPX	-0.0521 N(40) SIG .375
DRAW WITH THROW	0.3501 N(40) SIG .013	DRAW WITH SCISSOR	0.6059 N(40) SIG .000	DRAW WITH TOOTH	0.6123 N(40) SIG .000
DRAW WITH MATCH	0.4523 N(40) SIG .002	DRAW WITH BOX	0.3004 N(40) SIG .030	DRAW WITH BALL	0.4570 N(40) SIG .002
DRAW WITH RADIO	0.5882 N(40) SIG .000	DRAW WITH DOOR	0.4665 N(40) SIG .001	DRAW WITH MOM	0.0440 N(40) SIG .394
DRAW WITH TUBE	0.3698 N(40) SIG .009	DRAW WITH PLUG	0.3344 N(40) SIG .017	DRAW WITH DOTRATIO	0.9220 N(40) SIG .000
THROW WITH SPOON	0.3493 N(40) SIG .014	THROW WITH BROOM	-0.0258 N(40) SIG .437	THROW WITH MATCH	0.5470 N(40) SIG .000
THROW WITH BOX	0.1294 N(40) SIG .213	THROW WITH BALL	0.2205 N(40) SIG .086	THROW WITH BUG	0.0687 N(40) SIG .337
THROW WITH DOOR	0.2369 N(40) SIG .070	THROW WITH MOM	0.0648 N(40) SIG .346	THROW WITH FAMHAND	0.1673 N(40) SIG .151
THROW WITH PLUG	0.2189 N(40) SIG .087	THROW WITH DOTRATIO	0.3530 N(40) SIG .013	SCISSOR WITH TOOTH	0.3919 N(40) SIG .006

VARIABLE PAIR		VARIABLE PAIR		VARIABLE PAIR	
SCISSOR	0.4662	SCISSOR	0.4086	SCISSOR	0.4862
WITH	N(40)	WITH	N(40)	WITH	N(40)
MATCH	SIG .001	BOX	SIG .004	BALL	SIG .001
SCISSOR	0.3803	SCISSOR	0.4283	SCISSOR	-0.0094
WITH	N(40)	WITH	N(40)	WITH	N(40)
RADIO	SIG .008	DOOR	SIG .003	MOM	SIG .477
SCISSOR	0.5553	SCISSOR	0.4233	SCISSOR	0.6942
WITH	N(40)	WITH	N(40)	WITH	N(40)
TUBE	SIG .000	PLUG	SIG .003	DOTRAITU	SIG .000
TOOTH	0.3991	TOOTH	0.0730	TOOTH	0.2045
WITH	N(40)	WITH	N(40)	WITH	N(40)
MATCH	SIG .005	BOX	SIG .327	BALL	SIG .103
TOOTH	0.6780	TOOTH	0.6200	TOOTH	0.0721
WITH	N(40)	WITH	N(40)	WITH	N(40)
RADIO	SIG .000	DOOR	SIG .000	MOM	SIG .329
THROW	0.1302	THROW	0.1419	THROW	0.4057
WITH	N(40)	WITH	N(40)	WITH	N(40)
TELESCP	SIG .212	KEYHOLE	SIG .191	RADIO	SIG .005
THROW	0.6970	THROW	0.1718	THROW	0.1932
WITH	N(40)	WITH	N(40)	WITH	N(40)
BEANBAG	SIG .000	STEPX	SIG .145	TUBE	SIG .116
SCISSOR	0.3168	SCISSOR	0.5955	SCISSOR	0.2156
WITH	N(40)	WITH	N(40)	WITH	N(40)
KNIFE	SIG .023	SPOON	SIG .000	BROOM	SIG .091
SCISSOR	0.4232	SCISSOR	0.5645	SCISSOR	0.5475
WITH	N(40)	WITH	N(40)	WITH	N(40)
BUG	SIG .003	TELESCP	SIG .000	KEYHOLE	SIG .000
SCISSOR	0.3636	SCISSOR	0.0717	SCISSOR	0.2302
WITH	N(40)	WITH	N(40)	WITH	N(40)
FAMHAND	SIG .011	BEANBAG	SIG .330	STEPX	SIG .076
TOOTH	0.4536	TOOTH	0.7391	TOOTH	0.2701
WITH	N(40)	WITH	N(40)	WITH	N(40)
KNIFE	SIG .002	SPOON	SIG .000	BROOM	SIG .046
TOOTH	0.2439	TOOTH	0.4049	TOOTH	0.3888
WITH	N(40)	WITH	N(40)	WITH	N(40)
BUG	SIG .065	TELESCP	SIG .005	KEYHOLE	SIG .007
TOOTH	0.2403	TOOTH	0.3393	TOOTH	-0.1527
WITH	N(40)	WITH	N(40)	WITH	N(40)
FAMHAND	SIG .068	BEANBAG	SIG .016	STEPX	SIG .173

VARIABLE PAIR				VARIABLE PAIR				VARIABLE PAIR			
TOOTH WITH TUBE	0.2262	N(40)	SIG .080	TOOTH WITH PLUG	0.5545	N(40)	SIG .000	TOOTH WITH DOTRAITO	0.6958	N(40)	SIG .000
KNIFE WITH BOX	0.3508	N(40)	SIG .013	KNIFE WITH BALL	0.2156	N(40)	SIG .091	KNIFE WITH BUG	0.3224	N(40)	SIG .021
KNIFE WITH DOOR	0.3322	N(40)	SIG .018	KNIFE WITH MOM	-0.1894	N(40)	SIG .121	KNIFE WITH FAMHAND	0.2718	N(40)	SIG .045
KNIFE WITH PLUG	0.3824	N(40)	SIG .007	KNIFE WITH DOTRAITO	0.3510	N(40)	SIG .013	SPOON WITH BROOM	0.3187	N(40)	SIG .023
SPOON WITH BUG	0.2874	N(40)	SIG .036	SPOON WITH TELESCP	0.4869	N(40)	SIG .001	SPOON WITH KEYHOLE	0.4644	N(40)	SIG .001
SPOON WITH FAMHAND	0.3399	N(40)	SIG .016	SPOON WITH BEANBAG	0.2583	N(40)	SIG .054	SPOON WITH STEPX	-0.1136	N(40)	SIG .243
BROOM WITH MATCH	0.1959	N(40)	SIG .113	BROOM WITH BOX	0.2774	N(40)	SIG .042	BROOM WITH BALL	-0.0493	N(40)	SIG .381
BROOM WITH RADIO	0.3670	N(40)	SIG .010	BROOM WITH DOOR	0.4180	N(40)	SIG .004	BROOM WITH MOM	-0.0581	N(40)	SIG .361
KNIFE WITH SPOON	0.3406	N(40)	SIG .016	KNIFE WITH BROOM	0.2267	N(40)	SIG .080	KNIFE WITH MATCH	0.3350	N(40)	SIG .017
KNIFE WITH TELESCP	0.1524	N(40)	SIG .174	KNIFE WITH KEYHOLE	0.1426	N(40)	SIG .190	KNIFE WITH RADIO	0.2750	N(40)	SIG .043
KNIFE WITH BEANBAG	0.0838	N(40)	SIG .303	KNIFE WITH STEPX	-0.0951	N(40)	SIG .280	KNIFE WITH TUBE	0.0290	N(40)	SIG .429
SPOON WITH MATCH	0.4985	N(40)	SIG .001	SPOON WITH BOX	0.1490	N(40)	SIG .179	SPOON WITH BALL	0.3848	N(40)	SIG .007
SPOON WITH RADIO	0.6269	N(40)	SIG .000	SPOON WITH DOOR	0.4221	N(40)	SIG .003	SPOON WITH MOM	0.0457	N(40)	SIG .390

VARIABLE PAIR				VARIABLE PAIR				VARIABLE PAIR			
SPOON WITH TUBE	0.3479	N(40)	SIG .014	SPOON WITH PLUG	0.4949	N(40)	SIG .001	SPOON WITH DOTRATIO	0.8005	N(40)	SIG .000
BROOM WITH BUG	0.2117	N(40)	SIG .095	BROOM WITH TELESCP	0.2268	N(40)	SIG .080	BROOM WITH KEYHOLE	0.2172	N(40)	SIG .089
BROOM WITH FAMHAND	0.3046	N(40)	SIG .028	BROOM WITH BEANBAG	-0.0611	N(40)	SIG .354	BROOM WITH STEPX	0.1197	N(40)	SIG .231
BROOM WITH TUBE	0.0750	N(40)	SIG .323	BROOM WITH PLUG	0.2324	N(40)	SIG .075	BROOM WITH DOTRATIO	0.2876	N(40)	SIG .036
MATCH WITH TELESCP	0.2800	N(40)	SIG .040	MATCH WITH KEYHOLE	0.2561	N(40)	SIG .058	MATCH WITH RADIO	0.4342	N(40)	SIG .003
MATCH WITH BEANBAG	0.5141	N(40)	SIG .000	MATCH WITH STEPX	0.3366	N(40)	SIG .017	MATCH WITH TUBE	0.3367	N(40)	SIG .017
BOX WITH BUG	0.5759	N(40)	SIG .000	BOX WITH TELESCP	0.5169	N(40)	SIG .000	BOX WITH KEYHOLE	0.4993	N(40)	SIG .001
BOX WITH FAMHAND	0.0660	N(40)	SIG .343	BOX WITH BEANBAG	0.0481	N(40)	SIG .384	BOX WITH STEPX	0.4599	N(40)	SIG .001
BALL WITH BUG	0.5198	N(40)	SIG .000	BALL WITH TELESCP	0.7058	N(40)	SIG .000	BALL WITH KEYHOLE	0.6632	N(40)	SIG .000
BALL WITH FAMHAND	0.1957	N(40)	SIG .113	BALL WITH BEANBAG	0.2148	N(40)	SIG .092	BALL WITH STEPX	0.2579	N(40)	SIG .054
BUG WITH TELESCP	0.4108	N(40)	SIG .004	BUG WITH KEYHOLE	0.4420	N(40)	SIG .002	BUG WITH RADIO	0.3823	N(40)	SIG .007
MATCH WITH BOX	0.4180	N(40)	SIG .004	MATCH WITH BALL	0.4595	N(40)	SIG .001	MATCH WITH BUG	0.3925	N(40)	SIG .006
MATCH WITH DOOR	0.4002	N(40)	SIG .005	MATCH WITH MOM	-0.1035	N(40)	SIG .263	MATCH WITH FAMHAND	0.4111	N(40)	SIG .004

VARIABLE PAIR		VARIABLE PAIR		VARIABLE PAIR	
MATCH WITH PLUG	0.3539 N(40) SIG .013	MATCH WITH DOTRATIO	0.5260 N(40) SIG .000	BOX WITH BALL	0.4894 N(40) SIG .001
BOX WITH RADIO	0.2870 N(40) SIG .036	BOX WITH DOOR	0.2947 N(40) SIG .032	BOX WITH MOM	-0.1152 N(40) SIG .239
BOX WITH TUBE	0.5362 N(40) SIG .000	BOX WITH PLUG	0.1582 N(40) SIG .165	BOX WITH DOTRATIO	0.3806 N(40) SIG .008
BALL WITH RADIO	0.4350 N(40) SIG .003	BALL WITH DOOR	0.4020 N(40) SIG .005	BALL WITH MOM	-0.0199 N(40) SIG .451
BALL WITH TUBE	0.5591 N(40) SIG .000	BALL WITH PLUG	0.1316 N(40) SIG .209	BALL WITH DOTRATIO	0.4394 N(40) SIG .002
BUG WITH DOOR	0.4476 N(40) SIG .002	BUG WITH MOM	-0.1457 N(40) SIG .185	BUG WITH FAMHAND	0.1323 N(40) SIG .208
BUG WITH BEANBAG	-0.1130 N(40) SIG .244	BUG WITH STEPX	0.2661 N(40) SIG .049	BUG WITH TUBE	0.2868 N(40) SIG .036
TELESCP WITH RADIO	0.6580 N(40) SIG .000	TELESCP WITH DOOR	0.5921 N(40) SIG .000	TELESCP WITH MOM	-0.0806 N(40) SIG .311
TELESCP WITH TUBE	0.8504 N(40) SIG .000	TELESCP WITH PLUG	0.4811 N(40) SIG .001	TELESCP WITH DOTRATIO	0.5326 N(40) SIG .000
KEYHOLE WITH FAMHAND	0.2870 N(40) SIG .036	KEYHOLE WITH BEANBAG	0.1694 N(40) SIG .148	KEYHOLE WITH STEPX	0.3155 N(40) SIG .024
RADIO WITH DOOR	0.8191 N(40) SIG .000	RADIO WITH MOM	-0.0408 N(40) SIG .401	RADIO WITH FAMHAND	0.2369 N(40) SIG .071
RADIO WITH PLUG	0.6656 N(40) SIG .000	RADIO WITH DOTRATIO	0.6341 N(40) SIG .000	DOOR WITH MOM	0.0371 N(40) SIG .410
DOOR WITH TUBE	0.4494 N(40) SIG .002	DOOR WITH PLUG	0.6491 N(40) SIG .000	DOOR WITH DOTRATIO	0.5242 N(40) SIG .000

VARIABLE PAIR				VARIABLE PAIR				VARIABLE PAIR			
MOM WITH TUBE	0.0375	N(40)	SIG .409	MOM WITH PLUG	0.0777	N(40)	SIG .317	MOM WITH DOTRATIO	0.0689	N(40)	SIG .336
BUG WITH PLUG	0.1416	N(40)	SIG .192	BUG WITH DOTRATIO	0.4792	N(40)	SIG .001	TELESCP WITH KEYHOLE	0.9747	N(40)	SIG .000
TELESCP WITH FAMHAND	0.2558	N(40)	SIG .056	TELESCP WITH BEANBAG	0.1790	N(40)	SIG .135	TELESCP WITH STEPX	0.2707	N(40)	SIG .046
KEYHOLE WITH RADIO	0.6629	N(40)	SIG .000	KEYHOLE WITH DOOR	0.6100	N(40)	SIG .000	KEYHOLE WITH MOM	-0.0721	N(40)	SIG .329
KEYHOLE WITH TUBE	0.8439	N(40)	SIG .000	KEYHOLE WITH PLUG	0.5060	N(40)	SIG .000	KEYHOLE WITH DOTRATIO	0.5232	N(40)	SIG .000
RADIO WITH BEANBAG	0.3375	N(40)	SIG .017	RADIO WITH STEPX	0.1559	N(40)	SIG .168	RADIO WITH TUBE	0.5063	N(40)	SIG .000
DOOR WITH FAMHAND	0.3347	N(40)	SIG .017	DOOR WITH BEANBAG	0.2696	N(40)	SIG .046	DOOR WITH STEPX	0.2650	N(40)	SIG .049
MOM WITH FAMHAND	-0.5677	N(40)	SIG .000	MOM WITH BEANBAG	0.0875	N(40)	SIG .296	MOM WITH STEPX	0.0992	N(40)	SIG .271
FAMHAND WITH BEANBAG	0.2396	N(40)	SIG .068	FAMHAND WITH STEPX	0.1037	N(40)	SIG .262	FAMHAND WITH TUBE	0.2368	N(40)	SIG .071
FAMHAND WITH PLUG	0.3163	N(40)	SIG .023	FAMHAND WITH DOTRATIO	0.2192	N(40)	SIG .087	BEANBAG WITH STEPX	0.1260	N(40)	SIG .219
STEPX WITH TUBE	0.3780	N(40)	SIG .008	STEPX WITH PLUG	0.1058	N(40)	SIG .258	STEPX WITH DOTRATIO	0.0417	N(40)	SIG .399
BEANBAG WITH TUBE	0.2500	N(40)	SIG .060	BEANBAG WITH PLUG	0.3546	N(40)	SIG .012	BEANBAG WITH DOTRATIO	0.3301	N(40)	SIG .019
TUBE WITH PLUG	0.5319	N(40)	SIG .000	TUBE WITH DOTRATIO	0.4275	N(40)	SIG .003	PLUG WITH DOTRATIO	0.4749	N(40)	SIG .001

APPENDIX C

ALPHA AMPLITUDE SCORING

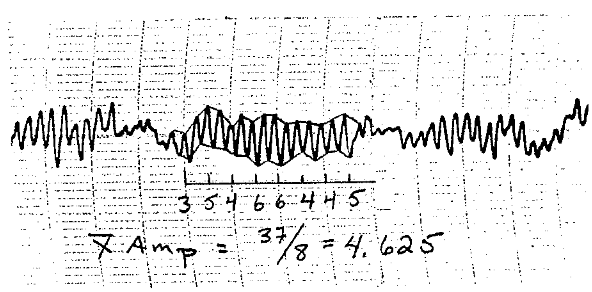

chart speed: 15mm/sec

deflection: 1 cm = 50 mV

In the amplitude measure used by Walter and Yeager (1956) the peaks and troughs are joined by lines and the distance between the lines is measured every 0.2 sec. (3mm) and averaged.

APPENDIX D

CORRELATIONS BETWEEN LATERALITY CATEGORIES AND TRANSFORMED AND NON-TRANSFORMED DISCRIMINANT VARIABLES

Pearson Product Moment Correlations with 2-tailed Test of Significance

Verbal Laterality

	Verbal Baseline Laterality Category	Verbal Task Laterality Category
only LH alpha:verbal	.0977	.6285**
residual only LH alpha:verbal	-.1480	.3713*
concurrent alpha:verval	.1042	.2975
residual concurrent alpha:verbal	.2028	.1394
verbal alpha frequenty ratio	.0669	-.1318
verbal alpha amplitude ratio	.0389	-.1697
residual amplitude: verbal	.1289	.1492
verbal latency-to-respond	-.0423	-.0344
residual latency-to-respond: verbal	.0490	-.1667
spatial latency-to-respond	-.0711	.0217
residual latency-to-respond: spatial	-.0920	-.2034

N = 40
* p < .05
** p < .01

Spatial Laterality

	Spatial Baseline Laterality Category	Spatial Task Laterality Category
only LH alpha: spatial	.0972	.7790**
residual only LH alpha: spatial	-.0488	.4770**
concurrent alpha: spatial	.0103	.2225
residual concurrent alpha: spatial	-.1307	-.0803
spatial alpha frequency ratio	-.0661	.4531**
spatial alpha amplitude ratio	-.0255	.5650**
residual amplitude: spatial	.1311	.4547**
spatial latency-to-respond	-.1764	.0965
residual latency-to-respond: spatial	-.1933	.0211
verbal latency-to-respond	-.2264	-.0532
residual latency-to-respond: verbal	-.2236	-.1082

N = 40
* $p < .05$
** $p < .01$

APPENDIX E

ROTATED LATERALITY FACTOR LOADINGS

Rotated Laterality Factor Loadings

Laterality Item	Factor 1	Factor 2
Hand (write)	0.876	0.035
hand (spoon)	0.871	0.056
Hand (draw)	0.850	0.053
Hand (tooth brush)	0.823	0.084
Hand (scissors)	0.760	0.112
Hand (match)	0.750	0.116
Hand (throw)	0.745	0.041
Foot (kick ball)	0.615	0.161
Hand (box lid)	0.547	0.113
Eye (key hole)	0.245	0.903
Eye (telescope)	0.260	0.735
Foot (bug)	0.424	0.195
Hand (broom)	0.433	0.062
Hand (knife)	0.312	-0.009
Ear (radio)	0.327	0.303
Ear (conversation)	0.246	0.345
Mother's handedness	0.009	-0.036
Father's handedness	0.008	-0.009
Variance explained	6.057	1.691