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Changes in hemispheric advantage during familiarization with facial stimuli: Influence of sex and handedness

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CHANGES IN HEMISPHERIC ADVANTAGE DURING FAMILIARIZATION WITH FACIAL STIMULI: INFLUENCE OF SEX AND HANDEDNESS

by

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Abstract

CHANGES IN HEMISPHERIC ADVANTAGE
DURING FAMILIARIZATION WITH FACIAL STIMULI:
INFLUENCE OF SEX AND HANDEDNESS

by

Diane C. Buchanan

Advisor: Professor Gerald Turkewitz

Photographs of faces were tachistoscopically presented in a recognition paradigm consisting of four Blocks of 24 trials. Previous research using this paradigm with female right-handers formed the basis for the dynamic shift model which was proposed to account for changes in visual field advantage during familiarization with complex visuospatial stimuli, as well as the relationship between those changes and proficiency. This model attributes the pattern of changes in hemispheric advantage as reflecting a sequence of global-analytic-integrative information processing strategies. The present research was intended to determine the effects of sex and handedness on the results predicted by the dynamic shift model.

It was hypothesized that differences in cerebral functional asymmetry between the subject groups would be reflected in their performance on this face recognition task. To assess degree and direction of verbal and visuospatial lateralization, subjects were tachistoscopically presented with letter identification and dot localization tasks .

Face recognition results for female right-handers were consistent with previous data. While the four sex and handedness subject groups tended to shift direction of visual field advantage during testing, the nature of these shifts and their relationship to proficiency were differentially effected by these variables. Among right-handers, proficiency was also dependent on the direction of the visual field advantage used on the first Block of trials.

For females, an initial left visual field advantage was optimal for overall task accuracy, whereas for males, an initial right visual field advantage maximized proficiency. Among left-handeders, direction of initial visual field advantage did not significantly effect task accuracy.

Cognitive strategy differences were suggested to account for certain sex effects on face recognition performance. Handedness effects were hypothesized to reflect greater relative efficiency of either hemisphere to process the faces utilizing more than one type of information processing strategy.

Results of the two lateral asymmetry tasks were consistent with existing evidence indicating males and right-handers to have greater functional asymmetry than females and left-handers. Hypotheses relating degree and direction of cerebral lateralization with performance on the face recognition task were offered. Further direct testing of these hypotheses is suggested by the present findings.

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I lovingly thank my husband for his support of my goals and dreams. He provided a context of encouragement and patience when the process must have seemed endless. To family and friends who always had faith in my abilities, please accept my gratitude and my love.

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INTRODUCTION

The principal objective of the present research is to determine the effects of sex and handedness on lateral asymmetries for processing faces as they become increasingly familiar. Secondary to the principal purpose is to test the hypothesis that such demonstrated asymmetries will be systematically associated with the degree and/or direction of underlying lateralization of verbal and visuospatial functioning. Therefore, an understanding of how males and females and right-handers and left-handers are likely to differ on this dimension is essential.

Due to the vast amount of research generated on the issues of cerebral lateralization of function and the differences between the sexes and handedness groups in that regard, the literature reviewed is of necessity abbreviated. The findings and theories offered to explain them that are included are intended to focus on the central topic of how males and females and right-handers and left-handers may differ in their cerebral organization of function. Evidence of asymmetries will focus on the visual modality due to its direct relevancy to the experimental design. Findings from studies of the recognition of facial stimuli have proven to be as complex as the nature of faces themselves. The number and types of variables which impact demonstrated hemispheric advantages for processing faces are reviewed and attempts are made to draw whatever conclusive statements may be reasonable given this complexity.

Seminal to the present study is the dynamic model of shifts in hemispheric advantage during familiarization with complex visual stimuli proposed by Ross-Kossak and Turkewitz (1986) which evolved from the research of its authors. Both the model itself and the findings relevant to it are reviewed in detail. It is hoped that the extension of that line of research to different sample populations as well as the testing of one hypothesis that is its corollary will serve to clarify some portion of the complexity surrounding investigations of the dramatic ability of the brain to individualize and learn each human face it encounters.

LITERATURE REVIEW

Cerebral Lateralization: Historical Overview

In essence, the beginnings of the concept of the dual brain can be traced to as early as medieval times when it was suggested that separate areas of the brain could carry out different functions. The faculties of perception, reasoning and memory were thought to be localized to the anterior, middle, and posterior parts of the brain, respectively, and this conceptualization was prevalent for nearly 2,000 years (Benson, 1985).

In the beginning of the 19th century, amidst a growing body of neuroanatomical data, Franz Gall, an Austrian anatomist, mapped human consciousness onto the two cerebral hemispheres and taught that each human faculty existed in duplicate such that each side of the brain might serve as a complete mind. Gall also proposed that within each hemisphere various mental functions could be localized to different parts of the brain. For example, he maintained that speech was localized to the two frontal lobes. An opposing viewpoint was prevalent at the time as well; i.e., that particular functions could not be localized to specific regions of the brain (Springer & Deutsch, 1981).

It is not surprising, then, that in 1836 when Marc Dax read his paper citing evidence of a connection between the control of speech and the left hemisphere but not the corresponding right hemisphere, his findings were largely ignored. Advocates of the duality of the mind were maintaining that the two hemispheres were functionally identical.

In addition, some men of science vehemently proposed that upsetting the equilibrium that normally existed between the two minds was the root of mental illness. This position was argued by a British doctor, Arthur Wigin in a paper published in 1844 in which he attempted to prove that each side of the brain was a distinct and perfect whole, capable of independent thought and independent volition (Harrington, 1985).

Not until several decades had passed was the scientific community ready to consider evidence of localization of speech to one side and one particular area of the brain. Dax's findings were posthumously published by his son in 1863 and from 1861-1863 Paul Broca accumulated and presented clinical evidence among aphasics which allowed him to localize speech to the third convolution of the left-hemisphere (Broca's area). Such clinical evidence could no longer be ignored, although it remained a curious clinical phenomenon and was not understood to be an indication of functional lateralization of the hemispheres until nearly a century later.

In 1864, Broca further proposed that the hemisphere controlling speech was on the side opposite to the preferred hand. The following year, in a speech before the Societe d'Anthropologie, he boldly declared that the majority of men are left-brained for speech and that the exceptions are left-handers who are right-brained.

While Broca has been credited with the localization of speech production in the left-hemisphere, the delineation of the area of the left temporal lobe posterior to "Broca's area" as being responsible for speech perception is accredited to Karl Wernicke, who published his work in 1874.

With clinical evidence of functional asymmetry of language abilities to the left hemisphere rapidly accumulating, the concept of cerebral dominance took hold. The left hemisphere became known as the dominant hemisphere with its concomitant control over the faculties of human intelligence.

In 1864, John Hughlings Jackson, a British neurologist and an ardent proponent of the idea of cerebral dominance, argued that the concept of two identical brains was untenable and that, in most individuals, the left side of the brain is the leading side.

Subsequently, the coexistence of the concept of the duality of the mind and cerebral localization of function was justified by Jackson when he wrote in 1874 that the brain is double in function but the two hemispheres are not mere duplicates of one another. For example, he believed that "doubleness in the verbalizing series is but one instance of doubleness in all the nervous processes of the organism." (Jackson, 1874, p.130) Processing images of objects had double locations with different specializations as well.

By the late 1800's, further clinical evidence had substantiated what was then widely accepted as the notion of cerebral dominance. However, it was not until new methods of investigating the functional differences between the hemispheres were devised 50 years later that renewed attention was focused on hemispheric differences.

In the 1930's, more sophisticated psychometric evaluation of specific verbal and spatial abilities in right- versus left-hemisphere damaged patients was underway. It was becoming apparent that the "minor" hemisphere was pre-eminant for numerous abilities, not limited to spatial skills. Deficits included certain agnosias; i.e., disturbances in the recognition or perception of familiar information, as well as musical abilities.

In the late 1950's and early 1960's, the pioneering research of Roger Sperry and his colleagues with patients who had undergone complete commissurotomies to relieve epileptic seizures dramatically demonstrated the unique capacities of each cerebral hemisphere to function independently. In addition, using the method of tachistoscopic presentation wherein stimuli appearing to the right of a central fixation point are registered in the left half of the brain and stimuli appearing to the left are received by the right side of the brain also allowed systematic experimentation among non-brain-damaged subjects.

A wealth of data from both clinical and experimental sources had shed light on what turned out to be some overly simplistic notions of the dual brain that were widely accepted just a century before. Ideas about the nature of hemispheric differences have gone from an almost mechanistic verbal/nonverbal distinction to more abstract and generalized notions about the relationship between higher mental functions and the two hemisphere. The left hemisphere is considered to process information mainly in a phonetic, sequential, analytic manner, while the right hemisphere is considered to process information predominantly in a nonlinguistic, holistic, synthetic manner and to have the specific function of synthesizing a gestalt representation of the environment (Herron, 1980).

Which hemisphere is differentially active in interpreting information the brain encounters appears to interact in complex fashion with the demands of the specific task involved, the context in which the information is presented, and even the information processing strategies each individual may utilize in some situations.

A cursory review of the way scientists have viewed cerebral lateralization from the inception of the construct in the early 1800's to the present decades, seems to reveal a progression from symmetry to asymmetry, and back to symmetry as far as the cognitive capacities of the two hemispheres are concerned. Beginning with the concept of a dual mind consisting of two perfectly symmetrical and independent brains, the focus turned to delineation of functional localization of specific cognitive capacities to specific brain areas. Moving ahead with that body of knowledge, theories have evolved which again attribute symmetry to the right brain and left brain, but on a higher level of function. More current theories espouse an interactive relationship between the hemispheres in which both have some capacities for which they are specialized but in which each is capable of processing any class of stimulus but differs in the type of information processing strategy it is likely to employ.

The rapid accumulation of data from the use of increasingly sophisticated measurement techniques have perhaps generated as many questions about the nature of cerebral lateralization of function in the human brain as they have answered. The scientific investigation of the complex and variable relationship between neuroanatomical asymmetry and demonstrated asymmetries of function continues to spark debate as it did in Broca's time.

Effect of Sex on Cerebral Lateralization

Even when notions of cerebral asymmetry were first entertained in the mid 19th century, some scientists were arguing that women's brains were less asymmetrical than men's (Harrington, 1985). A brief summary of neuroanatomical, clinical and experimental evidence relevant to this conclusion follows.

Neuroanatomical Evidence

Although there is little evidence of substantial differences in neuroanatomical organization of the female and male brain (Beaton, 1986; Herron, 1980), differences which may bear relevance to lateral asymmetries of function have been reported.

Sexual dimorphism in the shape and surface area of the corpus callosum has been demonstrated by deLacoste-Utamsing and Halloway (1982). This brain structure, especially the caudal or posterior portion (splenium), is more bulbous and larger in females than in males. The authors suggest that this difference could be related to differences in degree of lateralization for visuospatial functions since peristriate, parietal, and superior temporal fibers course through the splenium. Also, greater intrahemispheric connectivity in the female brain rather than greater bi-hemispheric language representation could, at least in part, account for experimental evidence indicating males have greater lateralization of verbal, visual, and spatial abilities than females (Curtiss, 1985).

Females are more likely to have a larger right than left planum temporale as well (Hines & Gorsky, 1985).

<u>Clinical Evidence</u>

Hecaen, DeAgostini, & Monzon-Montes (1981) have reported that among the right-handers in their study, the frequency of spatial disorders in the case of right lesions is significantly higher among males than among females. Clinical data pointing to sex differences in laterality patterns also include McGlone's (1978) finding of a less frequent incidence of language breakdown in females than in males following similar left hemisphere damage. In this study, the author administered verbal and performance subtests of the Wechsler Adult Intelligence Scale (WAIS) to males and females with unilateral brain damage. Her findings support a greater degree of functional asymmetry in males versus females. Males with left hemisphere lesions obtained lower verbal IQ scores whereas females with left-sided lesions obtained scores within the average range. In addition, female scores did not differ from males or females with right-sided lesions. McGlone found no sex differences on the performance subtests in that site of lesion did not significantly effect performance among males or females. Thus, in females, unlike males, there were no significant differences in IQ measures regardless of the side of the lesion.

Experimental Data

Reviews of investigations which have resulted in performance differences between the sexes using divided visual field and dichotic listening paradigms have led to a general conclusion that females tend to exhibit a lesser degree of lateral asymmetry, particularly in dealing with visuospatial stimuli (e.g. Herron, 1980; Hines & Gorski, 1985; Springer & Deutsch, 1981; Zaidel, 1985).

Usually it is only a difference in the degree of functional asymmetry between the sexes rather than a difference in the direction of functional asymmetry that is demonstrated by divided sensory field investigations. Using tachistoscopic presentation of three-letter nonsense words, Hannay and Malone (1976) found a significant right visual field advantage for males but females showed no significant visual field advantage. Also with nonsense syllables but dichotically presented, Lake and Bryden (1976) found a sex effect with males showing a significantly stronger right visual field advantage than females. This same sex effect with dichotically presented verbal stimuli was found by Piazza (1980).

In a study focusing on spatial lateralization, Kimura (1969) found a significant sex by visual field effect. Males showed a left visual field advantage on dot localization and females did not. A higher incidence of right visual field advantage on a dot enumeration task was found by McGlone and Davidson (1973) among females compared to males. The authors suggest that visual, nonverbal cerebral dominance may be more right hemisphere dependent in males than females, although they note that both visual field advantages were weak.

Levy and Reid (1978) found sex differences on a visuospatial tachistoscopic task but not on a verbal task. On dot localization, males had higher left visual field advantages and females had higher right visual field advantages, but on letter identification, both males and females showed a significant right visual field advantage.

While the consensus of reviews of the literature on the presence of sex differences in cerebral lateralization appears to be affirmative, specific investigations often produce negative results (See Fairweather, 1982 for review). Kimura (1966) found no sex differences in visual field advantage on letter identification and dot enumeration: a right visual field advantage on the verbal task and a left visual field advantage on dot enumeration were obtained regardless of sex. Young, Ellis & Bion (1984) also found no sex differences in performance on a divided visual field test using 3-letter nonsense words. Both males and females showed a significant right visual field advantage.

Unsystematic sex effects on lateral asymmetry are undoubtedly due to such effects being minimal and to the great variability that exists within each sex (Lake & Bryden, 1976) Generalizations from and comparisons between laterality research investigating sex effects should be cautiously made for a number of reasons. These include the fact that in some cases, the analyses of sex effects were based on subject groups balanced for handedness while in most studies only right-handers were used. In still others, subject groups were equalized on the basis of writing posture and/or presence and absence of left-handers in the immediate family (familial sinistrality).

Theories to Account for Sex Effects

To account for sex effects in demonstrated lateral asymmetry of function, several classes of theoretical interpretations have been proposed. These theories are most often based on maturational rate, genetic or hormonal effects, or cognitive strategy differences between females and males.

The fact that the hemispheres mature earlier and show less lateralization in females is thought to account in part for the significant sex differences in large-scale tests of intellectual and spatial abilities, with females scoring higher on verbal tests and males scoring higher on math and spatial processing tests (Sperry, 1985).

In a sample of adolescent males and females, Waber (1976) administered a dichotic test of phoneme identification to indicate lateralization as well as subtests of the Weschler Intelligence Scale for Children to compare verbal and spatial abilities. Subjects were rated and grouped on their physiological level of sexual maturity. The author found that, regardless of sex, early maturing subjects performed better on tests of verbal compared to spatial abilities and the later maturing subjects showed the opposite pattern. Those maturing late were also more lateralized for speech. Among the adolescents she tested, Waber also found that the group showing the greatest degree of lateralization was also superior in spatial abilities. Waber concludes that "sex differences in mental abilities reflect differences in the organization of cortical functions that are related to differential rates of physical maturation." (p. 572).

Differences in maturational rate with concomitant hormonal influences have been cited to account in part for sex differences in degree of lateralization. Buffery and Gray (1972) propose a species-specific and lateralized neural mechanism which is specialized for the extraction of certain linguistic features in speech perception. This mechanism is more developed in the female than male brain at the same age. The usual left-side lateralization for language function is accelerated in the female brain which facilitates the development of linguistic skills. A more bilateral representation for non-verbal function is established in the male brain which facilitates the development of spatial skill.

Levy and Reid (1978), on the other hand, argue that since differences in the neuropsychological organization of males and females can be found by age 5, the age of puberty is not a cause but a correlate of events that occur prenatally, such as levels of fetal sex hormones. Geschwind and Galaburda (1987) have proposed a comprehensive model to account for differences in lateral asymmetry which is based on levels of fetal hormones and their differing effects on the genetic male and female. (Their theory will be discussed in greater detail under "Effect of Handedness on Cerebral Lateralization".)

Research which includes delineation of subject groups by degree of field dependence/independence, as indicated by the Rod & Frame (Witkin, Dyk, Faterson, Goodenough & Karp, 1962) and Embedded Figures Tests (Witkin, Oltman, Raskin & Karp, 1971), suggests that field independent subjects have more clearly differentiated hemispheric specialization of function than field dependent individuals (Oltman, Ehrlichman & Cox, 1977; Pizzamiglio & Zoccolotti, 1981). Relatively field independent individuals show greater left hemisphere superiority than relatively field dependent individuals for tachistoscopically presented verbal stimuli (Pizzamiglio & Zoccolotti, 1981; Zoccolotti & Oltman, 1978).

Since males tend to be more field independent than females (Zoccolotti & Pizzamiglio, 1986), Pizzamiglio and Zoccolotti (1981) point out that when degree of field dependence is not controlled, investigations using experimental groups based on sex tend to be biased towards males who are more field independent and females who are more field dependent. Data from clinical studies that may be restricted to sex as the predictor of deficits should be evaluated with an interaction with cognitive characteristics in mind (Zoccolotti & Pizzamiglio, 1986).

If the proposition that differential hemispheric activation may be independent of competence differences between the hemispheres is credible (Gur & Gur, 1980), then strategies used by males and females in approaching the same task must be considered (Bryden, 1979). To explain the visual field differences between males and females on dot localization when no visual field differences in ease of detection between the sexes was shown, Kimura (1969) suggests that "where a task can be performed with either left- or right-hemisphere mechanisms, males will employ right hemisphere systems, but females will not." (p. 457)

Based on clinical evidence of performance deficits, Bryden, Hecaen & DeAgostini (1983) propose that the relationship between cognitive ability and cerebral organization may lie in the distinction between complementary and non-complementary specialization. The authors present data on the joint incidence of aphasia and spatial disfunction to support this theory. The main evidence is that they found no significant negative relationship between aphasia and spatial disorder, indicating that language and spatial functions are independently assigned to the two hemispheres. Since, however, complementarity is more evident in males and males are considered better at visuospatial tasks, it could be hypothesized that noncomplementarity leads to poorer performance on spatial tasks.

Summary Statements

Neuroanatomical, clinical and experimental evidence reviewed briefly here can be summarized in several general statements concerning the effects of sex on organization of cerebral function.

Neuroanatomical evidence suggests that interhemispheric connectivity is enhanced among females relative to males which could lead to demonstrated differences in degree of lateral asymmetry between the sexes.

Clinical evidence indicates that spatial performance deficits with right hemisphere lesions and language performance deficits with left hemisphere lesions are both less frequent among females than among males.

Experimental evidence that females tend to exhibit a lesser degree of lateral asymmetry than males, particularly in processing visuospatial stimuli, has been reported, although failure to demonstrate significant sex differences in lateral asymmetry is not uncommon.

Theoretical explanations for sex effects on lateral asymmetry are primarily based on differences in maturational rate, differential effects of fetal hormones, or differences in cognitive capacity and hence in the processing strategies typically applied to a task. Because task variables are likely to interact with the expression of cognitive strategy and therefore effect lateral asymmetry, direct evidence of sex differences may be difficult to demonstrate under certain experimental conditions.

Effect of Handedness on Cerebral Lateralization

Whereas sex differences in lateral asymmetry of function are mainly one of degree, handedness is likely to effect the direction of hemispheric specialization for language as well as the degree of asymmetry for both verbal and visuospatial processing.

Neuroanatomical Evidence

Neuroanatomical differences between right-handers and left-handers are well documented (e.g. Benson, 1985; Galaburda, LeMay, Kemper & Geschwind, 1978; Geschwind & Galaburda, 1987). "In most cases, right-handedness is associated with anatomical asymmetry in one direction, and left-handedness with less anatomical asymmetry or asymmetry in the opposite direction." (Witelson, 1980, p.81). Specifically, left-handers have a higher proportion of no significant asymmetry or a reversal in the direction of asymmetry in the temporo-parietal region. In addition, left-handers have a tendency to show greater right frontal expanse less frequently and greater left frontal areas more frequently than right-handers (Witelson, 1980).

Right-handers also tend to have a longer left Sylvian fissure, suggesting larger underlying temporal and parietal opercula. The left planum in right-handers is usually larger. Also, the occipital horn of the left lateral ventricle is usually longer than that of the right one in right-handers, whereas in left-handers, this asymmetry is minimal (Geschwind & Galaburda, 1987). In the right-hander, a wider right frontal lobe is nearly nine times more common than a wider left. In left-handers, the difference is much less striking (Galaburda et al., 1978).

There are also cytoarachitectonic, chemical, and pharmacological asymmetries between right-handers and left-handers. For example, the left pulvinar of the thalamus contains more norepinephrine in right-handers whereas the ventrobasal complex of the right hemisphere is richer in norepinephrine among left-handers (Geschwind & Galaburda, 1987).

Clinical Evidence

Incidence of Reversed Laterality for Language:

Data collected on the incidence of right-hemisphere specialization for language estimates 5% among right-handers and 15-20% among left-handers. Estimates of bilateral speech representation among left-handers range from 15-40% (Benson, 1985; Bryden, 1982; Geschwind & Galaburda, 1987; Levy & Reid, 1978; Satz, 1980; Springer & Deutsch, 1981). These estimates are based on incidence of aphasia following unilateral brain damage as well as on administration of the Wada test, which temporarily anesthetizes each hemisphere to determine which side normally controls speech .

The range of estimates for bilateral versus right hemisphere speech localization is wide due to the fact that some researchers feel that clinical data tend to underestimate bilateral representation while others (e.g. Levy & Reid, 1978) tend to favor either right or left hemisphere localization. Thus Levy & Reid (1978) estimate 60% left hemisphere language representation and 40% right hemisphere representation among left-handers.
Geschwind and Galaburda (1987) point out, however, that the Wada test underestimates the proportion of left-handers who have significant degrees of bilateral language

representation. While aphasia may be present in the acute stage of a syndrome, the rate of recovery of speech processes is higher among left-handers than right-handers.

Satz (1980) summarizes three perspectives that have been used in classifying patterns of hemispheric lateralization in left-handers: The "variable unilateral position" claims that speech is lateralized either in the right or left hemisphere with about 60% being left-sided and 34% right-sided. These percentages are consistent with Levy & Reid's (1978) estimates. The "variable unilateral and bilateral position" accommodates the incidence of bilateralization. Seventy percent of left-handers are left-sided for language, 15% are right-sided, and 15% are bilateral. This theory appears to be the most widely accepted in current literature. Finally, the "unilateral position" cites 96% incidence of left-sided language representation and 4% right-sided. There is little support for this position based on evidence to date.

It should be noted that determining incidence of reversed laterality or bilaterality for verbal processing among left-handers by either experimentation with normals or through clinical analyses both have limitations. Experimentation with the normative left-handed population is restricted by the fact that a single measure of lateralization of language cannot adequately assess the different components of language such as speaking, listening and reading (Herron, 1980). Estimates from clinical data, on the other hand, are based on an inability to produce speech and not necessarily the ability to perceive or comprehend speech (Searleman, 1977). The discrepancy between percentages of reversed laterality obtained from the clinical population and the usually lower percentages found by investigation of the normative population is based in part on the different aspect of language being assessed among each population.

Also, if it is assumed that higher-order functions are the result of complex cerebral interactions, limited brain damage is likely to interfere with only one stage in the process. Clinical evidence does not take into account the plasticity of the human brain in its ability to adjust its operations in the presence of damage (Springer & Deutsch, 1981).

Clinical Data:

Systematic analyses of deficits caused by left and right lesions in left-handers support the view that left-handers have cerebral functional ambilaterality based on the mixed and atypical characteristics of the resultant syndromes in comparison to syndromes appearing in right-handers with similar lesions (Hecaen, DeAgostini & Monzon-Montes, 1981).

For example, compared to right-handers, there is an increase in the frequency of spatial disorders in left-handers in the case of unilateral lesions, whether on the right or the left side.

Hecaen et al. (1981) examined various classes of verbal and spatial deficits among right-handers and left-handers with unilateral hemispheric lesions. Verbal deficits with right hemisphere versus left hemisphere lesions did not differ between right-handers and left-handers. However, deficits in spatial performance among right-handers were significantly more frequent with right lesions than left lesions. Such a difference was only found in left-handers with respect to unilateral spatial agnosia. Significant differences in verbal deficits as a function of side of lesion among left-handers did not emerge until familial sinistrality was included in the analysis.

Experimental Evidence

Since left-handers form a more heterogeneous group in terms of variability of neuroanatomical asymmetries compared to right-handers, when their performance is analyzed as a subject group, such individual variability tends to result in the lack of clear-cut indications of lateral asymmetries. Although exceptions can certainly be found, laterality research tends to indicate either no hemispheric advantage or a weak right hemispheric advantage with verbal stimuli (Bryden, 1965, 1973; Lake & Bryden, 1976; Levy & Reid, 1978; Orsini, Satz, Soper & Light, 1985; Piazza, 1980), and no hemispheric advantage for visuospatial stimuli (Bryden, 1973; McGlone & Davidson, 1973; Piazza, 1980).

Testing verbal asymmetries, Bryden (1965) gave right-handers and left-handers of both sexes dichotic listening and letter-recognition tachistoscopic tests. On both measures, regardless of sex, right-handers were significantly more accurate in identifying material presented to the right side while left-handers failed to show any consistent left-right differences. The left-right difference scores on the dichotic listening test were also much more variable among left-handers than right-handers, suggesting a lesser degree of lateralization.

On three verbal tasks, one dichotic and two dual manual, Orsini, Satz, Soper & Light (1985) found a robust relationship between handedness and side of advantage. Right-handers showed a significantly stronger right ear advantage compared to left-handers on the dichotic word task. On the dual manual speech vocalization test, right-handers showed a right side advantage whereas left-handers showed a left-side advantage. On the dual manual reading task, again, right-handers showed a right-side advantage and left-handers had a left-side advantage. Thus, a more variable pattern of cerebral speech/language representation is suggested for left-handers.

Testing for both verbal and visuospatial asymmetries, Bryden (1973) reported a significant handedness effect on tachistoscopic letter recognition but not on form recognition or dot localization. A significant right visual field advantage was obtained for right-handers on the verbal task whereas left-handers showed no significant visual field advantage. Neither right-handers nor left-handers evidenced a significant visual field advantage on the two visuospatial tasks.

On a dot enumeration task, McGlone and Davidson (1973) report no significant effect of handedness on spatial asymmetry, although there was a tendency for left-handers to show either a greater right visual field advantage or no visual field advantage compared to right-handers.

Summary Statements

Neuroanatomical, clinical and experimental evidence reviewed concerning the effects of handedness on cerebral organization indicates that left-handers tend to be less functionally lateralized than right-handers and are considerably more likely than right-handers to have reversed asymmetry for language representation. Explanatory emphasis for this handedness effect on lateral asymmetry is weighted towards neuroanatomical and genetic causes. The left-handed population represents a greater degree of heterogeneity along biological and behavioral dimensions than the right-handed population. Differences in demonstrated lateralization of verbal and spatial functions between left-handers and right-handers are likely to be in degree and often also direction of asymmetry.

Familial Sinistrality

Numerous studies have shown that individuals who have some family history of sinistrality more often depart from left hemisphere speech dominance, either demonstrating a lesser degree of lateralization or a right hemisphere dominance for speech (e.g. Piazza, 1980; Zurif & Bryden, 1969).

Clinical evidence of an effect of familial left-handedness on type and frequency of performance deficits is equivocal (Hecaen et al., 1981). However, Geschwind and Galaburda (1987) point out that, on average, left-handers and right-handers with a family history of sinistrality show better recovery from aphasia.

In patients with unilateral lesions, Hecaen et al. (1981) found a significant relationship between the presence of familial sinistrality and the bilateral distribution of cerebral representation of language in left-handers.

Based on their review of the literature, Hardyck and Petrinovich (1977) have suggested a classification of handedness and cerebral lateralization such that right-handers with no family history of left-handedness are the most strongly lateralized and left-handers with a positive family history of left-handedness show bilateral localization of functions. Indeed, some studies fail to find a significant handedness effect on lateral asymmetry unless the variable of familial sinistrality is also considered (Lake & Bryden, 1976; Piazza, 1980; Zurif & Bryden, 1969).

Zurif & Bryden (1969) used both dichotic listening and tachistoscopic presentation of verbal stimuli to male subjects to study the effect of familial sinistrality. Similar to right-handers, non-familial left-handers were significantly right-dominant on all tasks, while familial left-handers did not show significant asymmetry on any task. In right-handers, the presence of left-handedness in the family may be associated with a shift in asymmetry on verbal tasks away from a right visual field superiority (Beaton, 1986).

There is also evidence that the effect of the presence or absence of familial sinistrality has a differential effect in males and females. On a dichotic listening task presenting consonant-vowel syllables, Lake and Bryden (1976) found that females with positive familial sinistrality had an increased likelihood of a left ear advantage, while males with positive familial sinistrality showed a stronger right ear advantage. Their findings revealed a sex effect among positive familial sinistrality subjects, while nearly half of the left-handers without familial sinistrality, regardless of sex, were left ear advantaged.

Using a tachistoscopic presentation of trigrams, Andrews (1977) found that laterality was significantly negatively correlated with presence of familial sinistrality, but that this correlation was higher among males. On a spatial visualization task, McKeever, Seitz, Hoff, Marino & Diehl (1983) also found a significant sex by familial sinistrality interaction. Females without familial sinistrality outperformed females with familial sinistrality, while males with familial sinistrality outperformed males without familial sinistrality.

Hannay and Malone (1976) in a nonsense-word visual field presentation among right-handed females found a significant right visual field advantage only among females without familial sinistrality. Among females with familial sinistrality, visual field advantages were not significant.

A number of investigations, however, have not found a significant effect of familial sinistrality on demonstrated asymmetries. In a recent large-scale study, Orsini, Satz, Soper & Light (1985) failed to find a relationship between familial sinistrality and hemispheric representation of speech.

Also, Levy & Reid (1978) found no significant relationship between familial sinistrality and scores on tachistoscopic syllable and dot location tests.

In summary, a review of laterality research investigating the effects of familial sinistrality reveal somewhat conflicting results. Contributing to some of this disagreement may be confounding variables of family size and self-report of familial sinistrality (Beaton, 1986).

Writing Posture

Evidence exits that hand posture in writing may indicate localization of the dominant hemisphere for speech and may thus serve as a reliable indication of reversed lateralization for the language function on an individual basis. Levy and Reid (1978) argue strongly for the validity of writing posture as a measure of lateral asymmetry. "The failure up until the present time to discover any simple relationship between the directions of cerebral and manual lateralization would seem to be explained by the hand-position variable." (p.136) Forming the basis of this model, it is noted that hemispheric motor projections such as the pyramidal tracts, that control movements of distal musculature are primarily contralateral in non-inverted writers and ipsilateral in inverted writers. Consequently, the language-dominant hemisphere is on the same side as the writing hand in inverted writers and on the opposite side in non-inverted writers.

The originators of the model define a non-inverted writing posture as holding the pencil with the hand below the line of writing and the pencil slanting upward, pointing to the top of the page. The vast majority of right-handers use this writing posture, but only about 15-20% of left-handers do so. The remaining left-handers rotate their hand or the paper in such a way that the hand is held above the line of writing and the pencil points toward the bottom of the page (Levy & Reid, 1978).

In a research design which analyzed the effects of handedness, sex, and writing posture on lateralization as measured by tachistoscopic presentation of syllables and dots, Levy and Reid (1978) confirmed the ability of writing posture to predict cerebral localization of function. That is, among both right-handed and left-handed subjects, those with a non-inverted writing posture had language and spatial functions specialized to the contralateral and ipsilateral hemispheres, respectively. The reverse relationship was shown in subjects with an inverted writing posture. Thus, their findings indicated an association between writing posture and both direction and degree of lateral asymmetry.

Subsequent attempts to replicate this pattern of results are mixed. Studies using auditory or tactile stimuli have yielded a negative effect of writing posture on direction of hemispheric advantage while the use of visual stimulus presentation more often confirms the model's predictions.

Using EEG ratios of the two hemispheres to indicate differential activation, Herron (1980) found that hemispheric asymmetries among non-inverters and inverters differed on only the verbal task and only at the occipital leads. There were no differences between the two groups in hemispheric activation on the spatial task.

Moscovitch and Smith (1979) used a reaction time response to tactile stimulation, dot detection and auditory tonal presentation to test the writing posture predictions.

Differences between non-inverters and inverters were found only in the visual modality. The authors suggest that differences in neural organization between non-inverters and inverters lie primarily in the visual system or its interface with the motor system.

In another study by these authors, Levy and Reid's (1978) predictions were also partially supported. On the tachistoscopic presentation of consonant-vowel-consonant syllables, a right visual field advantage was obtained for inverted left-handers and a left visual field advantage for non-inverted left-handers. On dot localization and dichotic listening measures, however, these two groups were not differentiated with both favoring a left visual field advantage (Smith & Moscovitch, 1979).

Using color-naming and word recognition tests, McKeever (1979) showed that inverted writers had a right visual field advantage on the color-naming task whereas non-inverters were not significantly lateralized. On the word recognition task, however, writing posture was not associated with differences in performance.

Inversion is more prevalent among male left-handers than among female left-handers. In a review of studies investigating writing posture, Levy (1984) reports an incidence of 69.8% of inversion in males and 44.4% in females.

Levy and Reid (1976) have also reported that females as well as inverted writers had a smaller degree of lateralization than males with a non-inverted writing posture. Levy and Gur (1980) report 66% inversion among male left-handers and cite this data as evidence for a higher frequency of right hemisphere language representation among female left-handers.

Searleman, Porac & Coren (1984) correlated writing posture with lateral preference for hand, foot, eye, and ear and found sex differences among left-handers. Inversion in males was associated with a tendency toward left-sided preferences for all four indices, while in females, inversion was associated with right-sided preferences for hand, foot and eye. Their results showed that writing posture was not significantly associated with any of these lateral preferences in right-handed males or females.

Writing posture had a differential effect among male and female left-handers in a half-face preference test administered by Lawson (1978). Left-handed males with inverted writing posture did tend to resemble right-handers as predicted by the model (i.e., both showed strong left visual field advantages) whereas the relationship was reversed among females. One cautionary note in drawing conclusions from this data is that writing posture was assessed by self-report rather than direct observation.

Individual Differences in Cerebral Lateralization: Theoretical Constructs

Geschwind and Galaburda (1987) have proposed a theory of lateralization which comprehensively incorporates the effects of genetic, hormonal, and prenatal chemical environmental influences to account for differences in degree and direction of lateralization of function within the individual. They postulate some influence that slows the growth of parts of the left hemisphere in utero. The corresponding regions on the right develop more rapidly. This influence is claimed to be related to male sex, such as to testosterone, since there is a higher frequency of left-handedness in males. The expression of genes that are important to neural development is altered by this male-related influence.

One demonstrated effect of testosterone is to affect the growth of neural tissue. This effect may be dependent on the level of free hormone or on tissue sensitivity to it. Although male and female zygotes differ in the average degree of testosterone effect to which they are subjected, there is no absolute difference between the sexes.

Therefore, in some female fetuses, sensitivity to testosterone will be high, thus accounting for a certain proportion of females who are more asymmetrical and possess better spatial skills than females on average. Since the right hemisphere develops earlier, it will tend to be less subject to disrupting influences and therefore we would see less lateral asymmetry for visuospatial functions among both sexes.

To account for superior spatial abilities in males, the authors suggest that growth retardation is more marked in certain regions of the left hemisphere in males, who will consequently show a greater degree of shift to right hemisphere participation in handedness and language and will be more likely to have augmented right hemisphere skills.

To account for those individuals, predominantly left-handed, who are bilateralized for language, the hypothesis is that the influences that delay left hemisphere growth create brains in which the normal asymmetry for language function is diminished and the corresponding areas on the two sides of the brain are more symmetrical.

Geschwind and Galaburda theorize that there is an innate bias toward left hemisphere dominance for speech and handedness. Influences during fetal life diminish this innate tendency, thus creating random dominance. This perspective suggests a "left-shift" factor for dominance which drives the brain to symmetry.

Anomalous dominance, defined as any pattern of asymmetry which differs from a strong left hemisphere dominance for language and handedness and strong right hemisphere dominance for other functions, occurs in 30-35% of the population. Anomalous dominance with respect to right hemisphere functions being localized in the left hemisphere is rare due to the earlier and more rapid development of the right hemisphere, making it less subject to interfering influences.

"We have suggested that a major cause of anomalous dominance is markedly delayed development of a left hemisphere that is initially programmed for strong left-sided dominance for speech and handedness. The effect of the delay is primarily to create individuals who have more symmetrical brains, although a few will be reversed." (Geschwind & Galaburda, 1987, p. 72)

One implication of the Geschwind and Galaburda theory is that even if the genetic endowment of a particular fetus were known, it would not be possible to predict the exact lateralization pattern of the brain. "...if a fertilized ovum were transplanted into the uterus of an unrelated female, the final pattern of the brain would be quite different because the brain would develop in an environment of hormones and other substances that would certainly differ in many respects." (Geschwind & Galaburda, 1987, p. 134)

A theory to account for individual variation in cerebral lateralization based on differences in neuroanatomical organization is proposed by Kinsbourne (1980). According to Kinsbourne, differences in degree/direction of lateral asymmetry are consequences of differences in neuroanatomical connectivity between the brain stem and the cerebral hemispheres.

Specifically, among right-handers, cerebral dominance is based on left-lateralized activation for verbal processing which results from lateralized brain activity projected exclusively to the left hemisphere. A loss of function of the left hemisphere leaves the right-hander with a right hemisphere which has the potential for language processing but which cannot be accessed by the brain stem. Gradual recovery from left hemisphere damage would be due to the establishment of brain stem connections which could activate the right hemisphere for speech processing.

Among left-handers, cerebral dominance for language processing is based on diffuse cerebral activation which results from less lateralized brain stem influence. Therefore, a loss of left hemisphere function leaves the individual with a right hemisphere that can be accessed by the brain stem for language processing. Thus, left-handers show more rapid recovery from aphasia.

Contrary to a neural reorganization model in which verbal functions are localized exclusively in the left hemisphere unless pathology to the left hemisphere induces lateralization of verbal functions to the right hemisphere, Moscovitch (1973) argues for a "functional localization model". This model maintains that the left hemisphere normally inhibits or suppresses right hemisphere attempts to process information linguistically. In commissurized patients this inhibitory mechanism cannot operate. This would account for the discrepancy between clinical observations of 95% left hemisphere speech lateralization among right-handers and the experimental evidence which as a rule finds 70% of right-handers showing a right visual field advantage on verbal tasks (Searleman, 1977). Also, it would explain why patients who have become aphasic after unilateral left hemisphere damage are often unable to process any linguistic information. Areas of the intact left hemisphere are still inhibiting right hemisphere processing attempts.

According to Moscovitch, the right hemisphere possesses considerable verbal skills but is normally inhibited (not activated) by the left hemisphere when verbal processing is demanded. Lateralization is based on selective functional asymmetries as opposed to localization of verbal abilities to one hemisphere versus the other.

Numerous other theories have been proposed in attempting to account for individual variations in lateral asymmetry. A general classification of such theories into structural versus dynamic models has been offered by Cohen (1982).

Structural models attribute functional asymmetries to anatomical differences. Each hemisphere is specialized for different classes of stimuli, different types of processing, or different stages of processing due to the lateralization of underlying brain structures that mediate those particular functions.

The degree of such specializations may be absolute or relative. Absolute specialization in one hemisphere is refuted by clinical and experimental data. The language function is not always completely lost with hemispherectomy or extensive unilateral damage. There is right hemisphere language ability in split-brain patients. In divided visual field studies, a right visual field advantage for verbal material is not always obtained. Finally, the non-activated hemisphere is not necessarily wholly inactive as indicated by EEG, blood flow, and visual evoked potential data.

Relative specialization would mean that both hemispheres can perform a given function but that one is faster and more accurate than the other. This perspective allows for individual variation in the relative efficiency of the two sides of the brain for different functions based on genetic and maturational factors.

Several forms of specialization may also be based on structural underpinnings. Each hemisphere may be specialized for a particular type of processing, irrespective of the nature of the stimulus. The left hemisphere has been considered specialized for sequential, serial, temporal and analytic forms of processing, for example, whereas parallel, gestalt and holistic processing have been attributed to the right hemisphere.

There may also be structural specialization based on stages of processing. Thinking in terms of levels of processing, asymmetries may occur at higher levels of processing as opposed to lower levels, or they may be allocated to all levels. Information processing models distinguish between stages such as perception, categorization, memory, and response. Cohen points out that these models may be precarious to support in that they cannot be tested unless such processing stages are functionally separable.

The second major classification of lateral asymmetry theories Cohen labels dynamic models, which presuppose some dynamic mechanism which controls or influences the functioning of the hemisphere. Such models incorporate attentional and strategy hypotheses. For example, Kinsbourne's (1970, 1973) "attentional model" maintains that each hemisphere may be "primed" for a certain type of stimulus class which then effects the selection of a strategy. Priming may occur through practice. While asymmetry may be initially absent, it may appear and change direction with practice. Or asymmetry may wane and disappear with prolonged practice.

Theories of the Origin of Left-Handedness:

A genetic model to account for the occurrence of left-handedness and the concurrent variability in cerebral lateralization for speech among left-handers compared to right-handers known as the "right-shift" theory has been proposed by Annett (1975). This theory maintains that lateral asymmetries are due to chance plus a factor which biases the left hemisphere to develop language and also increases the chances of right-hand preference. When this biasing factor is absent, as is estimated to be the case in 18-20% of the population, there is no systematic bias to either side. Handedness and brainedness each depend on chance and on chances which are independent of each other (Annett, 1982).

The possibility that the right-shift in handedness is linked with left hemisphere speech is supported by the higher incidence of right-handedness among females who are known to have an advantage in early language acquisition over males in general. If there is an intrinsic capacity of the left hemisphere for language capacities, it is probably this production facility for language which is linked with a shift in handedness. With an initial impetus to the left hemisphere's role in speech, subsequent development of left hemisphere language skills would be predicted (Annett, 1975).

In summary, Annett has suggested that most left-handedness is due to a mechanism in which cerebral laterality is randomly determined. Those individuals who do not possess a "right-shift" gene, increasing the probability of left hemisphere dominance for language, will have lateralization of language randomly determined.

Corballis (1980) provides an extensive critique of Annett's right-shift theory. His main objections to a diallelic gene locus governing the presence or absence of the right shift in distribution of handedness is that it does not adequately fit with proportions of left-handedness among monozygotic twins or siblings. The incidence of left-handedness is higher among both groups than the model would predict. Also the incidence of left hemisphere speech localization in left-handers is probably higher than accounted for by the model.

As an alternative theory, Corballis proposes that the "right shift" is not directly coded in a gene (or genes) but is rather a genetically controlled expression of a more fundamental underlying gradient which normally favors more advanced development on the left. Genes may control the presence or absence of asymmetries, but he does not see justification that genes control the direction of a particular asymmetry. Environmental influences, prenatal or postnatal, need to be included to offer a more adequate model to account for observed frequencies of left-handedness in the population.

Levy and Nagylaki (1972) constructed a two-gene, four-allele model to account for the inheritance of handedness and cerebral lateralization. One locus pertains to left or right hemispheric dominance for speech and the other to ipsilateral or contralateral hand control relative to this dominant hemisphere. These authors claim that Annett's model fails to account for experimental findings with respect to the relationship between hand preference and cerebral organization.

Face Recognition: Evidence of Cerebral Lateralization

In contrast to the simple and artificial nature of stimuli characteristic of much psychological research, faces represent a natural set of stimuli which are complex, multidimensional, and meaningful. Faces command continuous attention in their paramount role in everyday communication. Because of their importance to us and their complexity as visual stimuli, disentangling how the information faces contain is processed by the brain has been a challenge met with increasing interest in clinical and cognitive experimental investigation.

Clinical Evidence

Disorders of visual recognition of faces had been reported as part of complex sets of symptoms from the late 1900's but the specification of a specific agnosic syndrome by Bodamer in 1947 first provoked interest in systematically investigating the correlation between such a deficit with damage to specific areas of the brain. Bodamer named this defect of facial recognition "prosopagnosia".

Key to the diagnosis of prosopagnosia is the patient's inability to identify faces he/she knew previously. The patient can distinguish different parts of the face but cannot identify what makes the face individual. In fact, details that are not an integral part of the face, such as hairstyle, beard, or glasses often form the only basis for identification (Hecaen, 1981).

Still not completely resolved is the issue of whether a unilateral lesion to the right hemisphere is necessary and sufficient to product prosopagnosia (Hecaen, 1981; Mazzuchi & Biber, 1983). Bodamer himself believed that lesions to the bilateral posterior region of the brain were critical for this syndrome, and on the basis of anatomical studies undertaken since the 1950's, it has been concluded that "no anatomoclinical case has even been reported with unequivocal prosopagnosia in which the lesions have been limited to the right hemisphere; they have also always been bilateral (Hecaen, 1981).

Post-mortem analysis of patients with prosopagnosia indicates that in 100% of autopsied cases of prosopagnosia the lesions were bilateral. Patients studied with computed tomography and magnetic resonance methods are consistent with this conclusion. Evidence from hemispherectomied and split-brain patients shows that both the left hemisphere and right hemisphere are capable of facial recognition (Damasio & Damasio, 1986).

Meadows (1974) reviewed anatomoclinical correlates of the defect and has concluded that there is strong involvement of the right occipitotemporal area along with lesions to the left hemisphere which are not similarly located. Malone, Morris, Kay & Levin (1982) report involvement in one case of bilateral lesions of the occipital lobes with right parietal damage; in another case, bilateral damage to both occipital and parietal lobes. Benton (1980) argues that prosopagnosia results from a combination of lesions to both the right inferior longitudinal fasciculus and the splenium of the corpus callosum, the latter lesion preventing visual memories from passing from the left visual association cortex to the right.

Since prosopagnosia is restricted to faces previously familiar to the patient, Ellis (1981) proposes that prosopagnosia may be understood at a cognitive level as representing a malfunction in the ability to move from a basic, early level of face-processing, in which the face is categorized as a face, to a subordinate level, in which faces are differentiated as being known or unknown.

Perhaps the greatest weight for the bilateral lesion concept comes from the conceptualization of what the process of face recognition means psychosocially and of how it must be specified cognitively and neurosphysiologicaly. It would be unlikely that nature would have relegated this fundamental ability to only one of the hemispheres. However, it is also probable that the mechanisms used by the right hemisphere are more efficient than those of the left hemisphere (Damasio & Damasio, 1986).

After an extensive review of case histories of prosopagnosia, Mazzuchi and Biber (1983) found strong evidence to conclude that the incidence of this disorder is significantly higher among males than females. The difference was upheld when compensation was made for the fact that cerebro-vascular disease in general occurs much more frequently among males. Given the possible role played by damage to the splenium of the corpus callosum in the occurrence of prosospagnosia cited above, it is interesting to note that there is neuroanatomical evidence that female brains are larger than male brains in this region (deLacoste-Utamsing & Halloway, 1982).

Attempts to functionally define prosopagnosia have brought into controversy the nature of its specificity. Despite over 40 years since Bodamer's initial specified diagnosis of prosopagnosia, an unequivocal theory to explain it has not been formulated. It is still unclear whether this inability to recognize faces should be considered genuine agnosia or a memory malfunction; nor whether prosopagnosia is a specific deficit or related to a general defect affecting other classes of objects (Tiberghien & Clerc, 1986).

Bodamer's hypothesis that prosopagnosia represents a perceptual disorder only affecting one particular category of stimuli has been contested by some investigators who argue that the syndrome is a more general deficit in the ability to make difficult discriminations from memory and is applicable to various classes of complex stimuli (DeRenzi, Faglioni & Spinnler, 1968; Ellis, 1981; Hecaen, 1981), while others argue that prosopagnosia is dissociable from any other type of agnosia (Tzavaras, Hecaen & LeBras, 1970; Yin, 1969, 1970).

Hecaen (1981) maintains that approximately the same complex of symptoms and defects found for prosopagnosia are also found for the spatial agnosias, particularly the loss of topographic memory. In an extensive neurological and neuropsychological review of a case of prosopagnosia, Tiberghien and Clerc (1986) make a case for the disorder being one of memory processing. The involvement of a memory element in addition to perception is implicated by the fact that some prosopagnosic patients are able to perform face matching tests (Malone, Morris, Kay & Levin, 1982).

DeRenzi et al. (1968) have presented evidence from one case of prosopagnosia of impairment of both unfamiliar face recognition as well as impairment on other visual tests requiring discrimination of complex patterns. The authors therefore argue against prosopagnosia as a specific, isolatable disorder.

Among brain-injured subjects, there is evidence of a differential deficit for face recognition as opposed to recognition of other visual stimuli. Tzavaras et al. (1970) found deficits in identification of photos and schematic faces with patients with right posterior lesions compared to unilateral left hemisphere damage. Impairment in identifying nonsense figures and pictures of churches was not significantly different between the two groups of subjects.

Also with clinically impaired subjects, Yin (1970) found upright faces were not any easier for right posterior damaged patients to identify than upright houses but inverted faces were harder to identify than inverted houses. The conclusion was that this group of subjects had a face-specific deficit. Yin (1969) also found that face recognition performance was more affected by inversion than pictures of houses, airplanes, and stick figures among normal subjects.

To partially accommodate both perspectives on the specificity of the disorder, different types or degrees of prosopagnosia may be postulated depending on the loci of neurological damage (Hecaen, 1981). If the syndrome is strong and persistent, then bilateral lesions are undoubtedly present. If there is only right unilateral damage, the deficit might be compensated for through intervention of the left hemisphere. Also if there are bilateral lesions, defects are found in other discrimination or recognition tasks. Where lesions are limited to the posterior region of the right hemisphere, there would be accompanying spatial defects only. Finally, a memory component could result from accompanying damage to the connections between the hippocampus and the right posterior cortex. From this viewpoint, it would be possible to find cases of prosopagnosia that represented a face-specific deficit as well as cases which included other visual and spatial agnosias.

Clinical Experimentation:

The assumption is made that experimental procedures with unfamiliar faces among clinical patients can elucidate the locus/loci of necessary and sufficient impairment suffered by prosopagnosic patients. Various investigators using unfamiliar face matching paradigms among patients with unilateral lesions have found a significant relationship between performance on such measures and localization of damage in the right hemisphere (Benton & VanAllen, 1968; DeRenzi et al., 1968; Warrington & James, 1967).

However, Sergent (1984c) argues that the effect of unilateral lesions is to produce deprivation of some aspects of the visual stimulus, particularly those on which the left hemisphere would normally operate. Thus, the visuospatial competence of the left hemisphere would not be displayed under such conditions, therefore potentially biasing the results of such clinical investigations. Benton and VanAllen (1968) found that patients with right hemisphere damage performed significantly worse than left hemisphere damaged patients on a matching task involving front views, 3/4 views, and front views under different light conditions. This performance deficit was not related to the presence of visual field defects or type or intrahemispheric locus of lesion.

DeRenzi et al. (1968) introduced a short delay between viewing and matching faces and found that patients with right hemisphere damage which included visual field defects performed significantly poorer on this test than patients with right hemisphere damage without visual field defects as well as left hemisphere damaged patients both with and without visual field defects. The authors conclude that hemispheric asymmetry in the recognition of unfamiliar faces is not enhanced by the introduction of a memory factor.

Also utilizing a delay between viewing and matching faces among patients with right and left hemisphere temporal, frontal, or parietal lobectomies, Milner (1968) showed that performance of patients with right temporal lobectomies was significantly poorer than the other patient groups. When the task was repeated without a delay, performance among the right temporal group was not improved, whereas performance among the left temporal group as well as the control group was significantly deteriorated. These results support the findings of DeRenzi et al. (1968) that memory does not influence the performance of right hemisphere face processing.

Contrary to clinical investigations with patients having some degree of interhemispheric communication in tact, Levy, Trevarthen & Sperry (1972) used chimeric facial stimuli (half of one face presented to the right visual field and half of another face simultaneously presented to the left visual field) and asked commissurotomy patients to pick out from a response set which face they perceived. Although recognition was especially difficult for the left hemisphere, subjects were able to describe the distinctive features of the face presented to the right visual field. When asked to identify the right visual field face by the name assigned to it, subjects found this extremely difficult. When stimuli other than faces were used ("antler" patterns, "chain" stimuli, and familiar objects) subjects also showed a strong preference for the left visual field stimulus when pointing and an increased right visual field error rate when naming was required. The authors cite their findings as evidence for a specific functional superiority of the right hemisphere for tasks involving recognition of visual form. However, when the task being tested must be performed by either hemisphere, the two sides can accomplish the task by using characteristically different strategies.

Experimental Evidence

Evidence of a predominant role of right hemisphere lesions in producing face recognition difficulties is corroborated by experimental results with normal subjects with very important exceptions. It should be remembered that finding significant between-groups differences in accuracy or reaction time means does not account for variation at the level of the individual (Benton, 1980). The association between facial discrimination and right hemisphere function is afflicted by numerous intervening variables leading to the conclusion that neural mediation of facial discrimination is not an exclusive property of the right hemisphere.

Influence of Stimulus and Task Variables On Hemispheric Advantage for Face Recognition

The various types of faces used as stimuli in divided visual field studies of lateralization of facial processing do not convey the same amount or type of information to the subject and this fact may contribute to differences in direction of visual field advantage. Schematic faces and line drawings differ from photographs in amount of detail provided, shading and contrast. Both left visual field and right visual field advantages have been reported with each type of face (Sergent, 1986).

The amount of information a stimulus face conveys is also effected by the exposure duration used as well as the luminance level of the face. There is a tendency for faces exposed very briefly to be better processed in the left visual field whereas a relatively long exposure duration tends to yield a right visual field advantage (Sergent & Bindra, 1981).

Exposure duration can be a critical procedural variable in eliciting a right or left visual field advantage due to its effect on whether higher spatial frequencies can be extracted from the stimulus. Sergent (1982) presents evidence for a left visual field advantage for shorter exposure durations from which only lower spatial frequencies of the face can be perceived and an emerging right visual field advantage with longer exposure durations which allow the processing of higher spatial frequencies. This differential effect of exposure duration on the stimulus representation interacts with the luminance level of the stimulus face.

Sergent (1982) found shorter reaction times in the left visual field with a 40 msec exposure of photographs of faces, no significant visual field advantage at 120 msec, and shorter reaction times in the right visual field at 200 msec. In the same study, Sergent found a left visual field advantage at a 40 msec exposure duration with a luminance of 10 millilamberts and a right visual field advantage at a 200 msec exposure with a luminance of 2 millilamberts. Sergent's results indicate that the duration over which energy from the stimulus face is integrated as well as the intensity of that energy may be a determinant in the emergence of a visual field advantage. When the faces in the stimulus set are fairly dissimilar, low frequency energy (i.e., short duration) may be sufficient to induce a left visual field advantage.

Another critical variable in determining visual field advantage might be the size of the stimulus set used for identification or comparison. Young and Bion (1981) found a significant left visual field advantage with a small set but not when twice as many faces were used. However, Hilliard (1973) did not find a significant visual field effect when using a larger set than Young and Bion's large set.

The difficulty of the discrimination between target and stimulus face in a same/different task can also determine the relative efficiencies of the two hemispheres. When Sergent (1984b) varied the number of features on which the faces differed, she found that a right visual field advantage resulted when the faces differed in one feature but was absent when they differed on all three manipulated features.

Also, the degree of similarity between faces in the stimulus set may contribute to the direction of visual field advantage. The use of very similar faces has resulted in a right visual field advantage for same/different judgments whereas decreasing the similarity yielded no visual field advantage or a left visual field superiority (Patterson & Bradshaw, 1975; Sergent, 1984b).

When Young, Hay & McWeeny (1985) varied the differences between stimulus faces by the degree to which the features were scrambled, they found a left visual field advantage for reaction times when the features of the target faces were only moderately scrambled. When the target facial features were highly scrambled, no visual field superiority was found. The authors suggest two explanations. When the target/test faces were more similar, a more detailed representation of the stimulus face was required and the right hemisphere is superior in constructing facial representations; or, task difficulty influenced the right hemisphere superiority, an argument consistent with Sergent's (1984b) data.

The type of face recognition operation required of subjects in a divided visual field study makes different demands on their perceptual abilities. Simultaneous matching involves two faces which must be compared and judged as same or different. Few studies have used this procedure and there have been no consistent visual field advantages obtained (e.g., Moscovitch, Scullion & Christie, 1976; Sergent, 1984a).

Moscovitch, Scullion & Christie (1976) introduced varying amounts of delay between target and test faces in their reaction time matching paradigm. At intervals of under 100 msec the response was in the direction of the ipsilateral responding hand whereas with a delay of over 100 msec a left visual field advantage emerged. The authors conclude that only higher order processes involved in maintaining a memory representation of a face require a function specialized to the right hemisphere. Without such a memory requirement (i.e., similar paradigms using exposure durations under 100 msec) face processing would be common to both hemispheres.

Delayed matching or recognition is the most widely used paradigm (e.g., Hilliard, 1973; Leehey & Cahn, 1979; Ross & Turkewitz, 1981). Subjects match a stimulus face to a target face among a distractor set. Such designs are distinguished from simultaneous matching tasks in that memory is involved. The target stimulus must be held in some kind of memory representation. Either reaction time or accuracy measures may be used. In reaction time studies, subjects memorize and study a small set of target faces and results usually indicate a left visual field advantage (e.g., Patterson & Bradshaw, 1975; Rizzolatti & Buchtel, 1977). Thus the similarity between the target faces becomes an important factor influencing visual field advantage. If the stimuli are fairly similar, there is sufficient information for the right hemisphere to make a quick decision.

Recognition studies using accuracy as the dependent variable are manipulated to induce a minimal error rate which may result in only partial encoding of the stimulus. Sergent & Bindra (1981) suggest that what may be tested in such paradigms is the ability of the two hemispheres to deal with degraded information. According to this one line of reasoning, the left visual field advantage usually obtained is due therefore to the right hemisphere being more efficient at processing such degraded information.

Another type of face processing task is identification in which subjects must recognize a face as belonging to a specific individual. Identification tasks involving faces known to the subject call for more stringent requirements in making a correct judgment (Sergent & Bindra, 1981). Higher frequency information would need to be extracted from the stimulus face which would, again according to Sergent's (1982) line of reasoning, elicit a right visual field advantage. In fact, it would appear that studies using an identification procedure have yielded either a right visual field advantage (e.g., Marzi & Berlucchi, 1977) or a left visual field advantage (e.g., Leehey & Cahn, 1979; Young & Bion, 1981). Differences in the way in which subjects knew the stimulus faces (i.e., famous persons or colleagues) might have contributed to the direction of the visual field advantages obtained. A detailed discussion of the differential processing of familiar and unfamiliar faces follows.

Influence of Familiarity on Hemispheric Advantage for Face Recognition

Identification of familiar faces has been shown both clinically and experimentally to rely on different mechanisms than identification of unfamiliar faces.

Clinical Evidence

Bilateral damage is the usual if not necessary condition for prosopagnosia (familiar face recognition deficit), while unilateral damage is apparently sufficient for impairment in the discrimination of unfamiliar faces (Benton, 1980). Different lesion sites, although both in the right hemisphere, were associated with failures in processing the two types of facial stimuli by Warrington and James (1967). Right hemisphere damaged patients performed significantly worse than left hemisphere damaged patients on matching tasks with unfamiliar faces (Benton & VanAllen, 1968).

Clinical evidence of a dissociation between the recognition of familiar and unfamiliar faces was reported by Malone et al. (1982). In one case of prosopagnosia, the defect in recognizing familiar faces resolved but the patient was still unable to match photos of unfamiliar faces. Brain damage consisted of bilateral lesions of white matter to both occipital lobes with damage on the right extending to the parietal area. In the second case, prosopagnosia remained but the patient could match unfamiliar faces. Damage in that case was to both occipital and parietal lobes involving cortex and white matter. Thus deficits for familiar face processing were related to more extensive bilateral damage.

Experimental Evidence

One of the initial investigations of the effect of familiarity on hemifield asymmetries among normals showed a right visual field superiority for identifying famous faces. Marzi and Berlucchi (1977), using photos of famous faces with an exposure duration of 400 msec, found scores for right visual field presentations significantly higher than for left visual field presentations. Such a relatively long exposure duration, on a molecular level, would mean detailed, clear representation of the stimulus which, as discussed above, purportedly favors left hemisphere processing. In addition, it can be argued that a 400 msec exposure would be adequate for a feature-by-feature analysis for which the left hemisphere is specialized. Finally, the equating of famous with familiar may not be tenable since we have different types of perceptual exposures to individuals we see often in our daily lives than with individuals who only appear to us in the media.

Also, famous and pre-familiarized faces might be encoded for salient verbalizable features which would differentially involve the left hemisphere (Leehey & Cahn, 1979).

Umilta, Brizzolara, Tabossi & Fairweather (1978) orthogonally varied stimulus dimensions of familiarity and naming to disentangle a possible bias to the left hemisphere involved with using naming in identifying known faces. Familiarity was achieved by giving subjects the photos several days before testing and instructing them to learn them. Names were added to one set of these pre-familiarized photos. In a discriminative reaction time procedure with an exposure duration of 100 msec, responses to unfamiliarized faces were significantly faster in the left visual field whereas familiarized faces were significantly faster in the right visual field. Naming did not differentially effect visual field performance. Contrary to these two studies just described, a left visual field advantage for both familiar and unfamiliar faces was reported by Leehey and Cahn (1979). Faces were neither famous nor experimentally pre-familiarized. They were colleagues who were familiar to one group of subjects and unfamiliar to another group. In a delayed matching procedure, familiar faces were exposed for 60 msec and unfamiliar faces for 120 msec to equate performance levels. In a second experiment, subjects were asked to name the faces and a significant left visual field advantage was also obtained. Either or both of the major differences between this study and the two previous findings of a right visual field advantage for familiar faces (i.e., type of familiarity and shorter exposure duration) could have contributed to the right hemisphere superiority that was shown.

A possible confounding variable in producing right visual field superiorities demonstrated by Marzi and Berlucchi (1977) and Umilta et al. (1978) is the fact that in both studies a block design was used wherein stimuli were repeatedly presented in one visual field and then switched to the other (Ellis, 1983).

Subjects may also use different aspects of faces known to them versus faces of strangers in a recognition or identification test. Ellis, Shepherd & Davies (1979) selectively masked inner or outer features of faces and showed that for famous faces, the central part was more likely to lead to successful recognition, whereas for unknown faces, there was no difference in ease of recognition based on inner or outer details of the faces. Possibly with faces the subjects had never seen before, recognition could not be based on one or two features alone but required a more comprehensive analysis to incorporate the individual elements into an individualized percept that could form a basis for discrimination.

In an attempt to clarify the cause of a left visual field advantage found for processing familiar faces, Young, Hay, McWeeny, Ellis & Barry (1985) used a task designed to eliminate the semantic and name-retrieval components involved in naming familiar faces, as well as the memory component required for identification of the face within a distractor set of faces. Subjects were presented with photos of famous and unfamiliar faces (150 msec exposure) and asked to respond on the basis of whether the face was familiar or not. Results showed that reaction times to familiar and unfamiliar faces were not significantly effected by visual field of presentation. In addition, there was no overall difference between left visual field and right visual field error rates. The authors conclude that the right hemisphere is superior for constructing a representation of a face (unfamiliar faces) as well as accessing such a representation (familiar faces).

To investigate the effects of stimulus and task variables on processing of familiar or unfamiliar faces, Glass, Bradshaw, Day & Umilta (1985) systematically varied exposure duration (190 versus 100 msec) and degree of stimulus degradation (altered distribution of spatial frequencies) using both familiar and unfamiliar faces in a matching to target design. In terms of exposure duration, reaction times were significantly faster for the left visual field at 100 msec for unfamiliar faces and at 190 msec, no significant visual field superiority emerged for familiar or unfamiliar faces. On this dimension of the procedure, the result of no visual field advantage at an exposure duration greater than 100 msec is consistent with Young et al. (1985). On the familiarity dimension, familiar faces elicited a left visual field advantage in reaction time. However, for unfamiliar faces there was no significant visual field superiority. The lack of a significant left visual field advantage for unfamiliar faces is contrary to most previous findings, but the authors suggest that this result could have been influenced by the fact that the unfamiliar faces were repeated many times during the course of the experiment allowing them to acquire a relatively detailed representation in memory. As far as hemispheric superiority in processing clear versus degraded stimuli is concerned, an overall left visual advantage was obtained in this study for degraded faces and a right visual field advantage for clear faces. Familiar faces were unaffected by degradation but degradation of unfamiliar faces resulted in significantly poorer performance regardless of visual field of presentation.

Varying task demands (verbal identification and membership categorization, and male/female categorization) and stimulus degradation in processing familiar faces, Sergent (1985) found that direction of visual field advantage was a function of those two variables. Verbal identification and membership categorization induced a right visual field advantage, while male/female categorization resulted in no significant visual field effects. With faces degraded by filtering out intermediate and high spatial frequencies, a left visual field advantage was obtained, regardless of type of task. The author explains the left hemisphere superiority for familiar faces which is contrary to previous findings (Leehey & Cahn, 1979; Young & Bion, 1981) as being due to better stimulus quality based on accuracy level. Also, other evidence of a left hemisphere advantage for familiar faces was obtained using a long exposure duration which would provide a quality stimulus (Marzi & Berlucchi, 1977) or also had a relatively low error rate (Umilta et al., 1978). Finally, Sergent argues for the effect of accessing semantic information in the verbal identification task on the right visual field advantage which resulted. The lack of right visual field superiorty in the male/female categorization task indicates the importance of the type of information that the subject needs to extract within a given paradigm.

It appears that, at least in the context of some methodologies, a left hemisphere advantage in the recognition of faces can be induced by either extended exposure duration using very high quality facial stimuli (i.e., including all higher spatial frequencies) or inducing extended familiarization via pre-exposure to the stimulus set or repeated exposure within the experimental session.

Influence of Sex on Hemispheric Advantage for Face Recognition

Sex is undoubtedly a contributing variable to individual variability in lateral asymmetries for processing facial stimuli. Unfortunately, relatively few face recognition studies have set out with the main intention of clarifying this contribution and those that have do not offer clear conclusions.

Sex differences in recognizing unfamiliar versus familiar faces have been summarized as indicating greater lateralization effects for males than females for unfamiliar faces, whereas studies using familiar or famous faces have yielded no sex effect. However, studies of the latter type have been too few to be conclusive (Zoccolotti & Pizzamiglio, 1986).

A review of the sex effects found in the face recognition literature might lead to the conclusion that "face recognition is a multi-component process, and that each of these components (which may be tapped to a greater or lesser extent by particular tasks) may be more definitively located (in whichever hemisphere) in males." (Fairweather, 1982, p. 188).

One of the most frequently cited investigations of sex differences in hemispheric superiority for face recognition is Rizzolatti and Buchtel (1977). Using reaction time in a go-no go discrimination task with four faces to which subjects were experimentally pre-familiarized, males showed a significant left visual field advantage at exposure durations of 100 msec as well as 20 msec, while females showed no significant visual field advantage at either exposure duration. With such a small stimulus set and subjects given the photos to examine prior to testing, this task seems to be at a low level of difficulty. The results might be interpreted therefore to indicate that on a task where either hemisphere might be capable of successful processing that males showing a greater degree of functional lateralization than females, will tend to utilize and maintain a one-sided visual field superiority. Females represent a more heterogeneous group with respect to lateral asymmetries and individual variation could have nullified a significant visual field advantage in either direction in this experiment.

The study of familiarity and naming by Umilta et al. (1978) reviewed above also found significant sex differences in presence of lateral asymmetries. Specifically, among males for unnamed unfamiliar faces, reaction times were significantly faster in the left visual field, whereas for unnamed familiar faces, the superiority was for the right visual field. In females, the only significant effect was a left visual field superiority for named unfamiliar faces. Significant laterality effects emerged for males under a greater number of experimental conditions.

Both the Rizzolatti and Buchtel (1977) and Umilta et al. (1978) studies were reaction time discrimination tasks and in fact the stimulus set was identical between the two studies, as was the 100 msec exposure duration. The only right hemisphere superiority demonstrated for females was when naming of unfamiliar faces was required. Why this was the only significant effect might be related to the way females approached the pre-familiarization process. In other words, having to associate a name with each unfamiliar face may have elicited a specific cognitive strategy that was not required in the other experimental conditions.

Other studies investigating lateral asymmetries as a function of familiarity with facial stimuli, however, found no significant sex differences. Leehey and Cahn (1979), discussed above, found no significant main or interaction effects of sex. The fact that they used different exposure durations (60 msec for familiar faces and 120 msec for unfamiliar faces) and a stimulus array of 12 could have represented sufficient differences in methodology compared to Rizzolatti and Buchtel (1977) and Umilta et al. (1978)

to negate significant differences between males and females.

Young et al. (1985) also failed to find a significant effect of sex on visual field advantage. In their reaction time to a familiar/not familiar classification task, both males and females responded more quickly to faces presented to the left visual field. Although males tended to be less accurate in the left visual field and females tended to be less accurate in the right visual field, performance differences were not significant. Exposure duration was 150 msec. It could be argued that such a classification task called for judgments based on whether or not a percept for the particular facial representation could be accessed, rather than for decisions based on a systematic comparison between stimulus faces as in a discrimination task. The former type of processing is considered by the authors to clearly have a right hemisphere superiority, while the latter type of processing could also be performed by the left hemisphere, depending on specific task constraints. The choice of processing strategy in this study was less open compared to the types of processing possible in other paradigms.

Young and Bion (1983) examined the effect of varying the number of stimulus faces to number of trials ratio. Going from four faces and 48 trials to 28 faces and then 96 faces, the left visual field advantage obtained for both males and females weakened. The left visual field superiority was eliminated by increasing the ratio of stimuli to trials, but the left visual field performance of females was affected by a rather small increase in this ratio than that needed to effect the left visual field performance of males.

One interpretation of this result by the authors is that females changed processing strategies from a configurational one involving spatial relations of individual features to an analysis of the features themselves at a different stimuli to trials ratio than males. Feature analysis is more likely with the more difficult task resulting from many more faces to encode. Males did not as readily change from configurational (right hemisphere) to feature (left hemisphere) analysis when the task became increasingly more difficult as did females.

Freeman and Ellis (1984) assessed the effects of level of task difficulty among males versus females by using photos and line drawings of faces which contained either little detail or a moderate amount in a same/different discrimination task. Test faces were exposed for only 15 msec. A left visual field advantage was found for the low-detail line drawings only. No sex effect was reported. In a second experiment, only line drawings were used. There was again a left visual field advantage for low-detail faces only, but only among male subjects. The authors conclude that males are more likely to demonstrate a right hemisphere superiority under impoverished viewing conditions.

Rizzolatti and Buchtel (1977) had also found a left visual field advantage only for males at a very short exposure interval. Thus one sex difference that appears to be fairly consistent is that males are more likely to exhibit right hemisphere superiority when the task is made relatively difficult whereas under such conditions females will tend to show no significant hemispheric advantage. Level of difficulty can be manifested through ratio of stimuli to trials, exposure duration, or information content of the stimulus faces.

In another categorization-type task (Jones, 1979), subjects were asked to classify faces as male or female. Using photos at an exposure duration of 200 msec, males showed a significant right visual field advantage while females showed no significant laterality effect. However, accuracy was no better in the right visual field versus the left visual field for either sex. The right visual field advantage, Jones points out, is contrary to clinical evidence suggesting a male/female classification task is more prone to disturbance following right hemisphere lesions. Since there is neither better perceptual accuracy nor clinical predisposition associated with a left hemisphere superiority on this test, sex-related differences in cognitive strategy may be a viable explanation for the results obtained.

Thus, it may be difficult to establish whether sex differences that are observed arise from particular methodologies or from basic underlying cognitive dimensions which themselves vary as a function of sex (Zoccolotti & Pizzamiglio, 1986).

Effect of Handedness on Hemispheric Advantage for Face Recognition

The subject characteristic of handedness has had little attention in face processing research. Very few data concerning the relationship between handedness and face recognition performance are available and the research that has been done offers inconclusive findings. Nearly all investigations have been limited to right-handers whose patterns of cerebral lateralization are more homogeneous than those of the left-handed population and therefore introduce less between-subject variability in lateral asymmetries found in divided visual field tasks.

Clinical Evidence

Neuroanatomical and clinical data relating face recognition deficits to handedness are almost nonexistent, probably due to the sparseness of detailed case reports and the fact that in many instances a valid indication of the patient's hand preference is not included in the case study. Tzavaras, Hecaen & LeBras (1971) did, however, report their investigation of face recognition performance comparing right-handed with left-handed patients with unilateral hemispheric damage.

In this study, a right hemisphere preference was observed for recognizing unfamiliar faces among both right-handers and left-handers. The results indicate the importance of the role of right hemisphere lesions in determining face recognition deficits, independent of handedness. However, it should be noted that the effect of right hemisphere damage for left-handers was less homogeneous; i.e., their right hemisphere advantage was nonsignificant.

Experimental Evidence

To address the question of whether face recognition mechanisms are right hemisphere-based regardless of speech lateralization or whether the asymmetry shifts in complementary fashion to speech lateralization, Gilbert (1977) measured handedness, performance on a face recognition task and performance on a letter identification task. Subjects were given time to pre-familiarize the faces. Reaction times to matching two "positive" faces within a distractor set of four revealed no differences between right-handers and left-handers in percentage of subjects showing a left visual field bias (70%). Also, there were no significant differences in magnitude of visual field advantage, regardless of its direction. Scores of left-handers overall did not differ from right-handers. Among those subjects who did exhibit a right visual field advantage, there was a significant negative correlation between magnitude of that advantage and performance, suggesting that a strong right visual field advantage was not advantageous for this task. Gilbert concluded that localization of the face processing function seems unrelated to handedness. With regard to the reaction times to letters, the results, according to Gilbert, did not prove to be an adequate measure of verbal hemifield differences due to response variance and lack of comparability to other such paradigms. Therefore, this study does not allow a direct assessment of the relationship between speech lateralization and asymmetry for facial recognition within the sample population used.

Piazza (1980) also attempted to compare lateral asymmetries between right-handers and left-handers on measures of verbal and nonverbal functions. Sixty pairs of male faces were presented bilaterally. Subjects selected the stimulus pair from a response card. Exposure duration was individually set during a practice session and averaged 31 msec. Results showed left-handers had a significantly lower error rate than right-handers. It should be noted that error rates on this face discrimination task were within a range of 57-70% depending on the sex and handedness of the subject group. These rates would seem to be unusually high for a reaction time study which generally is designed to produce a minimal level of errors compared to studies where accuracy is the dependent variable (Sergent & Bindra, 1981).

The only significant visual field advantage obtained for this task was a left visual field advantage among right-handers with no family history of left-handedness. Left-handedness did result in generally weaker left or right visual field advantages. However, this interaction was not significant.

Piazza used both dichotic and tachistoscopic indices of verbal asymmetry of function. On the tachistoscopic task, a significant right visual field advantage was found for both right-handers and left-handers, although weaker among left-handers.

Overall, Piazza's data show a trend toward stronger lateralization of the facial recognition function among right-handers than left-handers. This pattern was consistent for verbal functional indices as well.

Finally, studies by Gilbert and Bakan (1973) and Lawson (1978) used a half-face preference task to assess differences in direction of lateral asymmetry between right-handers and left-handers. Results from both investigations showed that while right-handers showed a significant left visual field half-face preference, left-handers did not exhibit any significant visual field advantage.

Effect of Age on Hemispheric Advantage for Face Recognition

The possibility of an innate cerebral specialization for faces is suggested by several lines of evidence. Neuroanatomical and functional asymmetries are present in the infant brain and some skills involved in processing faces are developed in early infancy. It is not within the scope of this review to treat the entire body of evidence in these areas. Since the investigation of developmental aspects of cerebral lateralization has tended to use dichotic listening or clinical performance deficits rather than divided visual field analyses (Beaumont, 1982), few such developmental studies are available for discussion. The following represents a brief summary of research which seems most relevant to the analysis of hemispheric advantage for facial recognition as it relates to variations in cerebral lateral asymmetries.

With nonverbal stimuli in divided visual field studies, only faces yield a consistent asymmetry, demonstrating a left visual field advantage (Beaumont, 1982). In general developmental studies show two possible trends with regard to face recognition. Some studies have shown that lateral asymmetries do not vary substantially with age. Other evidence indicates rapid shifts from the lack of demonstrated lateral asymmetry to an adult-like pattern of asymmetry.

The left visual field advantage for discriminating unknown faces has been shown as early as 5 years of age. With a delayed matching face recognition procedure, Young & Ellis (1976) found no differences in the demonstration of a left visual field advantage in number of errors between age groups of 5, 7, and 11-year-olds. The authors found no evidence of any increasing trend in the degree of lateralization and argue that their results indicate a well advanced lateralization of visual processing by age 5.

Using reaction time same/different judgments in a delayed matching task, Reynolds and Jeeves (1978) found a left visual field advantage among 13 to 14-year-olds, but no significant lateral asymmetry among 7 to 8-year-olds. There was more within-group variability among the 7 to 8-year-old subjects. While each of the adult and each of the 14-year-old subjects showed a left visual field advantage, four of the 7 to 8-year-olds demonstrated a left visual field advantage and eight showed a right visual field advantage. Also, on the first day of testing, most of the younger subjects showed a left visual field advantage, while on the following three days a right visual field advantage was demonstrated. These results are claimed to indicate that lateralization for face recognition involves processes which are not well established until some time between ages 8 and 13. Although no sex differences were reported by Young and Ellis (1976), the fact that Reynolds and Jeeves (1978) used only female subjects might have influenced these results.

To account for the discrepancy between their results and those of Young and Ellis (1976), Reynolds and Jeeves focus on a subject selection difference. In Young and Ellis' procedure, subjects who did not report a centrally presented stimulus with equal or greater accuracy than a laterally presented face were excluded from analyses. Reynolds and Jeeves argue that this method would remove the variability in performance which they found among 7 to 8-year-olds. Young and Ellis' subjects were "biased" towards a lower degree of lateralization or bilateralization.

Regarding a possible influence in sex of subject between these studies, it is interesting to note that significantly more boys than girls failed to meet this central presentation performance criterion. This suggests that not including males would have the tendency to increase asymmetry if males do have a tendency toward bilateralized representation of spatial function, as Young and Ellis hypothesize.

Carey and Diamond (1977) propose that the right hemisphere advantage generally shown by adults for unfamiliar face recognition does not develop until after 10 years of age. At age 6 and 8, children were able to identify target faces presented upside down almost as well as those presented upright, unlike 10-year-olds. It is suggested that prior to age 10, children encode unfamiliar faces from isolated features whereas sometime around 10 years of age, they are able to encode the particular configuration of a new face with a right hemisphere type of processing similar to that used by adults.

Diamond and Carey (1977) have suggested that a difference in cognitive strategy may underlie differences in asymmetry among younger children when asked to recognize unfamiliar faces. They conducted a recognition accuracy study among children aged 6-10 and found performance improved markedly between 6 and 10, with little change at later ages. When various disguises were applied to the stimulus faces, the younger children's performance was particularly disrupted. However, when familiar faces were presented performance of younger children improved and was not affected by applied disguises.

The authors conclude that variations in lateral asymmetry for recognizing unfamiliar faces that occur among younger children compared to children over the age of 10 are due to changes in processing strategies. Younger children are more likely to encode new faces via a feature extraction approach whereas older children and adults have developed the capacity to form a configurational representation and therefore will more consistently use a right hemisphere, holistic type of encoding strategy.

Also studying face recognition lateralization among children in this age range, Young and Bion (1980) found significant left visual field advantages among all age groups with no evidence of developmental increases in degree of lateralization. Interestingly, when the number of faces in the stimulus set was increased from four to forty, only boys maintained a left visual field advantage. If increasing the level of difficulty of the task in this manner is more likely to invoke specialized left hemisphere processing (as discussed above) and males have a greater tendency toward bilateralization of spatial function, this result is explicable.

To add perspective to the equivocal findings of presence or absence of a left visual field advantage for recognizing unfamiliar faces under the age of 10, Young and Bion (1980, p. 219) stipulate that "Although the presence of a left visual field superiority at a given age can, in a properly designed study, be taken to imply right hemisphere specialisation at that age, it is not the case that absence of left visual field superiority implies absence of right hemisphere specialisation." Rather, the constraints of the task chosen may be unsuitable to demonstrate such a right hemisphere specialization in young children.

In a design similar to that of Young and Bion (1980) (a four-face stimulus set in a recognition task), Turkewitz and Ross-Kossak (1984) also demonstrated a left visual field superiority for processing unfamiliar faces which was unrelated to age. They studied girls and boys at ages 8, 11, and 13. The authors propose, however, that the right hemisphere superiority shown by the younger children represents a different underlying processing strategy than does the right hemisphere advantage of the older children. (A more detailed treatment of the support for this theory is included in the section "Evidence for Shifts in Hemispheric Advantage During Facial Familiarization".)

Effect of Cognitive Style on Hemispheric Advantage for Face Recognition

Individual cognitive strategy predilections may also influence lateral asymmetries for face recognition.

Individual variation in demonstrated lateral asymmetries for facial processing has, in large part, been attributed to the cognitive dimension of field dependence/independence by investigators who have systematically researched this relationship.

Field dependence/independence is measured through the administration of the Rod and Frame Test, wherein the subject must set a rod surrounded by a tilted frame to its true vertical position, and the Embedded Figures Test, wherein the subject is asked to restructure a complex gestalt to find a simple geometric figure embedded within it. In the former test, field dependent individuals tend to be influenced by the tilted frame whereas field independent subjects are able to set the rod close to vertical. On the latter task, field dependent individuals tend to be influenced by the organization of the larger pattern which interferes with finding the target figure, whereas field independent subjects are able to restructure the gestalt organization to find the embedded figure (Zoccolotti & Pizzamiglio, 1986).

While relatively field independent individuals show greater lateralization effects on various measures of verbal functional asymmetry (Pizzamiglio, Zoccolotti, Mammucari & Cesaroni, 1983; Pizzamiglio & Zoccolotti, 1981; Zoccolotti & Oltman, 1978), the relationship of field dependence/independence to the lateralization of face perception is perhaps more complex.

Using a paradigm wherein the subject pressed a button for only two faces out of a four-face choice array, several studies have shown that field independent subjects evidence significantly faster reaction times to left visual field stimuli, whereas a trend in the opposite direction was found for field dependent subjects.

Among all males, Zoccolotti and Oltman's (1978) results showed opposite lateral superiorities for a letter discrimination task and a face discrimination task which was greater among field independent subjects than relatively field dependent subjects. On the verbal task, a right visual field advantage was demonstrated by the field independent group while field dependent subjects showed no significant visual field superiority. With unilaterally presented photos, field independent subjects showed a left visual field advantage while field dependent subjects showed no significant visual field superiority.

Using the same paradigm but including both male and female subjects, Pizzamiglio and Zoccolotti (1981) again found that field independent subjects were more strongly lateralized to the right visual field on the letter identification task than field dependent subjects. On the face discrimination task, field independent subjects demonstrated a significant left visual field advantage while field dependent subjects showed visual field preferences of smaller magnitude favoring the right visual field. Since this relationship between field dependence/independence and lateralization occurred regardless of sex of subject, the authors conclude that this dimension of cognitive style can significantly predict hemispheric advantage.

A left visual field advantage with the same face discrimination procedure was again found for field independent subjects with a nonsignificant right visual field advantage among field dependent subjects in a later study by Pizzamiglio, Zoccolotti, Mammucari & Cesaroni (1983). These results were also independent of sex of subject.

Oltman, Ehrlichman & Cox (1977) demonstrated a relationship between field independence and a left visual field preference on a non-tachistoscopic half-face preference task previously used by Gilbert and Bakan (1973). Two different half-faces were combined and presented bilaterally. Subjects selected a match to a whole-face presented centrally. On this task, field dependent subjects showed no visual field preference. Both male and female subjects were tested.

Using still a different face recognition task, Rapaczynski and Ehrlichman (1979) also found opposite visual field advantages for field independent and field dependent subjects, although the difference in degree of lateralization between these groups was not significant. After 5 minutes of pre-familiarization with a 7 memory-set face array, memory probe faces were unilaterally presented. Subjects pressed a switch to indicate whether or not the probe stimulus was a member of the memory set. When probe and memory stimuli were inverted, visual field effects among both field independent and field dependent subjects were eliminated. This study included only female subjects.

The authors suggest that the two cognitive style groups may have differed in the level to which they had processed the memory set of faces prior to testing. This might result in the opposite visual field asymmetries if it is assumed that "face perception can be thought of as involving different levels of processing, from precategorical perception of physical attributes through perception of features to perception of a fully elaborated configuration of a face." (p. 649). If it is further assumed that the left hemisphere is specialized for processes involved in using features to discriminate while an elaborated facial percept requires facial schema specialized to the right hemisphere, field dependent subjects may have been performing the task at a lower level of processing which engaged the left hemisphere. According to the authors' viewpoint, differences in lateral asymmetries between field independent and field dependent subjects reflect differences in relative left or right hemisphere involvement in the task and not differences in the capacities of the two hemispheres.

Evidence of Analytic and Holistic Processing Strategies in the Processing of Facial Stimuli

Given that a right visual field superiority for processing faces has been demonstrated in the context of variations in methodology as well as subject group, it can no longer be refuted that both hemispheres have some specialization for perceiving and processing facial stimuli (Sergent & Bindra, 1981).

The respective contributions of the right and left hemispheres vary as a function of both task demands and nature of the stimulus. Among the conditions that stimulate a right visual field advantage or the lack of a significant left visual field advantage, as reviewed above, are a longer exposure duration (e.g. Sergent, 1982; Sergent & Bindra, 1981), decreasing discriminability of the facial stimuli (e.g. Patterson & Bradshaw, 1975; Sergent, 1984b), familiar or famous facial stimuli (e.g. Marzi & Berlucchi, 1977; Umilta et al., 1978), use of female subjects (e.g. Freeman & Ellis, 1984; Rizzolotti & Buchtel, 1977; Young & Bion, 1983), use of left-handed subjects (e.g. Lawson, 1978), and field dependence (e.g. Pizzamiglio & Zoccolotti, 1981; Pizzamiglio, Zoccolotti, Mammucari & Cesaroni, 1983; Rapaczynski & Ehrlichman, 1979; Zoccolotti & Oltman, 1978).

Underlying differences in types of processing for which the two hemispheres are specialized have been proposed to explain why a left hemisphere advantage would be more likely to occur under these experimental conditions. One such theoretical construct is the holistic/analytic information processing dichotomy.

There is a consensus of clinical and experimental evidence, some of which has been reviewed earlier, using various modalities and classes of stimuli that the right hemisphere tends to process information in a holistic manner, treating a particular stimulus as a gestalt, or configuration, while the left hemisphere analyzes components of the stimulus in a sequential fashion.

Bradshaw and Nettleton (1981) have provided an extensive review of such evidence and conclude that the historical perspective of verbal/nonverbal types of processing associated with left and right hemispheric functions are inadequate. They support an interpretation of right hemisphere processing as holistic or gestalt apprehension, whereas left hemisphere processing is sequential and analytic. Global/right hemisphere and analytic/left hemisphere are not dichotomous classifications since functional differences between the hemispheres exist along a continuum of degree.

The global/analytic interpretation of visual field differences obtained in facial recognition research could account for the effects of certain task variables inducing a right visual field advantage. For example, a longer exposure duration in which clear and complete information can be encoded may provide for a feature analysis of the face, producing a left hemisphere advantage (Sergent & Bindra, 1981).

The study reported by Glass et al.(1985) (reviewed above) which interacted familiarity with clarity of the stimulus faces found superiority of clear stimuli presented to the right visual field and reverse superiority or no differences for degraded faces. This is taken by the authors as support for an analytic/holistic model of processing since the right hemisphere would not be able to make use of clear features but the left hemisphere could.

Increasing the similarity between facial stimuli and making a different judgment may require a more methodical comparison of the individual features of the faces for which the left hemisphere would be superior. Patterson and Bradshaw (1975) investigated the effects of storage duration (pre-familiarization), same versus different judgments and difficulty of discrimination in a face discrimination paradigm. They found a right hemisphere superiority when subjects were given 5 minutes pre-familiarization with fairly dissimilar faces; a right hemisphere superiority for same judgments with faces also differing on all manipulated features; and a left hemisphere superiority when the same/different judgment was made more difficult by using stimulus faces which differed on only one feature.

The authors hypothesize that the same judgments made use of a template model whereas different judgments made use of a serial search analysis. This interpretation supports a holistic operation for the right hemisphere and an analytic operation for the left hemisphere.

Recognition or discrimination of faces with which the subject is familiar may be based on the ability to discern a particular distinguishing feature which would be a left hemisphere type of analysis, or the more familiar a face is the more likely one or two features may trigger recognition (Ellis, 1986).

On a less molecular level, the processing of a complex, multidimensional stimulus such as the human face can be thought of as taking place in stages. For example, Ellis (1983, 1986) proposes a model which maintains that a percept is first classified as a face. This initial categorization acknowledges what he terms a "general facial schema". Next, an analysis of the physical attributes and expression of the face takes place. A mental representation of the face is formed and registers in memory. Ellis acknowledges that whether the nature of the formation of such facial representations and how they are organized involves analytic/holistic processing is yet to be resolved. He does claim, however, that "the perception of faces appears to involve both an overall analysis of features and the extraction of their configurational arrangement" and that "increased familiarity with the faces appears to alter the manner in which they are processed." (pp. 13-14)

In Milner's (1968) study with right and left brain damaged patients, face recognition with a memory delay was most detrimental to performance among patients with right temporal damage. Without a delay between stimulus presentation and recognition, there were no significant differences in performance between right and left damaged groups. These results may be considered to support the role of the right hemisphere in the third stage of Ellis' model.

Not only can face processing be considered as taking place in stages, such stages may be independently lateralized to the right or left hemisphere. Rhodes (1985) proposes that early visuospatial processing as well as the creation of facial representations are carried out by the right hemisphere. Comparisons of faces based on discrete features yields a left hemisphere advantage. Rhode's model is both hierarchical and interactive. Earlier stages are more likely to be lateralized to the right hemisphere, whereas later ones, including the analysis of features and the accessing of semantic information are lateralized to the left hemisphere.

The more familiar a face is, the more semantic information will be accessible. Since comparison and recognition of unfamiliar faces relies on early visuospatial analysis, a left visual field advantage is obtained on such experimental designs. Identification of familiar faces, depending on how familiar, accesses a feature analysis and/or semantic information analysis which would lead to a right visual field advantage or a diminished left visual field advantage. Rhodes points out that Ellis' model does not consider feature analysis or semantic information retrieval to be lateralized whereas experimental evidence suggests differently.

One way in which the differential specializations of the two hemispheres have been experimentally manifested is in laterality effects obtained when faces are presented in their normal upright position and when these same faces are turned upside down. Upright faces seem to be processed on the basis of their configuration whereas inverted faces are compared on the basis of their component features (Sergent, 1984a).

Yin (1970) studied the responses of brain injured and normal male subjects to upright and inverted faces. He found that patients with right posterior injury had a deficit which was specific to upright faces. However, they performed better on inverted faces. This is presumably because the left hemisphere was processing the faces with an analytic approach which was not so dependent on an integrated configuration.

Rapaczynski and Ehrlichman (1979) also found little evidence of lateralization when upright faces were inverted in a face matching task.

To more directly assess the effect of familiarization on hemispheric advantage, Ross and Turkewitz's (1981) subjects were given time to pre-familiarize four photos of faces and were then given a face recognition task requiring them to identify the stimulus face as one of the four pre-familiarized faces. In this manner, a group of subjects utilizing a left visual field advantage and a group using a right visual field advantage were identified.

To investigate the hypothesis that the left visual field advantaged group was using a holistic strategy whereas the right visual field advantaged group was using an analytic strategy, the faces were presented upside down. It was found that the left visual field advantaged group did make significantly more errors on the inverted faces compared to the upright faces, whereas there was no difference in number of errors using the two orientations among the right visual field advantaged subjects. As a further test of the analytic/holistic hypothesis, the same stimulus faces were presented, but with a particular feature blocked out on each trial. As expected, the performance of the right visual field advantaged group was significantly more adversely effected by the masking than the performance of the left visual field advantaged subjects.

These results with normal subjects along with Yin's data support the hypothesis that those subjects demonstrating a right visual field advantage on a face recognition task are utilizing an analytic processing strategy whereas subjects showing a left visual field advantage are processing the stimuli in a holistic manner. Ross and Turkewitz further propose that the two groups of left visual field advantaged and right visual field advantaged subjects were utilizing these different processing strategies either because they had each reached a different degree of familiarization with the faces, or because of differences in more stable individual cognitive modes of functioning.

Although it has been argued that face recognition which takes place in the left hemisphere must be language dependent based on clinical evidence among aphasics (Benton, 1980), when care is taken to eliminate any requirements for semantic processing among normals, a right visual field advantage may still emerge.

Clinical evidence of analytic processing of the left hemisphere is also available. "Left hemisphere lesions affect predominantly the placement of internal details whereas right hemisphere lesions tend to affect external configuration." (Geschwind & Galaburda, 1987, p. 103)

Goldberg and Costa (1981) specify differences in neuroanatomical organization of the two hemispheres to account for laterality effects that may occur in the process of acquiring a new descriptive system. They cite greater emphasis on interregional integration in the neuronal organization of the right hemisphere and greater emphasis on intraregional integration in the left hemisphere.

The right hemisphere would be better suited to perform an integration of the components of a visual percept, whereas the left hemisphere would be more efficient at focusing on a specific aspect or quality of that percept. Over the course of increased competence in processing such a percept, there would therefore be a right to left shift in relative hemispheric control. With reference to face recognition with unfamiliar faces a new descriptive system must be acquired whereas with familiar faces an already acquired descriptive system is utilized. The right to left shift in hemispheric advantage would occur during the familiarization process.

Given a dichotic listening task involving recognition of simple melodies, musically experienced subjects evidenced a right ear advantage while musically naive subjects performed better with the left ear presentations (Bever & Chiarello, 1974). The specific task was to identify a two-note sequence as belonging to a specific melody and the results are interpreted to indicate that the musically experienced subjects could organize a melodic sequence by the internal relation of its components. That is, with increased capacity for musical analysis, the left hemisphere becomes increasingly involved in processing music. The different strategies applied by musically experienced and musically naive subjects relate to the analytic left hemisphere and holistic right hemisphere modes of processing.

An alternative explanation to the analytic/holistic dichotomy for different directions of visual field advantage based on task variables is subject choice of strategy. That is, differences in an individual's cognitive skills may give him/her a predilection for a right hemisphere or left hemisphere advantage.

Rapaczynski and Ehrlichman (1979) found opposite visual field asymmetries among subjects assessed as field dependent versus subjects determined to be field independent. Since subjects were given time to pre-familiarize with the stimulus faces, the authors suggest that one possible explanation for the difference in hemispheric advantage may be the two groups differed in the level to which they processed the faces before testing. According to a levels model such as Ellis (1983, 1986) and Rhodes (1985) have proposed, a complete configuration of a face occurs late in the process. Field dependent subjects who by definition have more poorly developed visuospatial capacities processed with the left hemisphere. They may not have been able to achieve the higher level of configuration which relies on facial schemata presumably available only to the right hemisphere.

Summary Statements

The experimental conditions that tend to produce a left visual field advantage for face processing seem to be such that comparison of faces is achieved holistically. Sergent and Bindra (1981) list several types of holistic processing that might apply to face recognition: perceptual configuration generates a unitary percept or gestalt from a complex stimulus such as a face; functional categorization, which may be used when the stimulus is degraded and the subject needs to discriminate a critical combination of features; determining set when the subject is primed to perceive or identify a certain stimulus.

Task variables that increase the likelihood of a left hemisphere superiority may be a direct result of that hemisphere's specialization for feature detection and analysis. A left hemisphere superiority due to subject variables such as sex, handedness, or cognitive style may have an additional etiology: variations in underlying degree of cerebral lateralization of right and left hemispheric capacities, and in some percentage of the population, to reversal of the direction of hemispheric specialization as compared to the majority of the population.

Face Recognition: Summary Statements

There is clinical and experimental evidence that the processing of faces can and often does involve the capacities of each hemisphere. Analytic versus holistic types of information processing are proposed to account for the task variables in experimentation which tend to elicit a right hemisphere or left hemisphere advantage.

One such task variable which elicits differential hemispheric advantages is the degree of familiarization of the facial stimuli. Unfamiliar faces most frequently elicit a left visual field advantage whereas familiar or famous faces have a higher tendency to evoke a right visual field advantage, depending on certain other task variables such as exposure duration or type/degree of familiarity of the stimuli.

The influence of subject variables on hemispheric advantage for face processing is for the most part inconsistent. This inconsistency is probably due in large part to individual variability within subject groups in underlying lateral asymmetries, cognitive capacities, and information processing strategies employed. Such confounding effects are more likely to occur among females and left-handers given the evidence of variation in cerebral lateralization among those populations such as reviewed in this paper.

Changes in Hemispheric Advantage with Increased Familiarization with Facial Stimuli: The Dynamic Shift Model

Research findings reviewed in the preceding sections of this paper lead to two basic assumptions concerning the processing of facial stimuli: firstly, that both hemispheres have a specific capacity to deal with the processing of faces, and secondly, that different task and subject variables will tend to evoke the particular processing skills of either one or the other hemisphere.

There is also sufficient clinical and experimental data to conclude that familiar faces are processed differently than unfamiliar faces. That is, the use of familiar or famous faces and unfamiliar faces in an experiment will tend to elicit differences in direction and/or magnitude of the resulting visual field advantage. The evidence for this assumption may be equivocal in that inconsistent results can certainly be found. However, it can be reasonably argued that such inconsistencies may be due to variations in task design (e.g. exposure duration, size of stimulus set, delaying matching versus identification), the way in which the faces are familiar to subjects (e.g. famous faces, faces of colleagues, initially unfamiliar faces which have been "learned" prior to testing), and differences in the degree to which the faces are familiar.

In the context of these assumptions a series of investigations were conducted to systematically examine changes in hemispheric advantage that may occur within an individual as familiarization with an initially unfamiliar small set of faces progresses (Ross & Turkewitz, 1982; Ross-Kossak & Turkewitz, 1984, 1986; Turkewitz & Ross, 1983; Turkewitz & Ross-Kossak, 1984). The model that has been proposed by these investigators to account for the observed shifts in hemispheric advantage with increased familiarization will be discussed first, followed by the specific empirical data in support of that model.

The processing of complex perceptual information is proposed to proceed from a relatively simple level to a complex level with concomitant changes in the type of processing associated with shifts in the direction of hemispheric advantage. The pattern of these shifts is consistent with three stages of perceptual learning: undifferentiated processing, articulation of distinctive features, and integration of features into an entity. These stages are a derivative of a theoretical interpretation originally stated by Werner (1957) in a macrodevelopmental perspective of mental development. Werner wrote "The elements are not precedent to the whole, but the whole, as a basic entity, is the precursor of its component parts." (p. 8-9). Referring to the transition to a third stage or level, Werner alludes to "The fundamental law of development - increase of differentiation and hierarchic integration." (p. 44).

One translation of this perspective is that the initial, undifferentiated processing is specialized to the right hemisphere. The articulation of distinctive features is an analytic processing specialized to the left hemisphere. Thirdly, the right hemisphere is superior in the integration of information derived from the stimulus. The first two stages are analogous to holistic and analytic processing. The departure from any previous theoretical constructs is that the third stage represents a final second right hemisphere mode of processing that is more advanced than the left hemisphere analytic mode preceding it because it incorporates aspects of stimulus information attained by such left hemisphere processing.

With respect to the specific application of this model to the familiarization of faces, Ross-Kossak and Turkewitz (1986) acknowledge consistencies with Goldberg and Costa's (1981) theory of shifts in hemispheric advantage from right hemisphere to left hemisphere as a function of increased experience or competence with perceptual or linguistic types of information. According to Goldberg and Costa, a novel task which has no pre-existing descriptive system, such as processing unfamiliar faces, elicits a right hemisphere superiority. However, once a descriptive system exists or develops during the acquisition of a task, such as through increased familiarization with faces, a left hemisphere advantage is obtained. These sequential hemispheric advantages are consistent with the first two stages of the Ross-Kossak and Turkewitz model.

The overall pattern of results found in the series of studies relevant to this dynamic shift model indicate that: 1) Some subjects begin processing facial stimuli with a left visual field advantage and some with a right visual field advantage; 2) During the course of the experiment, both of these groups of subjects show changes in their visual field advantages. The nature of these changes is different for subjects beginning with a left visual field advantage or a right visual field advantage; 3) In addition, a relationship between proficiency and direction of visual field advantage at certain points in the familiarization process has been demonstrated.

The paradigm consistently used in these investigations involved the unilateral presentation of one of four photos of female faces for 100 msec. The subject then pointed to the face just seen from a response sheet showing all four faces. Each trial block contained 24 presentations with each face presented three times each to the right or left of fixation in random order. An index of hemispheric advantage was computed for each block by subtracting the number of errors in the left visual field from the number of errors in the right visual and dividing by the total number of errors on that block. The significance of changes in visual field advantage from block to block was computed using trend analyses.

The first study using this paradigm (Ross & Turkewitz, 1981), reviewed earlier, found a right visual field advantage for the subject group as a whole with no sex effect. A left visual field advantage might have been predicted if the subjects had not been given 5 minutes to familiarize themselves with the stimulus faces prior to testing. A substantial minority of subjects, however, did demonstrate a left visual field advantage (28%), indicating that the task evoked different patterns of laterality between individual subjects. As discussed earlier, support for an analytic interpretation for the right visual field advantaged subjects and a holistic interpretation for the left visual field advantaged subjects came from inverting the faces and masking their features. These manipulations resulted in greater performance deficits for the right visual field advantaged subjects compared to the left visual field advantaged subjects.

Following this support for different hemispheric strategies underlying different patterns of lateral asymmetry, the paradigm was expanded in order to examine sequential changes in lateral asymmetry which were predicted when the faces were processed along a continuum of totally unfamiliar to highly familiar. The number of blocks was extended to four and no pre-familiarization was given. Since there was reason to believe, based on preliminary data, that females would be more likely to show the full range of shifts in hemispheric advantage, only females were tested.

Three general conclusions relevant to the dynamic shift model are suggested by the results of Ross & Turkewitz (1982). First, despite the absence of pre-familiarization, the expected left visual field advantage on the first block of trials for unfamiliar face recognition was demonstrated by about half of the subjects. Those subjects who did have an initial left visual field advantage had a stronger advantage than initial right visual field advantaged subjects. So, although it was possible to have a left hemisphere advantage in processing unfamiliar faces, such an advantage tended to be weak.

Second, results indicated changes in visual field advantage across the four blocks of trials. The nature of the shifts was dependent on the direction of the visual field advantage on Block 1. Thus, the initial left visual field advantaged (ILVFA) group showed a decrease in that advantage until it disappeared by Block 3. On Block 4, the left visual advantage returned. Trend analyses showed significant changes in visual field advantages over the course of familiarization. For the initial right visual field advantaged (IRVFA) group, visual field advantages did not change significantly across blocks.

The failure of the ILVFA subjects to show a right visual field advantage before returning to a left visual field advantage on the final block is not predicted by the right hemisphere - left hemisphere - right hemisphere shifting model. The authors suggest that rate differences between subjects in changing their processing strategies from right hemispheric to left hemispheric may explain the nullifying of a group effect. Shifting patterns examined by individual subject did reveal that eight of the 18 ILVFA subjects showed a left-right-left visual field advantage pattern whereas only three of the 17 IRVFA subjects demonstrated a right-left-right visual field advantage pattern.

The third conclusion is that there was a relationship between magnitude of visual field advantage and performance which was more pronounced during certain phases of the familiarization process. The correlation between magnitude of visual field advantage and overall number of errors, regardless of direction of initial visual field advantage, was significant and negative. So, demonstrating a strong right or left hemispheric advantage was associated with better performance. In addition, the nature of this association differed for ILVFA and IRVFA subjects. For the former group, the relationship was strong for Blocks 1 and 2, weak for Block 3, and strong again for Block 4, supporting the conclusion that it was not beneficial to have a strong visual field advantage during transitions in the use of a right hemispheric versus a left hemispheric processing strategy. For the IRVFA subjects, a strong visual field advantage was not associated with better performance for Blocks 1 and 2, but was significant on Block 3 and relatively strong on Block 4. Since this subject group maintained their right visual field advantage throughout testing, these findings indicate that a strong left hemisphere advantage was not advantageous during the early phases of face processing.

In support of the dynamic shift model, Ross and Turkewitz point out that a right hemisphere/global processing strategy was advantageous at the beginning of familiarization. Using a left hemisphere/analytic strategy of feature distinction was not beneficial prior to the establishment of some degree of familiarity with the faces. A right hemispheric advantage at the end of the familiarization process was advantageous, regardless of the direction of initial visual field superiority.

To examine whether shifts in visual field advantage and concomitant shifts in processing strategies were a function of increasing familiarity with the specific set of stimulus faces or were due to the development of a generalized strategy for identifying faces in a tachistoscopic paradigm, Turkewitz and Ross (1983) switched to a new set of four stimulus faces on the last two trial blocks, while maintaining all other experimental parameters. Results supported the second hypothesis: Subjects develop a generalized strategy for face processing.

Even though a new set of stimuli were introduced mid-test, the mean number of errors across blocks showed a significant linear decline. The pattern of shifts in visual field advantage was not disturbed by the introduction of novel stimuli. ILVFA subjects showed a significant change in their visual field advantage across blocks, as found by Ross and Turkewitz (1982). This group shifted to a right visual field advantage on Block 2 and returned to a left visual field advantage on the last two blocks, evidencing the right-left-right predicted shifts in hemispheric advantage. IRVFA subjects, however, showed one transition to a left visual field advantage in Block 2 where they remained for Blocks 3 and 4. As in Ross and Turkewitz (1982), the direction of initial visual field advantage predicted subsequent patterns of hemispheric advantage.

The conclusion of this study that shifts in hemispheric advantage reflected the development of a generalized processing strategy does not support the view that the second right hemisphere advantage involves the integration of specific facial features learned in earlier trials since the pattern of shifts was not effected by introducing new faces with new sets of features.

It should be noted that in this study, as in Ross and Turkewitz (1982), a substantial minority of subjects displayed a right visual field advantage for processing unfamiliar faces.

To help clarify the incidence of individual differences in initial visual field advantage as well as the nature of the final right hemispheric advantage and whether it was reliably predicted, Ross-Kossak and Turkewitz (1984) extended the test session to eight blocks of 24 trials, instead of four. The focal issues were whether, given a longer period of familiarization, IRVFA subjects would eventually evidence the full range of shifts in hemispheric advantage displayed by ILVFA subjects, and to more fully examine the relationship between specific shifting patterns and performance as familiarization progressed.

Although slightly more than half of the subjects showed a right visual field advantage, those who began with a left visual field advantage made significantly fewer errors on Block 1, supporting the benefit of beginning the process with a right hemisphere strategy.

As found previously (Turkewitz & Ross, 1983), the IRVFA subjects changed to a left visual field advantage where they remained throughout the last four blocks. Extending the familiarization process did not effect the direction of shifts for these subjects. Replicating earlier findings (Turkewitz & Ross, 1983), the ILVFA subjects shifted direction to a right visual field advantage and then returned to a left visual field advantage. Extended familiarization did not effect the pattern of their shifts.

To examine more fully the relationship between shifting patterns and proficiency, subjects were divided into better- and poorer-performing groups based on a median number of errors for the first four blocks. Better-performing subjects with an IRVFA shifted to a left visual field advantage during testing, while better-performing subjects with an ILVFA showed a decrease and then an increase in their left visual field advantage across blocks. By the end of testing, better-performing subjects were more likely to demonstrate a left visual field advantage. For poorer-performing subjects, no systematic shifts in visual field advantage were evidenced.

The authors conclude that these results are evidence that a particular sequence of hemispheric advantages is associated with better performance. It also seems apparent, based on the consistent finding of individual variation in processing strategies employed for this task, that subject variables not necessarily correlated with improved performance are at work in influencing how these face processing demands are approached.

Individuals with a right hemisphere advantage performed better at the beginning of the task when faces were completely unfamiliar. Use of a left hemisphere advantage early in the process may be inefficient if there is insufficient information on which to use a distinctive feature strategy. Once some familiarization has taken place, a right hemisphere advantage is no longer advantageous and feature analysis may be optimized. Finally, a second right hemisphere advantage with increased familiarization late in the process would reflect a more advanced mode of processing than the initial right hemisphere superiority.

Support for this interpretation on a more molecular level comes from Sergent's (1982, 1983) findings that at early stages of complex information processing low spatial frequency information is attended to, a specialization of the right hemisphere.

To further investigate the proposed dual mode of right hemisphere processing from a developmental perspective, Turkewitz and Ross-Kossak (1984) presented a modified version of their experimental paradigm to 8-, 11-, and 13-year-old boys and girls. The same four stimulus faces were used with varying exposure durations previously determined to yield comparable accuracy levels (140 msec for 8-year-olds and 110 msec for 11- and 13-year-olds). Subjects were given 3 minutes before testing to familiarize themselves with the faces. Five blocks of eight trials were given.

Accuracy was significantly greater in the left visual field, regardless of age or sex. The percentage of subjects showing a right visual field was fairly consistent across age groups and ranged from 25-34%.

To explore age-related differences in the use of dual modes of right hemispheric processing, the distribution of error scores for subjects with a right visual field advantage and subjects with a left visual field advantage were analyzed separately. It was hypothesized that if there were age-related changes in the distribution of subjects using the two right hemisphere modes, among the 8-year-olds the left visual field advantage would be primarily based on a more diffuse and less effective type of processing, whereas among 13-year-olds it would be based on a more integrated and effective right hemisphere strategy.

Results showed a unimodal distribution of error scores for 8- and 11-year-olds with a left visual field advantage. For 13-year-olds, there was a bimodal distribution, with more subjects at the lower range of error scores than at the other two ages. The differences in the nature of these distributions suggests that at age 13 a new and more efficient type of processing has emerged. Right visual field advantaged subjects did not form a bimodal distribution of error scores at any age.

On the basis of sex alone, the same data analysis revealed that although a substantial number of females used a more diffuse right hemisphere processing mode, many females did show evidence of a more integrative type of right hemisphere processing. For males with a left visual field advantage, the distribution of error scores was basically unimodal while for females with a left visual field advantage it was clearly bimodal. Distributions among male and female right visual field advantaged subjects were unimodal.

The conclusion that there is a dual mode of right hemisphere functioning present in older females was substantiated by an analysis of variance which indicated a significant interaction between sex and direction of visual field advantage. Females with a left visual field advantage outperformed females with a right visual field advantage while the reverse was true for males. Also, for females the association between magnitude of visual field advantage and error scores was negative and significant, while for males the association was not significant. Analyzed by age of female, correlations for 8- and 11-year-olds were not significant, while for 13-year-old girls, there was a significant association.

Having a stronger visual field advantage regardless of its direction was significantly correlated with fewer errors for the total subject group. Separate correlations by sex and age also indicated that this association was significant and negative for males, females and 13-year-olds. It should be noted that the failure to find significant associations among the younger children was due in part to those ages showing more limited visual field advantages, regardless of direction.

The overall findings of this study indicate that there are age- and sex-related differences in the type of hemispheric processing used for facial information. The results also indicate that the processing of facial information takes place in stages with varying types of hemispheric advantages underlying these stages. Older children and females were more likely to show evidence of a dual mode of right hemisphere processing.

The generality of the pattern of shifts in hemispheric advantage observed with the face familiarization paradigm to familiarization with other complex visuospatial stimuli was tested using Japanese ideograms called Kanji (Kittler, Turkewitz & Goldberg, in press). Initially novel Kanji were unilaterally presented for recognition at an exposure duration of 66 msec to female right-handers. Six blocks of 24 trials were presented. As with the face recognition research, subjects were divided into those showing an ILVFA (45%) and those showing an IRVFA (35%). Results indicated that those subjects beginning with a left visual field advantage changed direction of that advantage in Block 2 and maintained a right visual field advantage for the remaining four blocks, while IRVFA subjects showed a weakening of their right visual field advantage but did not shift to a left visual field advantage. Support for a right-left shift in hemispheric advantage was thus shown but the later shift to a right hemisphere advanced mode was not present. The authors speculate either that effective processing of Kanji stimuli did not require an integrative approach or, because the stimuli were so extremely novel in nature, there was not a sufficient number of trials for an integrative mode of processing to be evidenced.

In a checkerboard pattern discrimination task with an extended number of presentations, Eisner (1987) demonstrated a sequence of right-left-right shifts in hemispheric advantage. The frequency range of the stimuli she used (2-3 cycles per degree) also includes the salient frequencies for facial recognition.

Finally, evidence of shifts in hemispheric advantage with increased familiarization using a non-visual modality has been found by Devenny (1987). In a dichotically presented voice recognition task, individual differences in initial ear advantage were present and shifts in direction of hemispheric advantage during the task were shown for both initial right ear advantaged subjects and initial left ear advantaged subjects.

Summary Statements

Evidence from studies of familiarization with facial stimuli indicate that sequential changes in hemispheric advantage reliably occur. Shifts in hemispheric advantage are differentially related to proficiency and appear to be age-dependent and related to gender.

A right-left-right sequence of hemispheric shifts is hypothesized to reflect changes in processing strategy from holistic/diffuse to analytic to integrative. Support for the initial right to left shift in hemispheric advantage for familiarization with faces has been extended to other complex visuospatial stimuli as well as to the aural modality. Support for the second, advanced right hemisphere advantage is more limited and somewhat indirect.

Research Design: Issues Related to Measurement of Lateralization and Handedness

The purpose of measuring lateralization of function in the present study is to confirm the presence and extent of differences in magnitude and/or direction of lateral asymmetry which might account in part for differences in magnitude and/or direction of hemispheric shifts during the facial familiarization task. Therefore issues relevant to the measurement of subjects on the basis of cerebral lateralization should be confronted.

Tachistoscopic Presentation:

The tachistoscopic presentation of stimuli as a method of measuring functional lateral asymmetry has been in use since the early 1950's. The neuroanatomical premise of this technique is that optic fibers from the temporal half of the retina project to the ipsilateral lateral geniculate nucleus and then to the visual cortex, while fibers from the nasal half of the retina cross at the optic chiasm and continue to the contralateral lateral geniculate nucleus and then to the visual cortex. Therefore stimuli presented to the right of a central fixation point impinge on the left temporal and right nasal hemiretinae and are thus conducted to the left visual cortex, while the reverse occurs for stimuli presented to the left of fixation (Zaidel, 1985).

Provided stimuli are exposed for less than about 200 msec, which is the estimated latency for saccadic eye movements to occur (Young, 1982), this technique gives reasonable assurance as to the information each side of the brain is receiving independent of the other side.

The dependent variable most frequently used in tachistoscopic investigations is either reaction time to a "positive" stimulus or accuracy in recognizing, identifying or matching a stimulus to a target. Although results from these two types of dependent variable are considered comparable, they may involve differences in the type of information the brain perceives from the stimulus. Reaction time studies are designed to afford maximum accuracy and so involve a maximum degree of stimulus clarity whereas accuracy studies are generally designed to produce a higher baseline error rate so stimulus quality is generally less than optimal (Sergent, 1986). The three tachistoscopic paradigms used in the present research use accuracy as the dependent variable to provide maximal comparability of performance on the face recognition task with measures of laterality on the verbal and visuospatial tasks.

Since a variety of experimental conditions which are not related to hemispheric specialization can effect demonstrated visual field superiorities, at least two tests are necessary to assess lateral asymmetry. Each test should depend as much as possible on the operational strategies or capacities of one hemisphere while resisting solutions based on the strategies or capacities of the other hemisphere (Levy & Reid, 1978; Smith & Moscovitch, 1979).

The assessment of degree and direction of lateralization of verbal and visuospatial functions using a within-subjects design was based on commonly used tachistoscopic paradigms which have yielded the most consistent results.

Assessment of Verbal Asymmetry:

To indicate lateral asymmetry of verbal function, consonant-vowel-consonant trigrams were used in horizontal array and presented unilaterally. Nonsense syllables were used instead of words to induce maximal performance differences between language dominant and nondominant hemispheres by minimizing whatever confounding influences might be associated with attaching meaningfulness to the verbal stimuli.

A justification for using nonsense syllables as opposed to words is suggested by the results of Levy and Trevarthen (1977) who found that the hemisphere nondominant for speech in commissurotomy patients demonstrated some degree of proficiency in the recognition of words but not in dealing with purely phonetic linguistic material. Thus lateral asymmetry would be potentiated using nonsense syllables.

Nonsense syllables were also used to minimize any potential left-to-right directional scanning bias. Some investigators have argued that vertical arrays should be used to counteract left-to-right word tendency which may effect visual field advantage (Bryden, 1966; Levy & Reid, 1978). However, such a confounding effect is most likely to occur using words and in a bilateral visual field presentation (Beaton, 1986).

Hellige and Sergent (1986) have argued that a more critical scanning problem with words might be a bias to scan rightward from fixation toward the right visual field which would not be disrupted with a vertical arrangement. The authors maintain there is insufficient reason to use a vertical array of letters to control for scanning biases.

Also, since all three letters had to be correctly identified for a positive response to be recorded, the fact that letters farthest from the fixation point would be most difficult to perceive would not affect direction of visual field advantage because of randomized unilateral presentation.

Assessment of Visuospatial Asymmetry:

As an indication of lateral asymmetry of the visuospatial function, a dot localization task was used. To maximize the potential to discriminate lateralization, the stimulus field included two frames with the dot presented within one of those frames.

Using dot localization, Kimura (1969) found a significant left visual field advantage for male right-handers and no significant visual field advantage for female right-handers using such a stimulus design. Bryden (1973), however, failed to find a significant visual field advantage among right-handers or left-handers on a dot localization task and alludes to the fact that Kimura (1969) presented the dot within a rectangular frame while he did not use a frame. In that vein, it is interesting to note that when Kimura (1969) surrounded the dot with a single circle instead of using two symmetrical frames, both male and female subjects demonstrated a left visual field advantage.

Fixation Control:

Fixation for all three laterality tasks will be a neutral symbol, such as a black dot. There is insufficient evidence to conclude that the use of a fixation stimulus such as a digit to be reported does not introduce as many confounding variables as it intends to eliminate (Beaton, 1986).

McKeever, Suberi & VanDeventer (1972) systematically investigated the effect of using a fixation digit versus a fixation dot on visual field advantage in a word recognition task. With unilateral presentation, a right visual field advantage was obtained regardless of mode of fixation with no interaction effect. With bilateral presentation, results showed greater overall accuracy with a fixation dot. Again, a right visual field advantage was demonstrated regardless of fixation mode. The authors conclude that fixation digits do not produce or significantly augment visual field superiority in either unilateral or bilateral presentation.

Hellige and Sergent (1986) have reviewed the issue of fixation control and recommend several important steps to take to encourage correct fixation. Instructions to subjects should be strongly worded and frequent reminders interjected. There should be a warning interval long enough to permit fixation prior to stimulus presentation but not too long as to make maintenance of fixation difficult to maintain. They recommend 1-2 sec. Left visual field and right visual field should be stimulated in an unpredictable manner. The present design has followed each of these suggested steps.

Hellige and Sergent also point out in reference to the use of a fixation digit reported by the subject prior to stimulus response that subjects might be able to shift their gaze by 1 or 2 degrees of visual angle and still identify the fixation digit. More importantly, requiring identification of the fixation stimulus changes the information processing demands of the laterality task.

Measuring Visual Field Advantage with Laterality Indices:

The use of any measure of laterality to quantify cerebral asymmetry for a particular function relies on the basic assumption that such asymmetry is a relative condition and that one subject group will tend to be more lateralized than another subject group for that function (Colbourn, 1978; Marshall, Caplan & Holmes, 1975).

Investigations of lateral asymmetry have not been entirely consistent in the application of an index with which to reflect direction and magnitude of lateral advantage.

Researchers concerned with this situation have suggested criteria for an "ideal" index which would tend to maximize the potential validity of any such measurement. One of the most frequently debated issues concerns the relationship between the laterality index and overall accuracy on a particular task designed to assess differences in lateralization of function between subject groups.

Specifically, should the laterality index be independent of level of performance or should it reflect not only lateral advantage but also the influence of lateral advantage on accuracy for a given task? For example, it has been argued that the laterality index should be unconstrained by total accuracy such as to allow for subjects showing a LVF superiority and performing well or poorly, and subjects showing a RVF superiority and performing well or poorly (Marshall et al., 1975). However, the relationship of laterality to accuracy might be one in which accuracy would be greater with a LVFA, for example, compared to some other demonstrated pattern of asymmetry (Birkett, 1977). To allow for the empirical expression of such a relationship, a laterality index not related to accuracy may not be desired.

The issue of independence of laterality measures and overall accuracy was pointed out early on by Kimura (1963) when she used a right correct score minus left correct score (Rc–Lc) index with subjects of varying ages on a dichotic listening task. Using this measure, she found that lateral advantage decreased with age while overall accuracy increased. This interpretation was not intuitively supportable. Kimura then noted that larger Rc–Lc scores were mathematically possible the closer overall accuracy was to 50%. Thus, there was a negative correlation between lateral advantage and accuracy which caused her to question the index used.

Several methods for quantifying lateral advantage which have directly addressed the issue of the influence of overall accuracy on such an advantage have been proposed. Marshall et al. (1975) claim that for any pair of correct scores in the right and left fields of presentation, the laterality index should take into account the possible range of values that Rc and Lc would have at the particular level of accuracy. The index they propose (f) is such that when accuracy < 50%, laterality index = Rc–Lc/Rc+Lc; and when accuracy > 50%, laterality index = Rc–Lc/R errors + L errors. The authors argue that this method is an improvement over previous measures such as the percent of correct (POC = Rc/Rc+Lc) which is constrained above accuracies of 50% and the percent of error (POE =L errors/R errors + L errors) which is constrained at accuracies below 50%. Marshall et al.'s objective was a laterality index not positively or negatively constrained by accuracy.

The f equation, along with three other laterality indices (Rc-Lc, POC, POE) were applied to dot localization data in a study by Birkett (1977). He found that all four measures were negatively correlated with overall accuracy and were all positively correlated with each other. His results indicated no significant VFA's. Birkett claims that the significant intercorrelations were due to the overall scores being clustered around the mean.

The phi coefficient was suggested by Kuhn (1973) to measure laterality using the Pearson correlation betweendichotomous variables. It is computed between side of presentation and accuracy. The phi coefficient indicates to what extent overall accuracy is dependent on one or the other sides of presentation and allows evaluation of the statistical reliability of such dependence through the relation between phi and the chi square distribution (Colbourn, 1978).

Hellige, Zatkin, and Wong (1981) conducted a study comparing the four measures used by Birkett (1977) plus the phi coefficient. Hellige et al. also examined between-task differences in the laterality measures using dichotic listening and visual field word recognition tasks. Because both tasks yielded significant right ear and RVF advantages, the findings are particularly enlightening.

For both tasks, there were significant positive intercorrelations between the five indices as found by Birkett (1977). However, on the dichotic listening task, correlations between laterality and accuracy were positive and significant for all five indices, while on the word recognition task, only POC was significantly (negatively) correlated with overall accuracy.

These results suggest a tendency for overall accuracy to increase as the right ear advantage increased with the dichotic listening task, while for word recognition, there was no consistent pattern of accuracy correlations. The issue of a laterality index being sensitive to the dynamic nature of brain/behavior relationships is exemplified by these findings. It is also interesting to note that intercorrelations between laterality indices were high regardless of the relationship of those indices to accuracy.

Critical of all the laterality measures discussed above, Chapman and Chapman (1988) point to an artifactual relationship between Rc-Lc and overall accuracy which they claim no indices have yet successfully eliminated. This statistical artifact plus a change in lateral advantage in response to a variable may both influence the same set of findings and the goal of researchers studying lateral asymmetry should be to tease apart these influences before making conclusions about their data. Chapman and Chapman show that the relationship between accuracy and Rc-Lc is curvilinear so that the highest difference scores can occur in the middle range of overall accuracy. In addition, an increase in overall accuracy may produce either a larger or smaller difference score, depending on the range of accuracy. When results of a study do not fit this curvilinear relationship, it can more confidently be argued that group differences are due primarily to lateral asymmetry and not an artifactual influence of accuracy level.

One of the possible solutions suggested by Chapman and Chapman to minimize the overall accuracy artifact is to use a matched task design such as a verbal task to measure a left hemisphere function and a spatial orientation task to measure a right hemisphere function. With regard to matched tasks and lateral function, the important assumptions would be that the two tasks are differentially lateralized, as well as that they do not differ in difficulty.

To provide a different perspective on the measure of lateral advantage used in the present investigation, the Results section includes analyses of data for the Letter Identification laterality task using the other indices discussed above. The relationship of these laterality index values to task accuracy is also examined.

Eye Dominance:

A measure of eye dominance was not included in the present design. When such a measure has been included in laterality studies it has most frequently not been correlated with performance on laterality measures using unilateral presentations (e.g. Hilliard, 1973; Kimura, 1966; Levy & Reid, 1978). Complicating the relationship between eye dominance and laterality is the fact that eye dominance can be designated as sighting dominance or acuity dominance and each type of dominance may have a differential effect on laterality results depending on either the nature of the stimulus (Bryden, 1973) or sex of subject (Gur & Gur, 1977).

Bryden (1973) found a complex interrelation between sighting dominance, acuity dominance and handedness on a forced choice letter recognition task but no effect of either form of eye dominance on a dot localization task. Bryden disavows the ability of eye dominance to produce a laterality effect, stating that the laterality effect for letters was somehow related to eye dominance but not directly caused by it.

Gur and Gur (1977) found that handedness and sighting dominance were associated with lateral asymmetry only for males and handedness and acuity dominance were associated with lateral asymmetry only for females.

Assessment of Handedness:

Not all activities are preferentially performed by one hand over the other, making handedness a continuous variable. In the present research "degree of handedness" was assessed with a questionnaire indicating level of hand preference for 15 daily activities. The items included in the handedness questionnaire represent a modified version of the Edinburgh Inventory (Oldfield, 1971).

In a study of the validity of commonly used questions concerning handedness, Raczhowski, Kalat & Nebes (1974) scaled those questions on their reliability as well as their validity when compared to observed performance of the tasks in question. The items comprising the questionnaire used in the present research were shown to have high rankings on these two dimensions, as well as the ability to differentiate relative degrees of left-hand preference. Scoring of the questions allowed subjects to indicate degree of hand preference from strong to indifferent (Bryden, 1977).

The criteria used in the present study for experimenter evaluation of inverted and non-inverted writing postures are identical to those specified in Levy and Reid (1978). In her review of the writing posture literature, Levy (1984) reports that use of other forms of identification of writing posture (such as self-report, the assessment of others, or use of criteria at variance with those of Levy & Reid, 1978) result in inconsistent findings in terms of the relationship between writing posture and direction/degree of lateral asymmetry.

Task Order:

The three divided visual field tasks comprising the present research design were presented in the same order to all subjects. The replication of the Ross and Turkewitz (1982) paradigm for face recognition preceded the administration of the letter identification and dot localization tasks. It was not known whether task order would effect performance on the face recognition task since such an effect had been demonstrated previously (e.g. Klein, Moscovitch & Vigna, 1976). In the interest of replicating the task constraints and experimental conditions of the Ross and Turkewitz (1982) paradigm, it was decided not to vary task order.

Evidence of a biasing effect of task order on visual field advantage was absent in a study wherein a letter identification task always preceded a face recognition task (Hilliard, 1973). A left visual field advantage for face recognition was demonstrated following a right visual field advantage for the verbal task among 11 out of 20 subjects. Only three subjects demonstrated a right visual field advantage on both letters and faces.

Counterbalancing for task order for letter identification and dot localization did not contribute significantly to analyses of variance results in the Levy and Reid (1978) investigation.

In a series of experiments which varied task order of bilateral word presentation with bilateral face recognition, Klein et al. (1976) did find evidence that priming the left hemisphere with a verbal task diminished the observed left visual field advantage for faces and priming the right hemisphere with the face recognition task reduced the right visual field advantage for words. In the second experiment, however, when subjects responded to the words by pointing to a response card rather than saying them out loud, the priming effect was not shown. In each situation, a 5 minute break was given before or between tasks.

In a third experiment of the Klein et al. (1976) study, subjects were simultaneously presented with a word and a face and asked to attend to either one or the other first. The right visual field advantage for words remained regardless of order of attention whereas the visual field advantage for faces was determined by order of attention. Klein et al. (1976) suggest that these results reflect differences in the nature of processing strategies required of the two types of stimuli. Faces require greater differentiation skills and are more difficult to encode due to their unfamiliarity compared to words. An alternate explanation could be that face recognition is more likely to be a bilateralized function than is verbal processing and hence would be more susceptible to priming producing shifts in hemispheric advantage.

The "priming" hypothesis for selective hemispheric attention to various classes of stimuli proposed by Kinsbourne (1970, 1973) states that attention in a divided sensory field presentation will be biased toward the sensory field contralateral to the more active hemisphere. One effect such priming can have, therefore, is to improve the detection of stimuli presented to the primed hemisphere when that hemisphere is not normally dominant for the task at hand.

Klein et al. (1976) reason that the cognitive operations involved in naming versus recognition engage the processing capacities of the two hemispheres differentially. If this is a correct interpretation, it may be that under still other task constraints such a "priming" effect will also be absent. For example, as the authors point out, "Within the test set, practice shifts the subject's attention back towards the hemisphere dominant for that set, as is consistent with the attention model. Within the priming set, however, practice increases the score of the visual field projecting to the non-primed, subordinate hemisphere, contrary to the prediction of the attention model." (p. 59).

Leehey and Cahn (1979) also counterbalanced presentation of words and faces, but found no significant effect of task order. This was true despite the fact that subjects responded to the words verbally, as did the subjects in the initial experiment of Klein et al. (1976).

Exposure Duration:

The setting of exposure duration covaries with the luminance level in determining the relative clarity (or degradation) of the stimulus as perceived by the subject. This relationship has been shown to differentially effect visual field advantage demonstrated (Sergent, 1982). Therefore, it is relevant to discuss how these task variables were determined in the present experiments.

The face recognition procedure was intended to replicate that used by Ross and Turkewitz (1982) to the fullest extent possible. However, in the original paradigm stimuli as slides were rear-projected onto a screen, whereas in the present procedure, tachistoscopic presentation was used. Care was taken to use the same visual angle of presentation.

Pilot subjects were used to determine the appropriate luminance level which would result in an error rate ranging from 27-70% at the exposure duration used in the original paradigm (100 msec).

Because it was not certain to what extent subject performance might vary by sex and/or handedness, it was decided to determine exposure duration for the verbal and visuospatial laterality tests independently for each individual subject. This method has been previously used for letter identification (Hilliard, 1973; Levy & Reid, 1978; Smith & Moscovitch, 1979) as well as dot localization (Levy & Reid, 1978; Smith & Moscovitch, 1979) paradigms.

For trigram identification, Hilliard (1973) reported a modal exposure duration of 50 msec while Smith and Moscovitch (1979) reported an average of 80 msec. The exposure duration at which pilot subjects in the present study achieved a 50% accuracy level was at 75-80 msec. For the experimental subjects, testing with practice trials therefore began at 75 msec and was stepped up or down if necessary in an attempt to achieve an accuracy level of 50% across visual fields.

For dot localization, the stimulus design used was essentially a replication of Kimura (1969), Experiment I. She used an exposure duration of 10 msec. Again, to allow for accommodation of suspected individual variability due to subject variables, a longer starting exposure duration was used so that subjects could be stepped up or down to achieve a 50% accuracy level during the practice trials. The exposure duration at which pilot subjects achieved 50% accuracy was 25-30 msec.

In the designs that formed the models for the verbal and visuospatial tasks, luminance levels, when they were reported, varied to such an extent (e.g. .49 to 15 ft-lamberts on the trigrams and .30 to 15 ft-lamberts on the dots) that finding an "ideal" luminance level for these tests was not attempted.

INTRODUCTION TO THE RESEARCH

The main objective of this research is to assess the relative effects of gender and handedness on the demonstration of shifts in hemispheric advantage during familiarization with facial stimuli and to determine the association between those shifts and level of proficiency.

The research design was intended to carry out this objective as well as to test the hypothesis that patterns of hemispheric advantage, both their direction and their magnitude, would be related to underlying patterns of cerebral lateralization of function, in terms of both degree and direction of lateral asymmetry.

The following predictions concerning the effects of gender and handedness on patterns of hemispheric advantage and their effect on proficiency during facial familiarization, as well as the relationship between performance on the face recognition task and degree/direction of lateral asymmetry, are offered:

1) Regardless of gender or handedness, all subject groups will manifest changes in hemispheric advantage during the course of testing.

Several types of evidence support this prediction: Considerable clinical evidence of bilateral involvement in face recognition deficits; anatomical correlates of unfamiliar versus familiar face recognition deficits; and experimentally demonstrated differences in visual field advantage for unfamiliar versus familiar faces.

Undoubtedly, individual variability in demonstrated asymmetries for this task will be fueled by individual differences in cognitive strategy as well as differential effects of task difficulty.

2) Those subject groups who have higher degrees of lateral asymmetry for verbal and visuospatial functions will be more likely to utilize both hemispheres in a right-left-right sequence of hemispheric shifts predicted by the dynamic shift model (Ross-Kossak & Turkewitz, 1986).

This prediction is based on the hypothesis that hemispheric shifts in the face recognition paradigm are due to different processing strategies which in turn are based on underlying lateral asymmetry of function. If degree or direction of functional lateral asymmetry varies, shifting will be affected. Since the weight of evidence is towards greater functional asymmetry among males and among right-handers compared to females and left-handers, the two former subject groups are predicted to be more likely to evidence the full sequence of hemispheric advantages during the familiarization process.

The more advanced right hemisphere processing mode which is part of the model has to date been demonstrated only among female right-handers. It is not unreasonable to predict that the full sequence of shifts will be even more likely to occur among males due to their greater degree of lateral asymmetry. It should be noted, however, that it is not known to what extent specific task variables in the present study will interact with the expression of this asymmetry.

With reference to left-handers and right-handers, the higher incidence of reversed lateralization for language representation among left-handers may prove to be of critical influence in determining patterns of hemispheric shifts. Since the left-handed population represents a more heterogeneous group in terms of degree and direction of functional asymmetry than the right-handed population, it could be argued that a systematic pattern of hemispheric shifts would be less likely to emerge among the left-handed group.

3) Insufficient data exist on which to make predictions concerning the relationship between hemispheric shifts and proficiency based on gender and handedness. Although previous results with this face recognition paradigm showed proficiency to be associated with certain directions of visual field advantage at different points in the familiarization process, this association has been limited

to female right-handers. If cognitive style is an important contributing factor to the effectiveness of a holistic versus analytic information processing strategy, and the influence of cognitive style is partly a function of gender, it may be difficult to predict within the context of the present experimental design whether the same relationship between direction of changes in hemispheric advantage and proficiency will be upheld for males.

The likelihood of a greater proportion of left-handers having reversed lateralization of functional capacities compared to right-handers may not affect the relationship between magnitude of hemispheric advantage and proficiency between the handedness groups. However, it is not unreasonable to expect that differences in underlying cerebral asymmetry may affect when during the course of familiarization such a relationship optimizes performance.

METHOD

The determination of the effects of sex and handedness on patterns of hemispheric advantage during familiarization with faces was based on a replication of Ross and Turkewitz (1982). The assessment of lateralization of verbal and visuospatial functions was based on two tachistoscopic paradigms providing indices of lateral asymmetry for letter identification and dot localization. Procedural details for each task will be described under separate sections for each of the three experiments.

Subjects

All subjects were recruited from psychology classes at the University of Wisconsin - Milwaukee in the following manner. A brief description of the experimental procedure was given to each class as a group, and a sign-up sheet was then circulated so that students could indicate their interest in participating. Only classes in which professors offered extra credit for research participation were approached. Subjects ranged in age from 18-40.

Total number of subjects tested in each sex/handedness classification were as follows: 30 female right-handers; 31 male right-handers; 30 female left-handers; and 29 male left-handers. In addition to self-report of handedness, experimenter observation of hand used for writing was obtained in the writing posture test and all subjects completed a handedness questionnaire (Appendix 1) prior to beginning the experiments. The questionnaire included a question on whether or not any members of the immediate family (father, mother, sisters, brothers, children) were left-handed.

Before experimentation began, subjects were given a brief description of the tachistoscopic method and were told to expect the entire test session to take about 1 hour.

Apparatus

Stimuli for all three Experiments were presented using a Gerbrands Model 300-6T connected to a Gerbrands Lamp Drive Circuit Model 400-3. The viewing distance was 79 cm.

Face Recognition

Stimuli

Four photographs of female faces wearing white caps, identical to those used by Ross & Turkewitz (1982) represented the facial stimuli (See Figure 1).

The photographs were mounted such that the center of each face was 4.5 cm to the right or left of fixation, subtending a visual angle of 3.2 degrees. Each face, as mounted, measured approximately 3 cm by 4 cm.

Subjects were not shown the stimulus faces prior to the presentation of the first trial.

Procedure

Preceding each trial, the experimenter said "Ready" and a card with only a central fixation dot was shown for 1.2 sec prior to stimulus presentation. Following each stimulus presentation, a card with all four faces on it numbered 1 through 4 was presented. Because stimuli were tachistoscopically presented, use of a response sheet to which subjects would refer in order to select the face just seen was not feasible. Instead, the response card was presented in one of the channels of the tachistoscope and the subject's response was the number corresponding to the face just shown. Verbalizing a number as opposed to pointing to a face was not anticipated to induce any amount of visual field bias. There was no time limit to respond, but subjects were encouraged to guess if unsure.

There were four blocks of 24 trials. Within each block each face was presented three times to the right visual field

(RVF) and three times to the left visual field (LVF) in random order. Duration of stimulus exposure was 100 msec at a luminance of .2 ft-lamberts. Correct identifications by visual field were analyzed for each block of trials to derive an index of visual field advantage for each of the four trial blocks.

Writing Posture

After completing the face recognition experiment, the lights in the experimental room were turned on and subjects were given paper and pencil to take the writing posture test. A card with a typed sentence on it was put in front of the subjects. The subject was asked to copy the sentence writing as he/she "normally" would. The experimenter designated the subject as inverted or non-inverted using the criteria from Levy and Reid (1978):
Inverted, based on one or more of the following indices: 1) the writing hand was rotated so that the hand was held above the line of writing; 2) the paper was rotated so that the hand was held to the side or above the line of writing; 3) the tip of the pencil pointed to the bottom of the page.

Non-inverted, based on: 1) the writing hand held below the line of writing; and 2) the pencil pointed toward the top of the paper.

Immediately following the writing posture assessment, the experimental room was darkened and subjects were given the letter identification task to assess verbal lateralization.

Letter Identification

Stimuli

Twenty-four consonant-vowel-consonant (CVC) nonsense syllables were taken from Noble's (1961) table of "scaled meaningfulness" of CVC's. Standardized values for the table range from .00-4.80. Only CVC's with a meaningfulness value of 2.00 or less were chosen.

Each trigram consisted of block letters located 3.2 cm to the right or left of fixation, subtending a visual angle of 2.3 degrees at the center letter. Each letter measured approximately 1.27 cm by 1.27 cm.

Procedure

Preceding each trial, the experimenter said "Ready" and a card with only a central fixation symbol was shown for 1.2 sec. Immediately following presentation of the stimulus CVC, a mask card containing a bilateral partial noise field was shown for 150 msec. Subjects responded to each CVC presentation by naming the three letters they perceived.

No time limit was set but subjects were encouraged to guess. The 24 CVC stimuli were randomly presented twice to either the RVF or LVF for a total of 48 experimental trials.

Exposure duration of the stimuli was individually determined for each subject using non-experimental CVC's in 20 initial practice trials. The duration determined necessary from pilot data for an accuracy level of 50% across visual fields at a luminance of .1 ft-lamberts provided a baseline exposure from which the duration was stepped up or down to achieve the desired accuracy level for each subject. The range of exposure durations used was 55-140 msec with a mean of 79.3 msec.

Following a 3-5 minute rest period, subjects were given a dot localization task to assess visuospatial lateralization.

Dot Localization

Stimuli

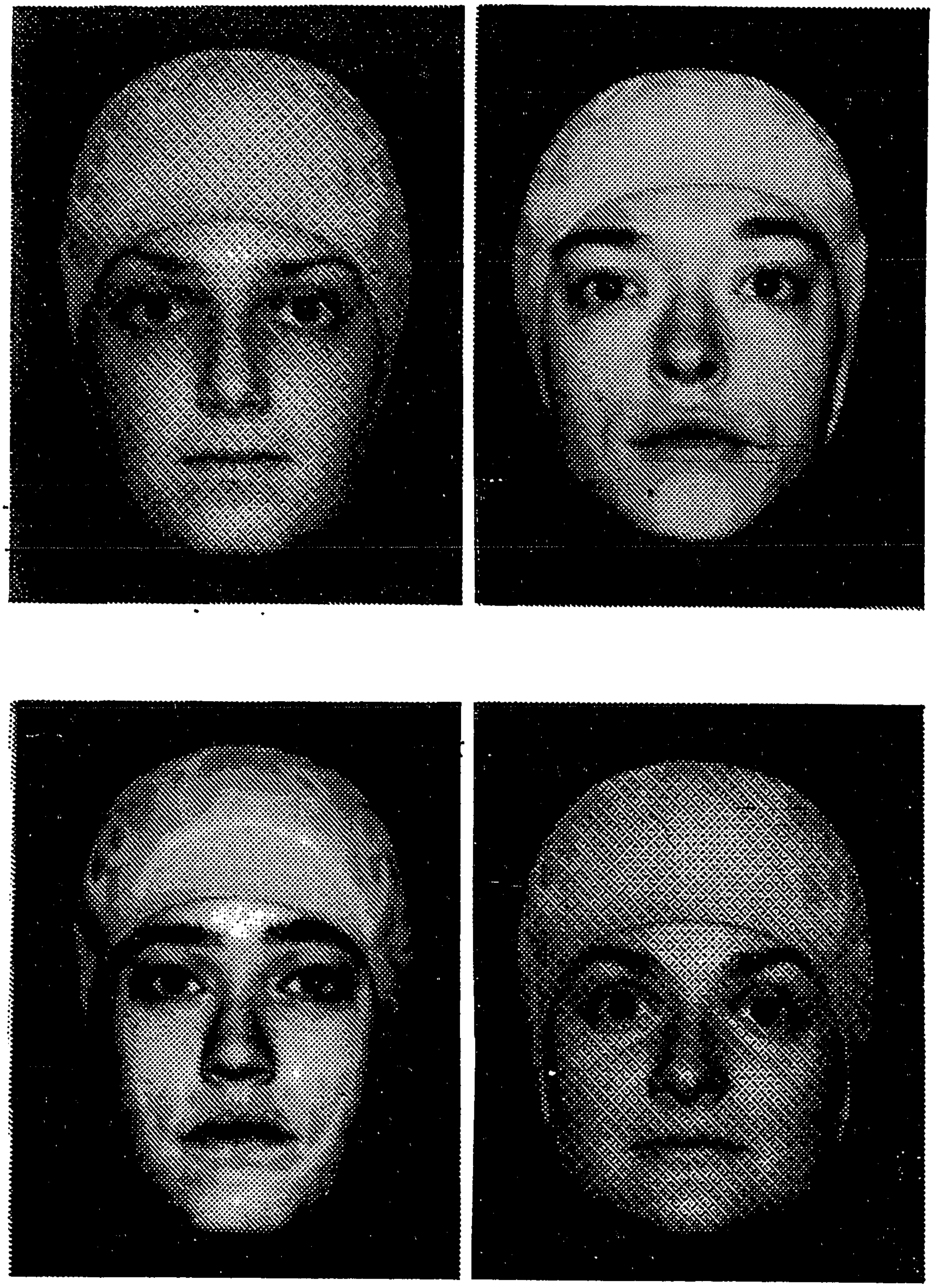
A black dot measuring approximately 3 mm and appearing in one of 24 possible locations, 12 to the right of fixation and 12 to the left, served as the stimulus. The dot appeared within one of two rectangles which were positioned to the right and left of fixation. Each rectangle measured 4.5 cm by 5.7 cm, subtending a visual angle of 2.1 degrees at its center.

Procedure

Preceding each trial, the experimenter said "Ready" and a card with a central fixation symbol along with the two rectangles was shown for 1.2 sec. Immediately following presentation of the stimulus dot, a mask card containing a bilateral partial noise field was shown for 150 msec. The mask was followed by presentation of the response card which consisted of the two rectangles with numbers corresponding to the 24 possible dot locations. Subjects responded by saying the number corresponding to the location perceived. No time limit was set, but subjects were encouraged to guess. Each of the 24 dot positions was presented twice in random order for a total of 48 experimental trials.

Exposure duration of the stimuli was individually determined for each subject in 20 initial practice trials. The duration determined necessary from pilot data for an accuracy level of 50% across visual fields at a luminance of .6 ft-lamberts provided a baseline exposure from which the duration was stepped up or down to achieve the desired accuracy level for each subject. The range of exposure durations used was 20-80 msec with an average of 32.2 msec.

Figure 1



RESULTS

Face Recognition

Data were analyzed by subject groups on the basis of sex, handedness, and initial visual field advantage (IVFA = the visual field in which fewer errors were made during Block 1). Face recognition data from five subjects (two male left-handers, two female left-handers, and one female right-hander) were eliminated from face recognition analyses due to overall error rates above 70%.

Shifts in Visual Field Advantage

Calculations relating to visual field advantage (VFA) were based on the following index:

$$\frac{\text{left visual field errors} - \text{right visual field errors}}{\text{left visual field errors} + \text{right visual field errors}}$$

Clinical and experimental evidence of differential hemispheric asymmetry for recognizing unfamiliar versus familiar faces was supported by the fact that both sexes and both handedness groups tended to evidence shifts in the nature of their VFA's during the process of familiarization with the faces.

Sex

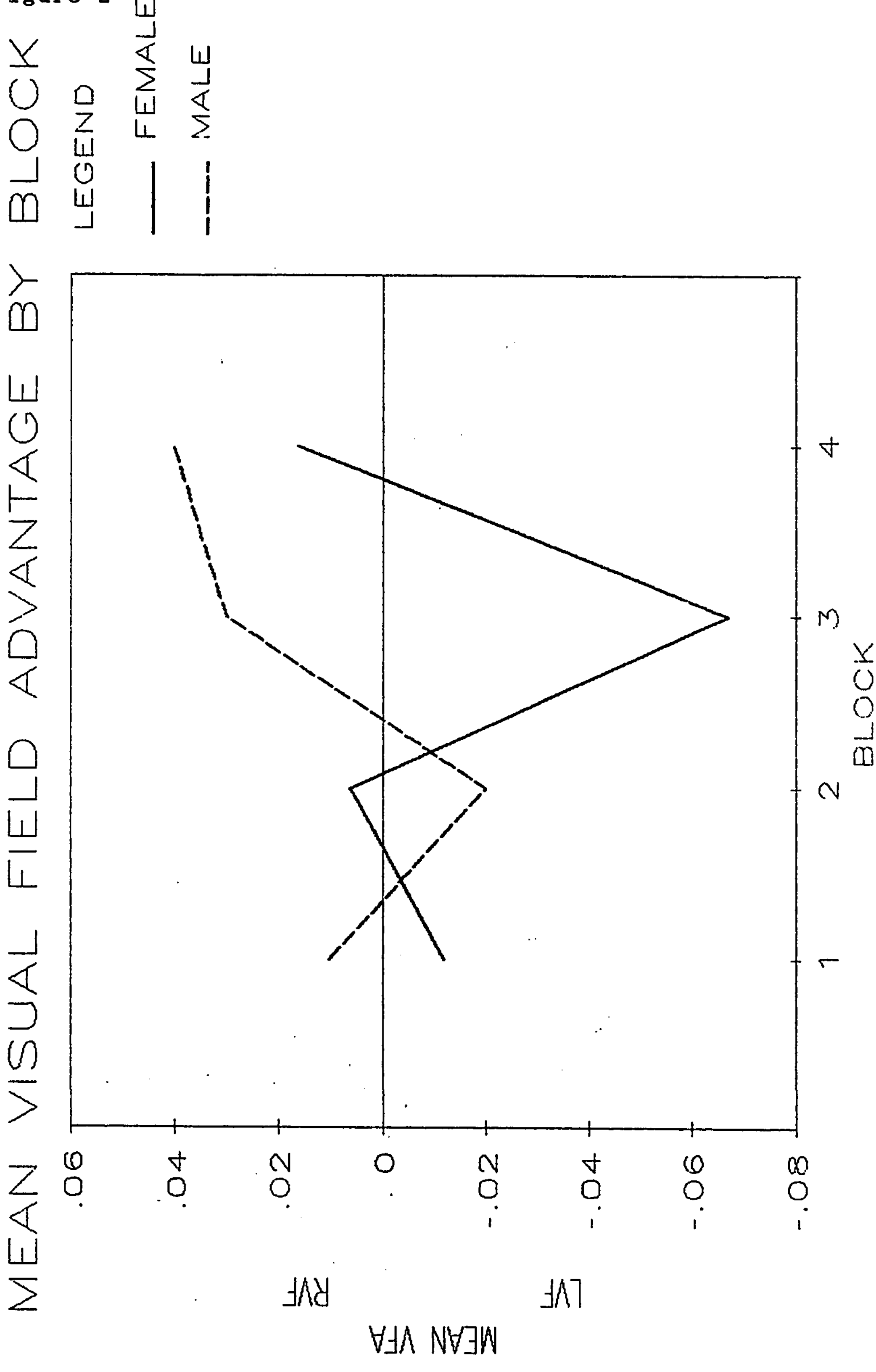
The major difference in shifting patterns between the female and male subject groups, which included both right-handers and left-handers, was in the direction of the IVFA. Females began the familiarization process utilizing a LVFA while males began with a RVFA.

The pattern of changes in direction of VFA for Blocks 1, 2 and 3 was opposite for females and males (See Figure 2), but these VFA changes were not significant. The tendency for females to evidence a sequence of right-left-right hemispheric advantages is consistent with previous results (Ross & Turkewitz, 1982; Turkewitz & Ross-Kossak, 1983), and the absence of a second right-hemisphere advantage among males is not incongruous with data from male children using this paradigm (Turkewitz & Ross-Kossak, 1984).

For both sexes, the magnitude of VFA tended to be weaker for the first half of the task compared to the second half.

Trend analyses revealed no significant linear or higher order components to the sequence of VFA's for either sex.

Figure 2


MEAN VISUAL FIELD ADVANTAGE BY BLOCK
LEGEND
FEMALE
MALE
.06
.04
.02
0
-.02
-.04
-.06
-.08
RVF
LVF
MEAN VFA
1
2
3
4
BLOCK

Handedness

The pattern of hemispheric advantages among right-handers compared to left-handers differed in the direction of IVFA as well as in the presence of significant changes in hemispheric advantage from Block to Block (See Figure 3).

Right-handers began with a right hemisphere advantage while left-handers began with a left hemisphere advantage. Subsequent changes in VFA as familiarization progressed, although not significant, tended to follow a left to right sequence of hemispheric advantages for right-handers. Left-handers showed a nonsignificant shift to a right-hemispheric advantage followed by a significant change to a left-hemispheric advantage for the last Block ($F_{quad} = 4.19$; $df = 1,184$; $p<.05$).

Direction of Initial Visual Field Advantage

Beginning with a LVFA (41% of the total sample) versus a RVFA (46% of the total sample) did not effect the presence of significant shifts in VFA during the task (See Figure 4).

Collapsed across sex and handedness, both ILVFA subjects and IRVFA subjects showed a significant shift in VFA from

Figure 3

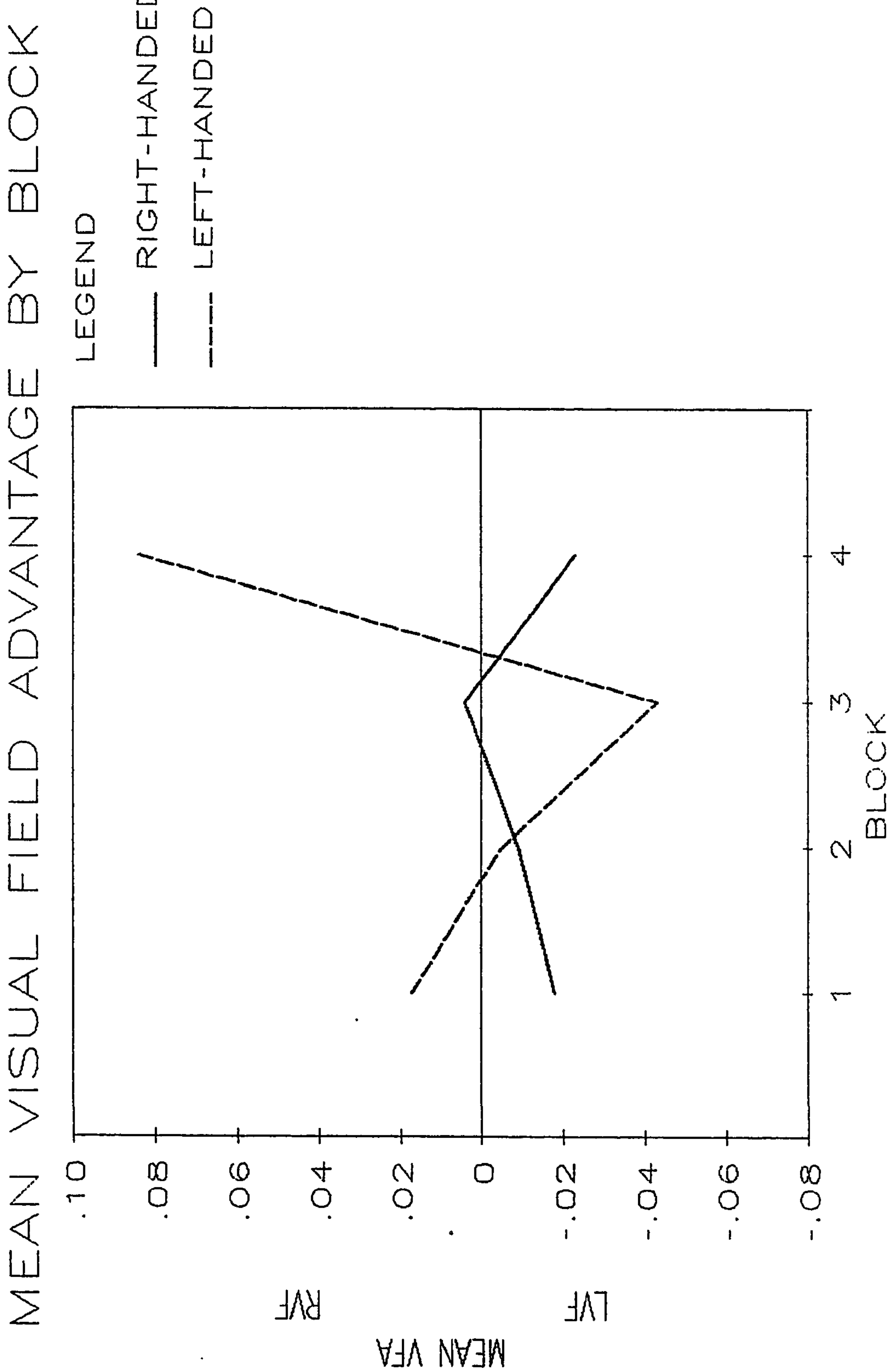
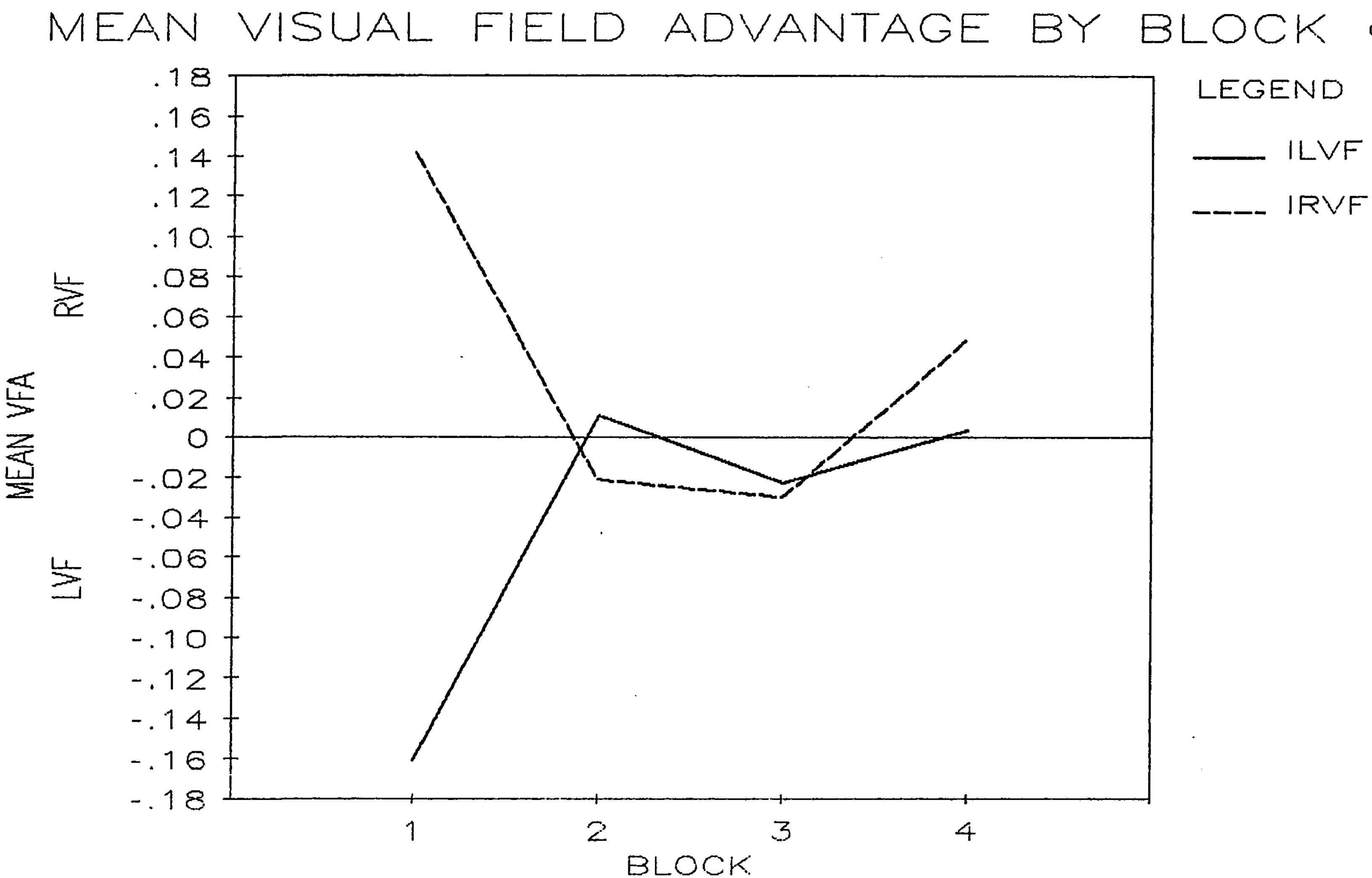

MEAN VISUAL FIELD ADVANTAGE BY BLOCK
LEGEND
RIGHT-HANDED
LEFT-HANDED
.10
.08
.06
.04
.02
0
-.02
-.04
-.06
-.08
RVF
LVF
MEAN VFA
1
2
3
4
BLOCK

Figure 4


MEAN VISUAL FIELD ADVANTAGE BY BLOCK
LEGEND
ILVF
IRVF
MEAN VFA
RVF
LVF
.18
.16
.14
.12
.10
.08
.06
.04
.02
0
-.02
-.04
-.06
-.08
-.10
-.12
-.14
-.16
-.18
1
2
3
4
BLOCK

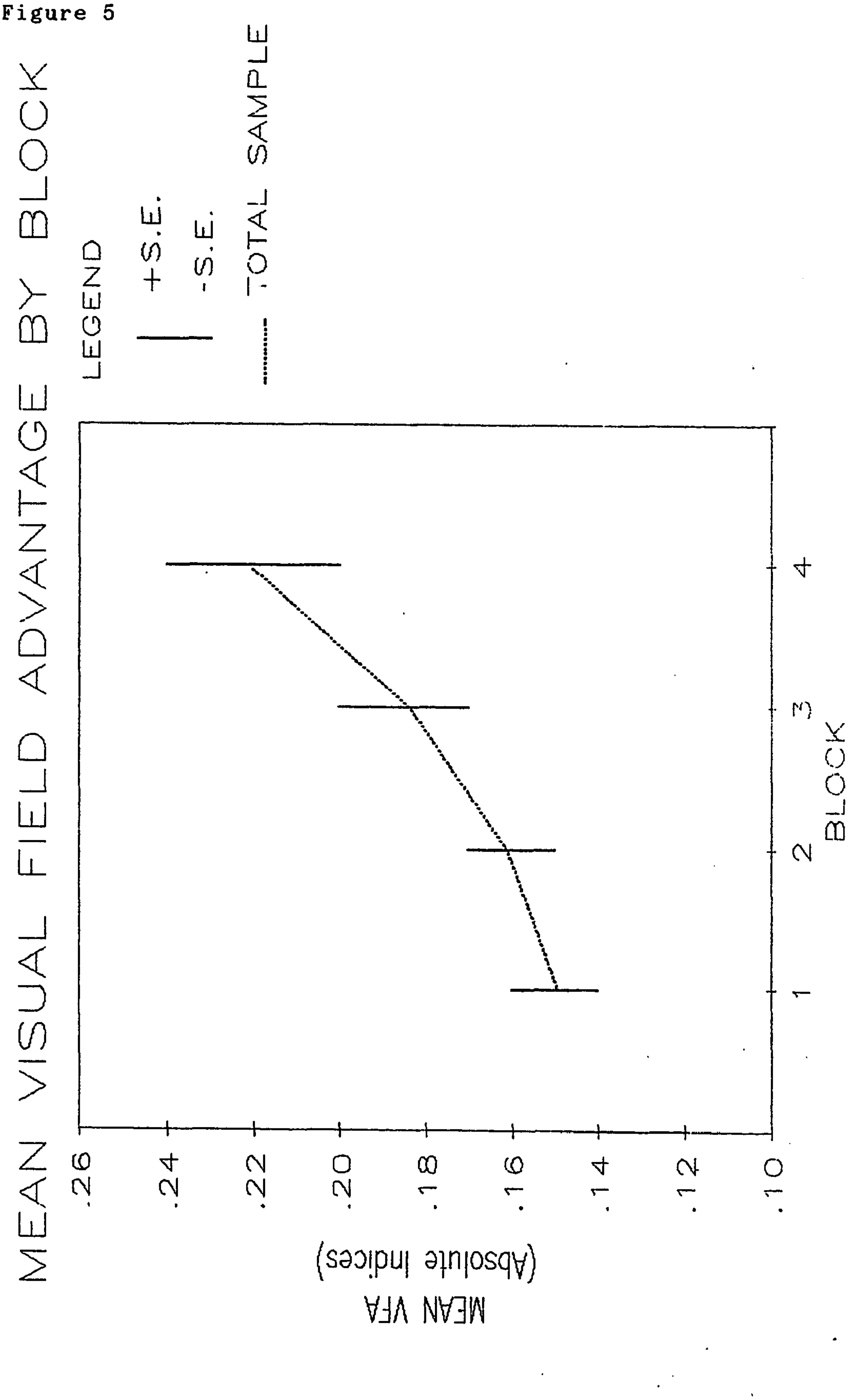
Block 1 to Block 2 with no subsequent significant changes in VFA for the remaining Blocks. Because the direction of IVFA was used to form these subject groups on a post hoc basis, a significant linear component to their VFA trend lines would not be unexpected. (For the ILVFA group: $F_{lin} = 8.39$; $df = 1,184$; $p<.05$. For the IRVFA group: $F_{lin} = 4.38$; $df = 1,208$; $p<.05$).

However, the presence of a significant change in direction of VFA from the IVFA shown for both groups means that regardless of initial hemispheric advantage, a shift to processing the faces by the other hemisphere took place. (For the ILVFA group: $F_{quad} = 4.33$; $df = 1,184$; $p<.05$. For the IRVFA group: $F_{quad} = 16.07$; $df = 1,208$; $p<.001$.)

<u>Analysis of Variance Results</u>

As subjects shifted their VFA during the familiarization process, each successive VFA, regardless of its direction, was of a greater magnitude than the one before it (See Figure 5). A 4-way ANOVA on the effects of sex, handedness, IVFA, and Block, with repeated measures on Block, on magnitude of VFA revealed a significant main effect of Block (F Block = 3.84; $df = 3,381$; $p<.05$).

Figure 5


MEAN VISUAL FIELD ADVANTAGE BY BLOCK
LEGEND
+S.E.
-S.E.
TOTAL SAMPLE
.26
.24
.22
.20
.18
.16
.14
.12
.10
1
2
3
4
BLOCK
MEAN VFA
(Absolute Indices)

The particular IVFA used by subject groups had a significant effect on overall VFA (four Blocks combined) which depended on sex. That is, females with an ILVFA and males with an IRVFA had significantly stronger overall VFA's than females and males beginning with an opposite VFA (F sex X IVFA = 5.96; df = 1,93; $p<.05$) (See Figure 6). The interaction of sex and IVFA significantly effected the magnitude of Block 4 VFA in the same manner (F sex X IVFA = 4.64; df = 1,93; $p<.05$).

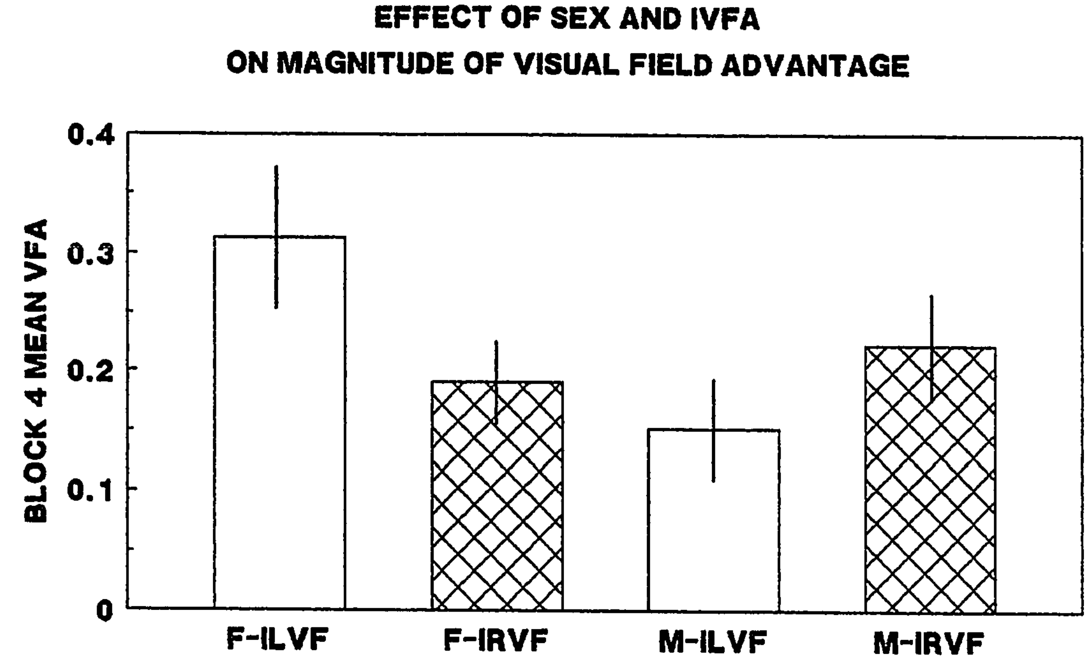
There were no significant main effects or other interaction effects of sex, handedness, or IVFA on VFA.

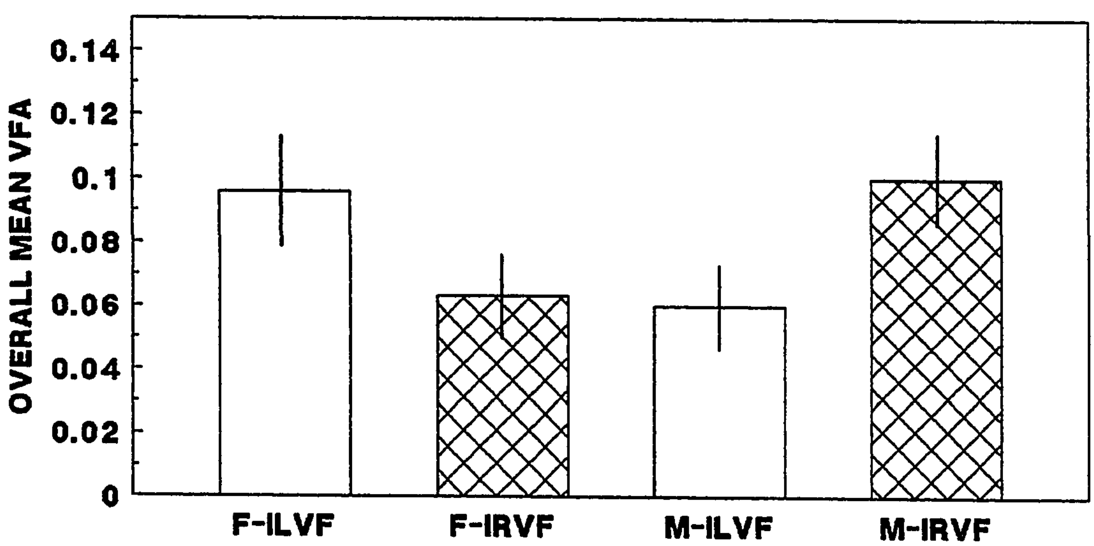
Sex/Handedness Variables Combined

To determine comparability of the present results to previous related research which involved only female right-handers, data were analyzed on the basis of sex/handedness combined. Findings compared included:

1) Percentages of subjects with no IVFA
2) Percentages of ILVFA subjects versus IRVFA subjects
3) Shifts in VFA across Blocks
4) Presence of a second right hemisphere advantage among ILVFA subjects

Figure 6


EFFECT OF SEX AND IVFA
ON MAGNITUDE OF VISUAL FIELD ADVANTAGE
BLOCK 4 MEAN VFA
0.4
0.3
0.2
0.1
0
F-ILVF
F-IRVF
M-ILVF
M-IRVF


OVERALL MEAN VFA
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
F-ILVF
F-IRVF
M-ILVF
M-IRVF

1) Previous results with female right-handers (FR) revealed a range of 10-15% of subjects with no IVFA (Ross & Turkewitz, 1982; Turkewitz & Ross, 1983). In the present study, FR and male right-handers (MR) approximated this range (7% and 16%, respectively). If demonstrating no IVFA is in some way related to weak lateral asymmetry, left-handers would be expected to show a higher percentage of no IVFA subjects than right-handers. This was true only for female left-handers (FL). FL had 29% with no IVFA and male left-handers (ML) had 0% no IVFA subjects. There were significantly more females than males with no IVFA (X^2 = 5.00; df = 1; $p<.05$).

2) Consistent with previous data from FR (Ross & Turkewitz, 1982; Ross-Kossak & Turkewitz, 1984; Turkewitz & Ross, 1981, 1983), when the faces were completely unfamiliar, subjects were just as likely to show a RVFA as a LVFA. This was true regardless of sex or handedness. However, the size of the ILVFA was not significantly greater than the IRVFA for any of the sex/handedness groups, unlike the reports of differences in magnitude of IVFA among FR (Ross & Turkewitz, 1982; Ross-Kossak & Turkewitz, 1984).

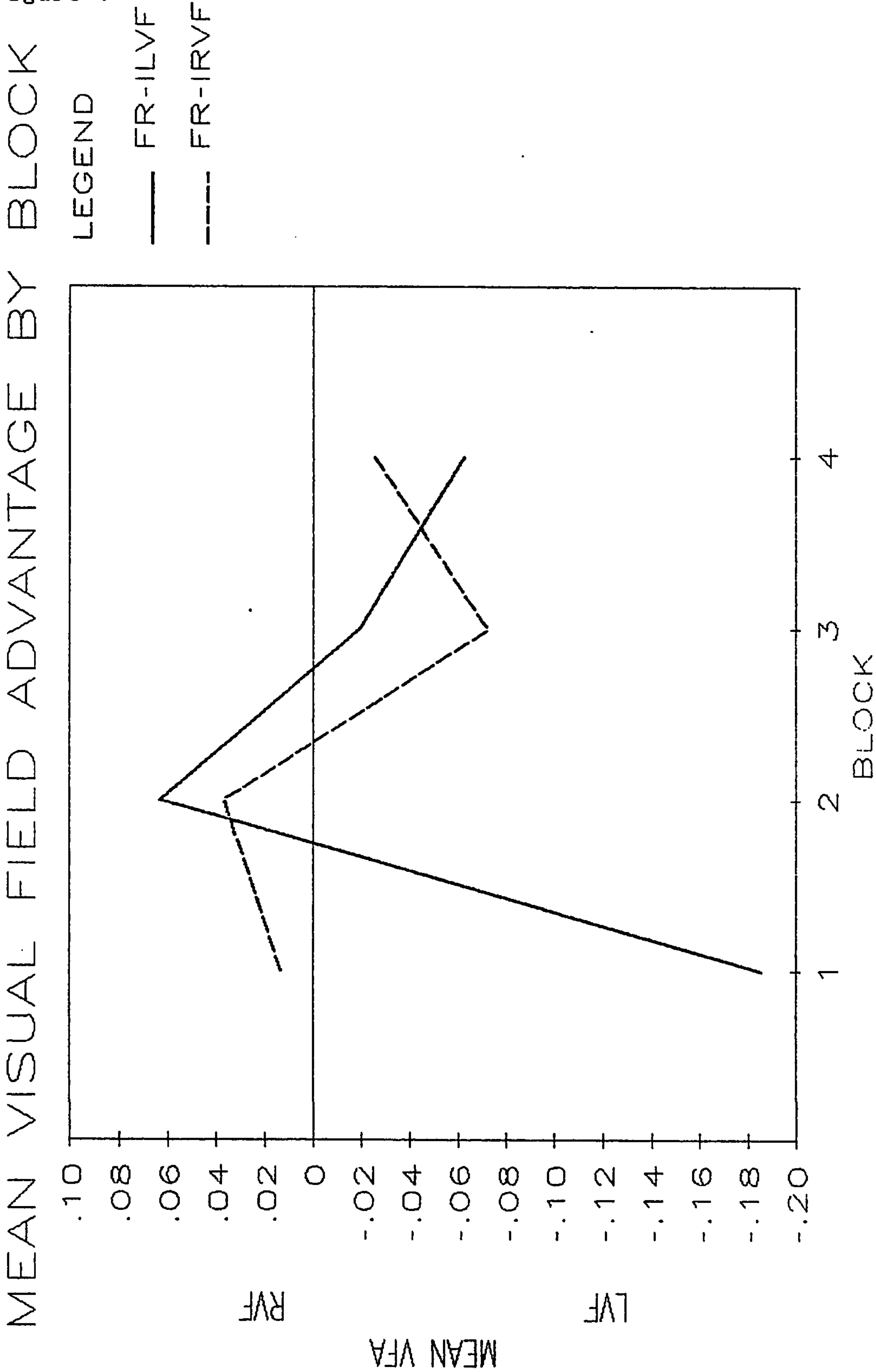
3) & 4) The direction and presence of significant changes in VFA for FR with an ILVFA and FR with an IRVFA replicated previous findings (Ross & Turkewitz, 1982; Turkewitz &

Ross, 1983). FR-ILVFA subjects showed a decrease in the magnitude of that advantage and then an increase in their LVFA in the fourth Block, thus showing a tendency toward utilization of two distinct phases of right hemisphere processing during familiarization with the faces. FR-IRVFA subjects shifted to a LVFA for the second half of the task (See Figure 7).

The nature of changes in VFA, as revealed by trend analyses, were similar to previous findings for both FR groups (Ross-Kossak & Turkewitz, 1984; Turkewitz & Ross, 1983). The quadratic component of the FR-ILVFA subject group approached significance, reflective of a shift back to a LVFA between Blocks 2 and 3 ($F_{quad} = 3.30$; df = 1,48; $p<.10$), while the linear component for FR-IRVFA subjects was significant ($F_{lin} = 5.68$; df = 1,52; $p<.05$), with no significant higher order components.

Left-handedness among females was related to a different effect of IVFA on subsequent shifts compared to right-handedness (See Figure 8). Unlike FR-ILVFA subjects, the FL-ILVFA group did not evidence a tendency toward a two-phase right hemisphere advantage. They maintained their LVFA across all four Blocks. FL-IRVFA subjects significantly shifted direction of VFA from Block 3 to Block 4, thus beginning and ending with a RVFA.

Figure 7


MEAN VISUAL FIELD ADVANTAGE BY BLOCK
LEGEND
FR-ILVF
FR-IRVF
.10
.08
.06
.04
.02
0
-.02
-.04
-.06
-.08
-.10
-.12
-.14
-.16
-.18
-.20
1
2
3
4
BLOCK
RVF
LVF
MEAN VFA

Trend analyses showed no significant changes in VFA for FL-ILVFA subjects, while the quadratic component for the FL-IRVFA group was significant (Fquad = 20.09; df = 1,36; $p<.001$).

MR who began with an ILVFA showed a decline in that advantage and ended with a very weak LVFA in the last Block (See Figure 9). The linear component to their trend line was significant (Flin = 5.60; df = 1,48; $p<.05$) with no significant higher order components.

MR-IRVFA subjects, like FR-IRVFA subjects, utilized a left hemisphere advantage for the second half of the familiarization process. MR-IRVFA subjects had a significant quadratic component to their trend line, reflecting the shift back to a RVFA between Blocks 2 and 3 (Fquad = 4.07; df = 1,48; $p<.05$).

ML with an ILVFA showed a weakening of that advantage and ended the task with a RVFA (Flin = 4.10; df = 1,40; $p<.05$). ML-IRVFA subjects did not shift to a right hemisphere advantage for any of the four Blocks (See Figure 10). There were no significant components to the ML-IRVFA trend line.

Figure 8

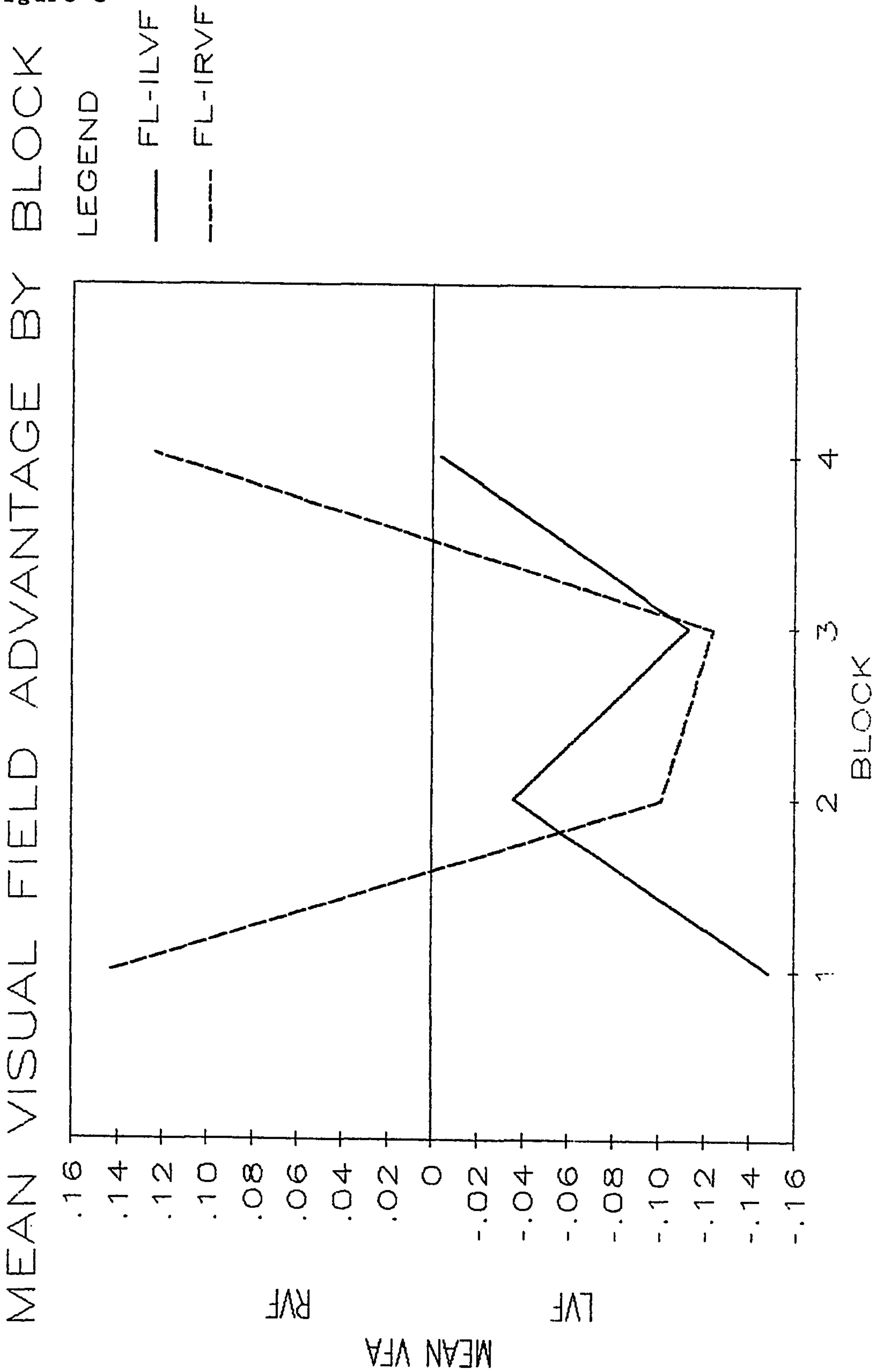

MEAN VISUAL FIELD ADVANTAGE BY BLOCK
LEGEND
FL-ILVF
FL-IRVF
.16
.14
.12
.10
.08
.06
.04
.02
0
-.02
-.04
-.06
-.08
-.10
-.12
-.14
-.16
RVF
LVF
MEAN VFA
1
2
3
4
BLOCK

Figure 9

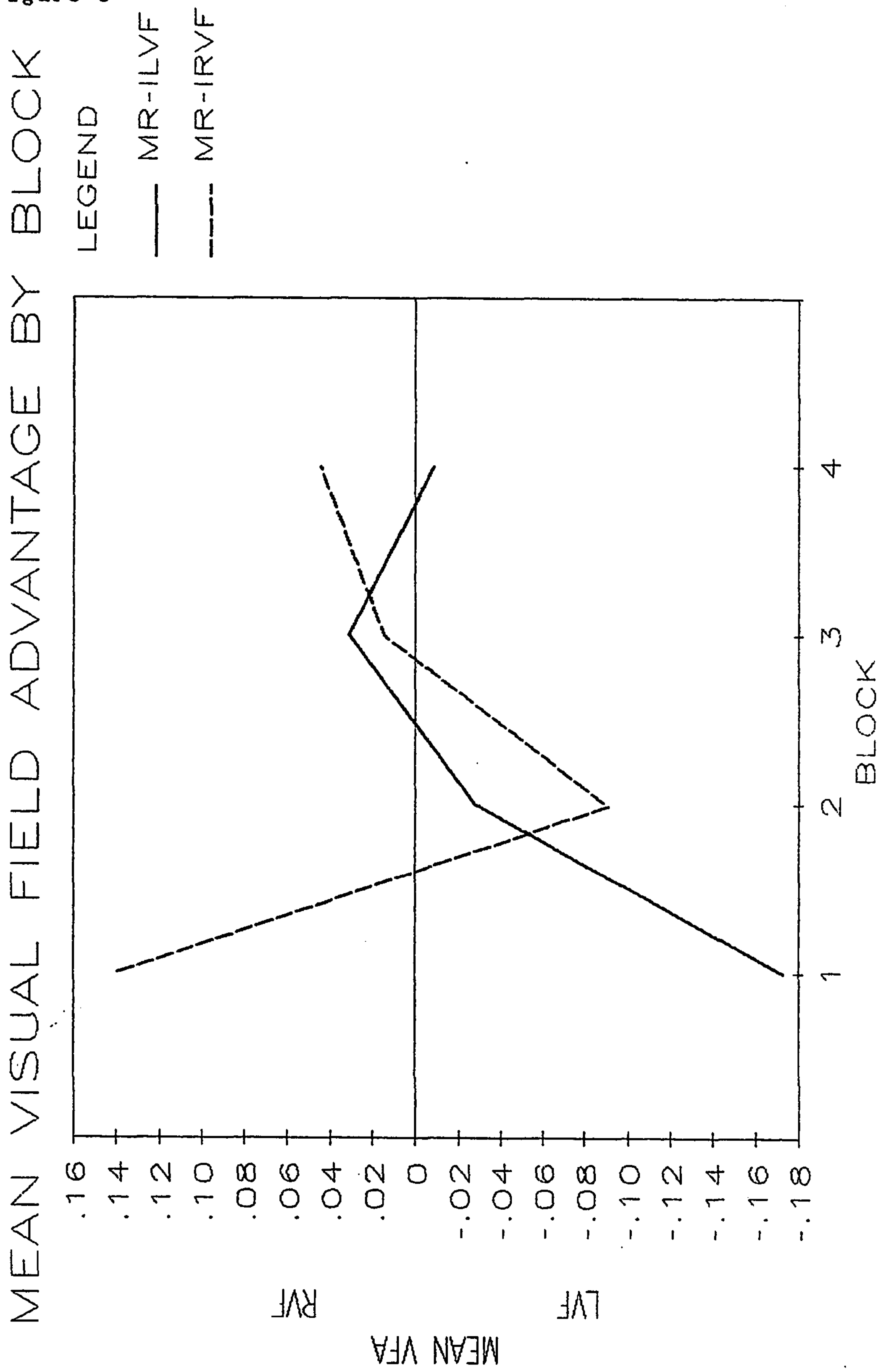
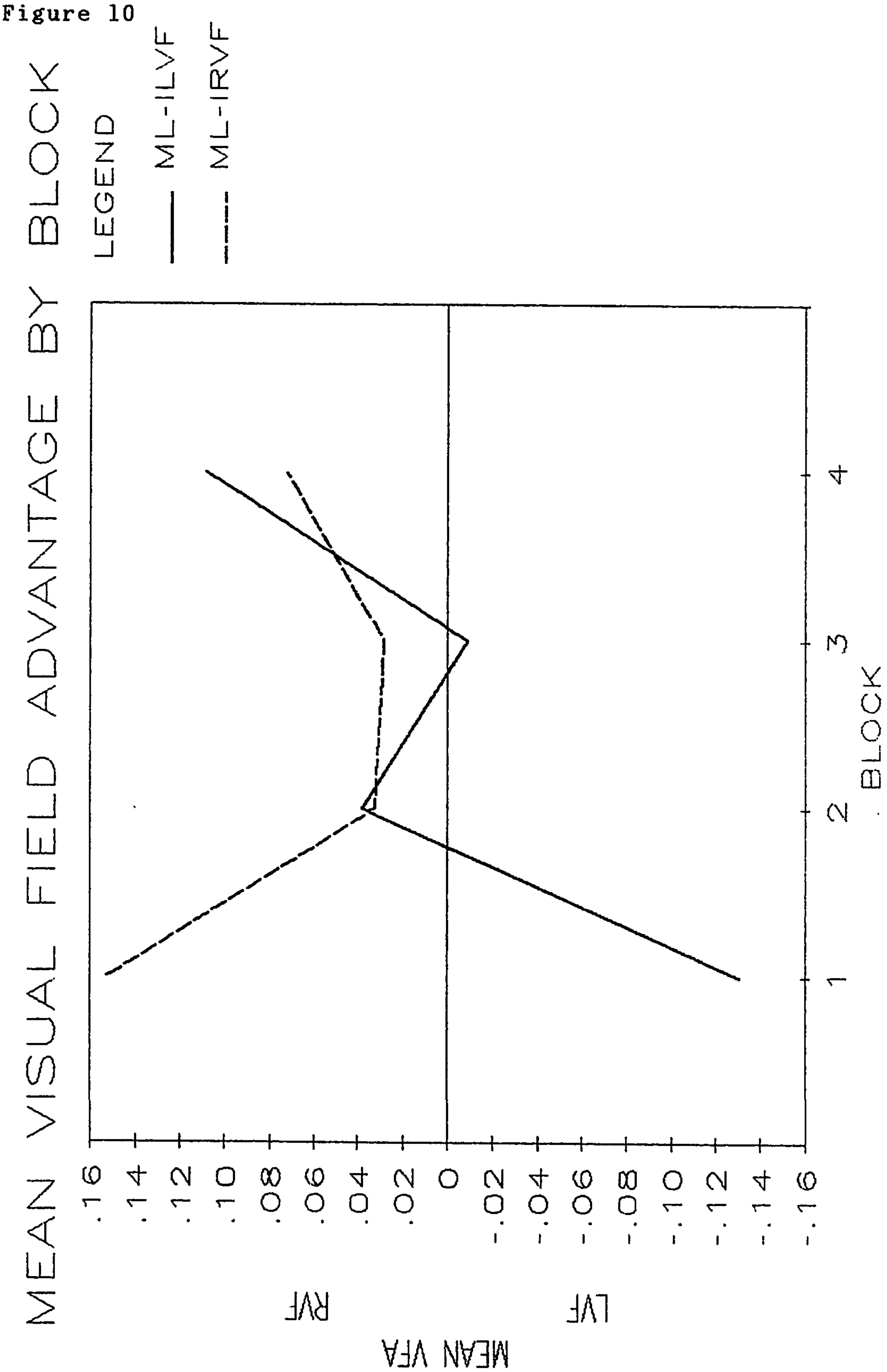

MEAN VISUAL FIELD ADVANTAGE BY BLOCK
LEGEND
MR-ILVF
MR-IRVF
.16
.14
.12
.10
.08
.06
.04
.02
0
-.02
-.04
-.06
-.08
-.10
-.12
-.14
-.16
-.18
RVF
LVF
MEAN VFA
1
2
3
4
BLOCK

Figure 10


MEAN VISUAL FIELD ADVANTAGE BY BLOCK
LEGEND
ML-ILVF
ML-IRVF
.16
.14
.12
.10
.08
.06
.04
.02
0
-.02
-.04
-.06
-.08
-.10
-.12
-.14
-.16
1
2
3
4
BLOCK
RVF
LVF
MEAN VFA

Means, standard deviations, and standard errors for visual field advantages by Block are listed for all subject groups in Tables 1 and 2.

Presence of a Second Right Hemisphere Shift

To further examine the effects of sex and handedness on the use of a dual right hemisphere strategy during the face familiarization task, the percentage of subjects within each ILVFA group who returned to a LVFA were compared.

In a previous study with FR (Ross & Turkewtiz, 1982), 44% of those with an ILVFA returned to a second right hemisphere phase. In the present study, 23% of FR did so.

Among right-handers, MR-ILVFA subjects were twice as likely as FR-ILVFA subjects to return to a LVFA (46% and 23%, respectively). However, the reverse was true among left-handers; 40% of FL-ILVFA subjects returned to a LVFA versus 18% of ML-ILVFA subjects.

Although these differences were not significant, probably due to small sample sizes, they suggest a differential handedness effect between the sexes as far as the utilization of a dual right hemisphere strategy during this facial familiarization process is concerned.

TABLE 1

MEANS, STANDARD DEVIATIONS AND STANDARD ERRORS

FOR VISUAL FIELD ADVANTAGES BY BLOCK

FOR SEX, HANDEDNESS AND IVFA GROUPS

	BLOCK 1	BLOCK 2	BLOCK 3	BLOCK 4
FEMALES				
MEAN	-.012	.006	-.067	.016
S.D.	.159	.197	.220	.352
S.E.	.021	.026	.029	.047
MALES				
MEAN	.010	-.020	.030	.040
S.D.	.174	.206	.242	.284
S.E.	.023	.027	.032	.037
RIGHT-HANDED				
MEAN	-.018	-.009	.004	-.023
S.D.	.176	.220	.231	.284
S.E.	.023	.028	.030	.037
LEFT-HANDED				
MEAN	.017	-.005	-.043	.084
S.D.	.154	.179	.239	.346
S.E.	.021	.024	.032	.047
ILVFA				
MEAN	-.161	.011	-.023	.003
S.D.	.106	.212	.238	.350
S.E.	.015	.031	.035	.051
IRVFA				
MEAN	.141	-.022	-.030	.049
S.D.	.084	.209	.242	.289
S.E.	.011	.029	.033	.040

TABLE 2

MEANS, STANDARD DEVIATIONS AND STANDARD ERRORS

FOR VISUAL FIELD ADVANTAGE BY BLOCK

FOR SEX/HANDEDNESS IVFA GROUPS

	BLOCK 1	BLOCK 2	BLOCK 3	BLOCK 4
FR-ILVFA				
MEAN	-.186	.063	-.019	-.063
S.D.	.122	.238	.268	.441
S.E.	.034	.066	.074	.122
FR-IRVFA				
MEAN	.013	.037	-.072	-.026
S.D.	.056	.151	.236	-.026
S.E.	.015	.040	.063	.076
FL-ILVFA				
MEAN	-.149	-.036	-.113	-.004
S.D.	.082	.187	.206	.434
S.E.	.026	.059	.065	.137
FL-IRVFA				
MEAN	.142	-.102	-.124	.124
S.D.	.071	.246	.147	.182
S.E.	.023	.078	.046	.058
MR-ILVFA				
MEAN	-.173	-.028	.031	-.009
S.D.	.134	.245	.197	.152
S.E.	.037	.068	.055	.042
MR-IRVFA				
MEAN	.139	-.091	.015	.044
S.D.	.091	.260	.261	.266
S.E.	.025	.072	.072	.074
ML-ILVFA				
MEAN	-.131	.038	-.009	.108
S.D.	.064	.163	.277	.340
S.E.	.064	.049	.084	.103
ML-IRVFA				
MEAN	.152	.032	.028	.072
S.D.	.107	.165	.274	.366
S.E.	.027	.041	.069	.092

Accuracy

There were no significant differences between the sex, handedness and IVFA groups in accuracy on the face recognition task. Familiarization with the faces occurred at a similar rate regardless of these variables (See Figures 11-13).

A 4-way ANOVA for the effects of sex, handedness, IVFA, and Block, with repeated measures on Block, on accuracy revealed a significant main effect for Block (F_{block} = 41.56; df = 3,381; $p<.001$) (See Figure 14). None of the other main effects was significant.

Utilizing a right hemisphere strategy when the faces were completely unfamiliar was advantageous for females, but disadvantageous for males. A parallel finding to the significant sex and IVFA interaction effect on magnitude of VFA was found for accuracy. A 3-way ANOVA for the effects of sex, handedness, and IVFA revealed a significant sex and IVFA interaction on overall error rate ($F_{sex\ X\ IVFA}$ = 7.34; df = 1,93; $p<.01$), as well as on accuracy in the terminal Block ($F_{sex\ X\ IVFA}$ = 14.99; df = 1,93; $p<.001$). As shown in Figure 15, females with an ILVFA performed significantly better overall and on Block 4 than females with an IRVFA. The reverse was true for males.

Figure 11

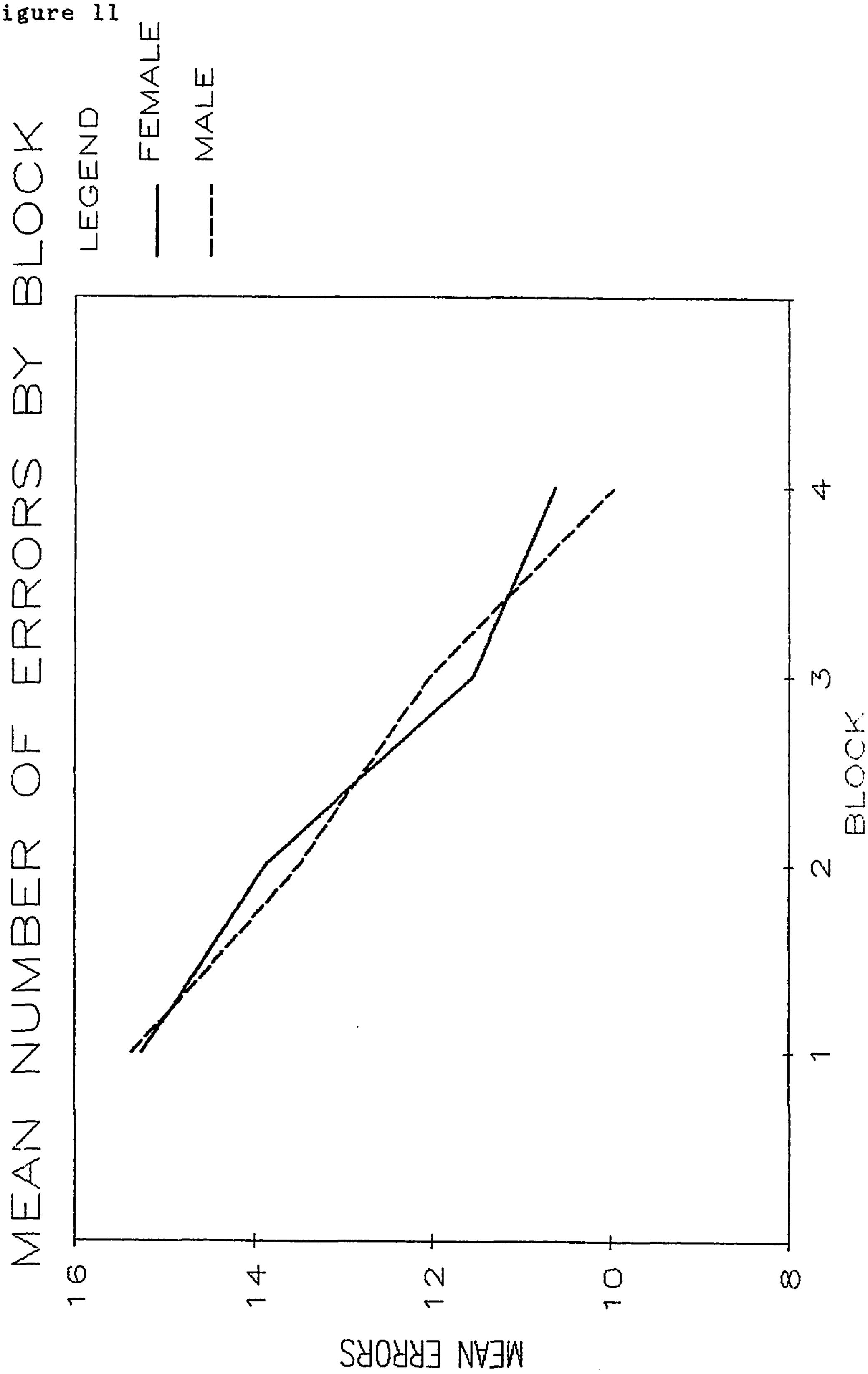

MEAN NUMBER OF ERRORS BY BLOCK
LEGEND
FEMALE
MALE
16
14
12
10
8
MEAN ERRORS
1
2
3
4
BLOCK

Figure 12

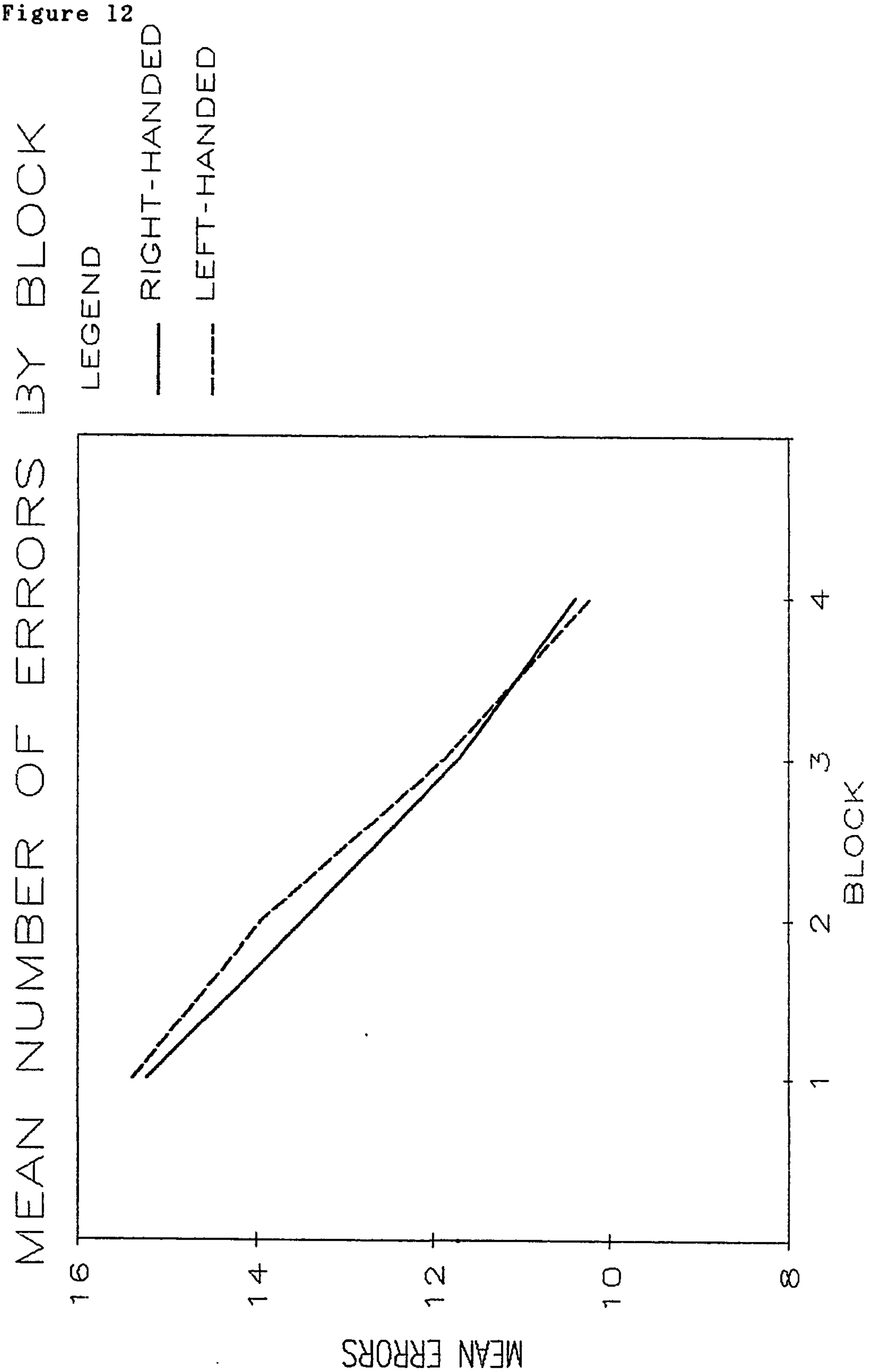

MEAN NUMBER OF ERRORS BY BLOCK
LEGEND
RIGHT-HANDED
LEFT-HANDED
MEAN ERRORS
16
14
12
10
8
BLOCK
1
2
3
4

Figure 13

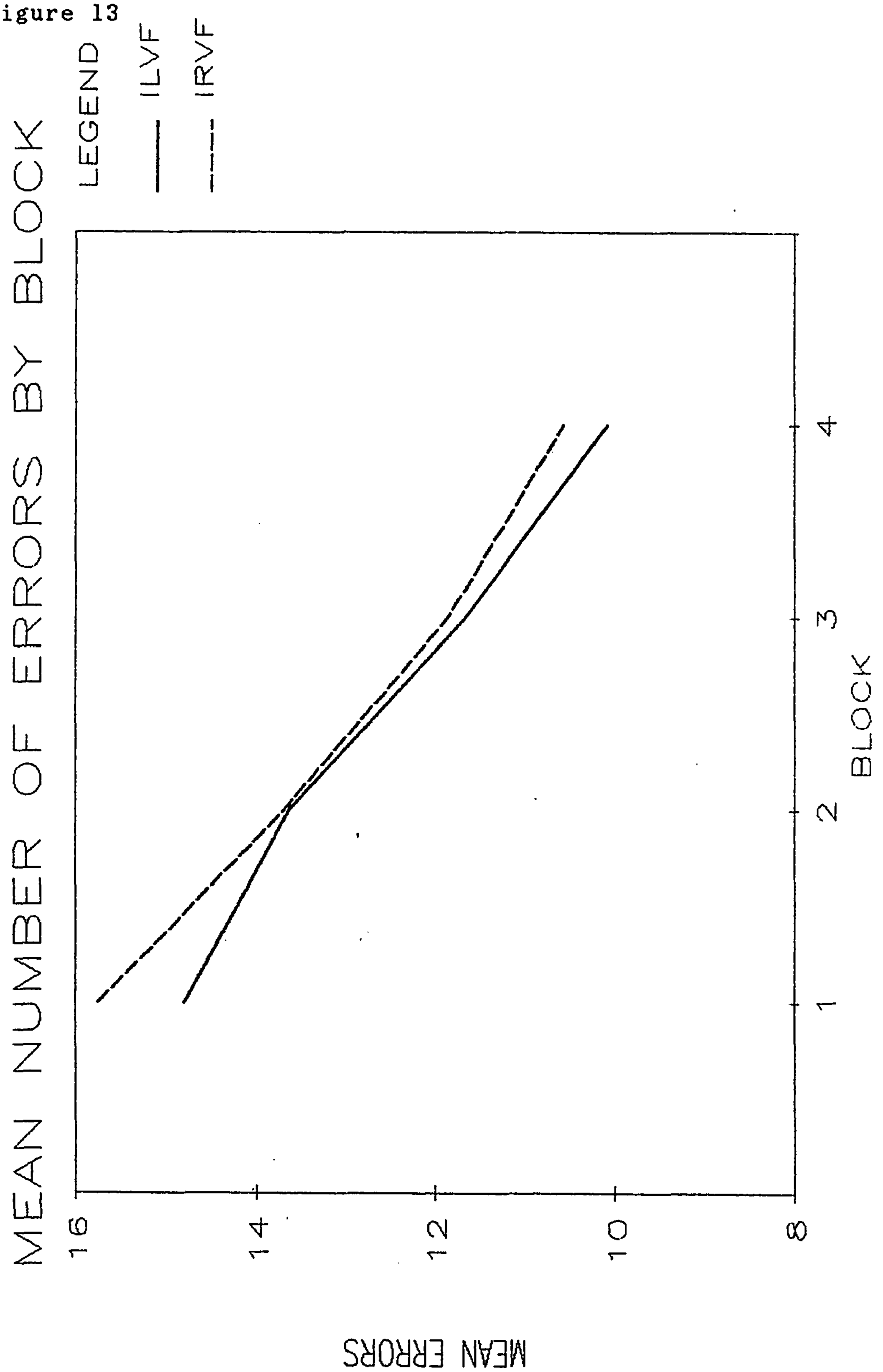

MEAN NUMBER OF ERRORS BY BLOCK
LEGEND
ILVF
IRVF
MEAN ERRORS
16
14
12
10
8
BLOCK
1
2
3
4

Figure 14

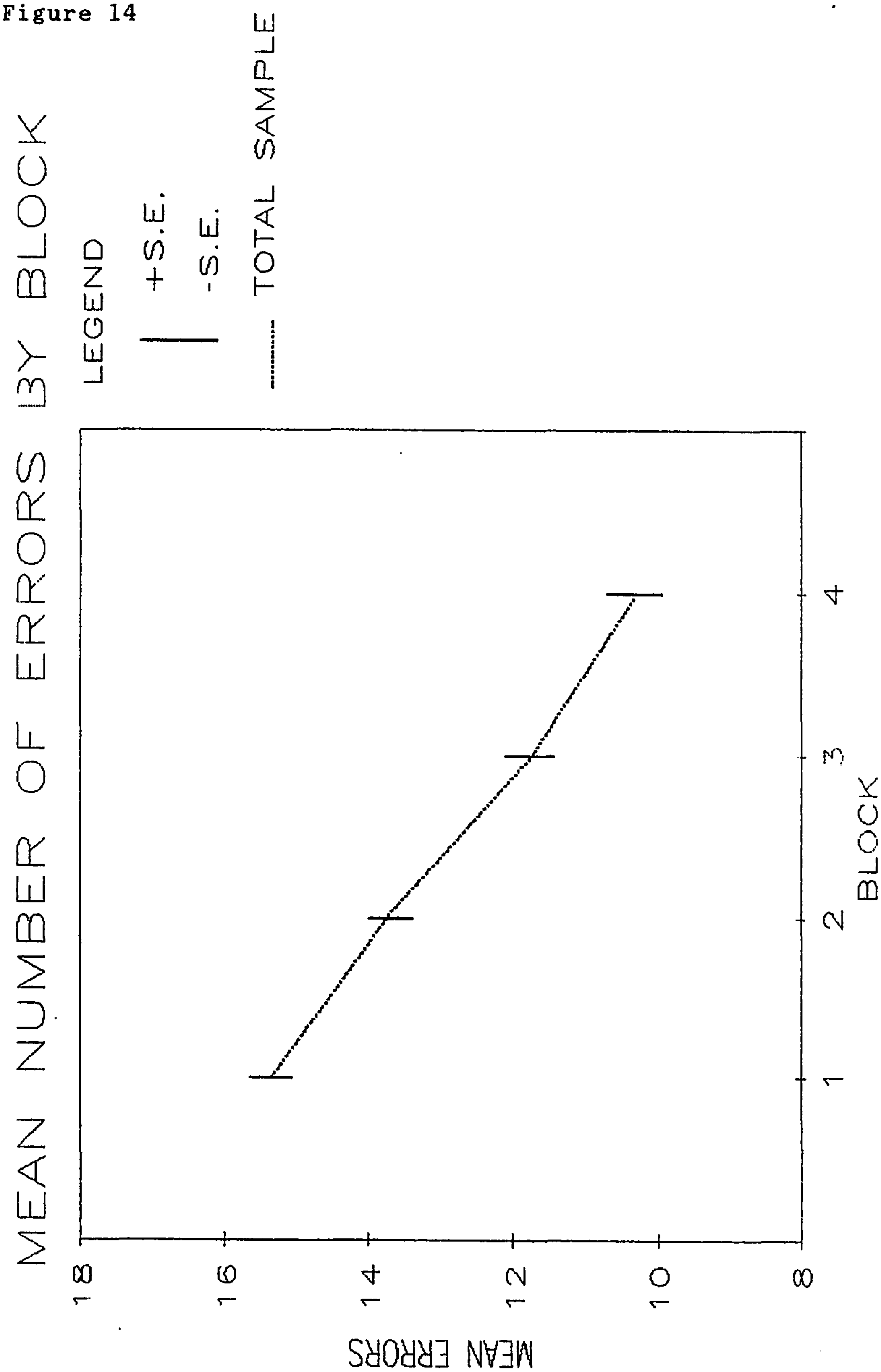
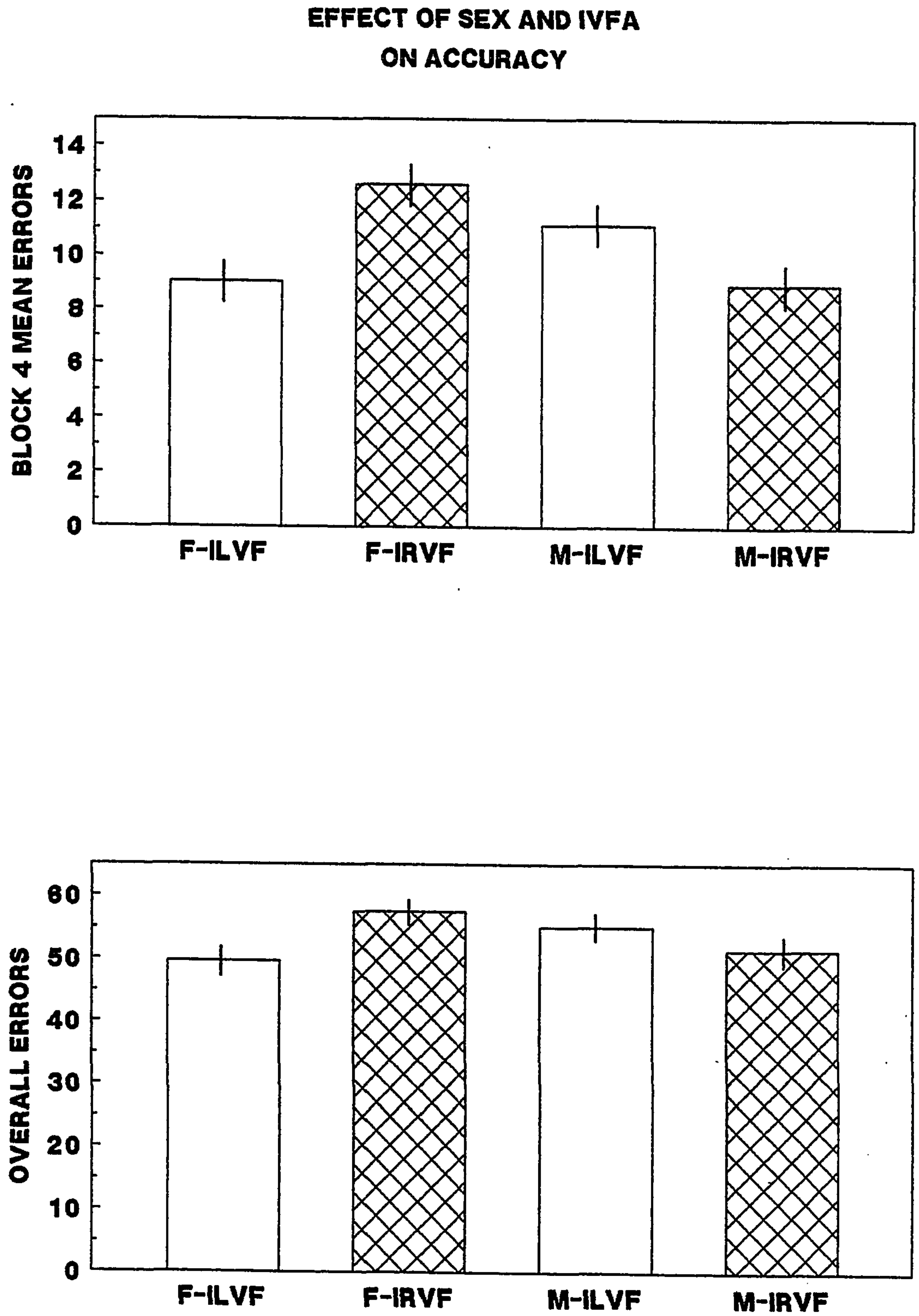

MEAN NUMBER OF ERRORS BY BLOCK
LEGEND
+S.E.
-S.E.
TOTAL SAMPLE
MEAN ERRORS
18
16
14
12
10
8
BLOCK
1
2
3
4

Figure 15


EFFECT OF SEX AND IVFA
ON ACCURACY
BLOCK 4 MEAN ERRORS
14
12
10
8
6
4
2
0
F-ILVF
F-IRVF
M-ILVF
M-IRVF
OVERALL ERRORS
60
50
40
30
20
10
0
F-ILVF
F-IRVF
M-ILVF
M-IRVF

If left-handers show greater bilateralization of function than right-handers as the literature establishes, the utilization of a right-hemisphere versus left-hemisphere type of analysis at the beginning of familiarization would be of less importance to left-handers and the data indicate a tendency in that direction.

Although there were no significant handedness effects on the ANOVA analyses of accuracy, there was a tendency for the choice of an IVFA to have more of an effect among right-handers than among left-handers. When subjects were combined into sex/handedness/IVFA groups (See Figures 16-19), significant differences emerged between FR and MR IVFA groups but not between FL and ML IVFA groups.

FR-ILVFA subjects made significantly fewer errors on Block 4 than did FR-IRVFA subjects ($t = 3.01$; $df = 25$; $p<.01$). In fact, FR-IRVFA subjects were the only group to show an increase in errors in the terminal Block. On both Block 2 and Block 4, MR-IRVFA subjects made significantly fewer errors than MR-ILVFA subjects ($t = 2.55$; $df = 24$; $p<.05$, and $t = 3.02$; $df = 24$, $p<.05$, respectively).

Means, standard deviations, and standard errors for number of errors by Block are listed for all subject groups in Tables 3 and 4.

Figure 16

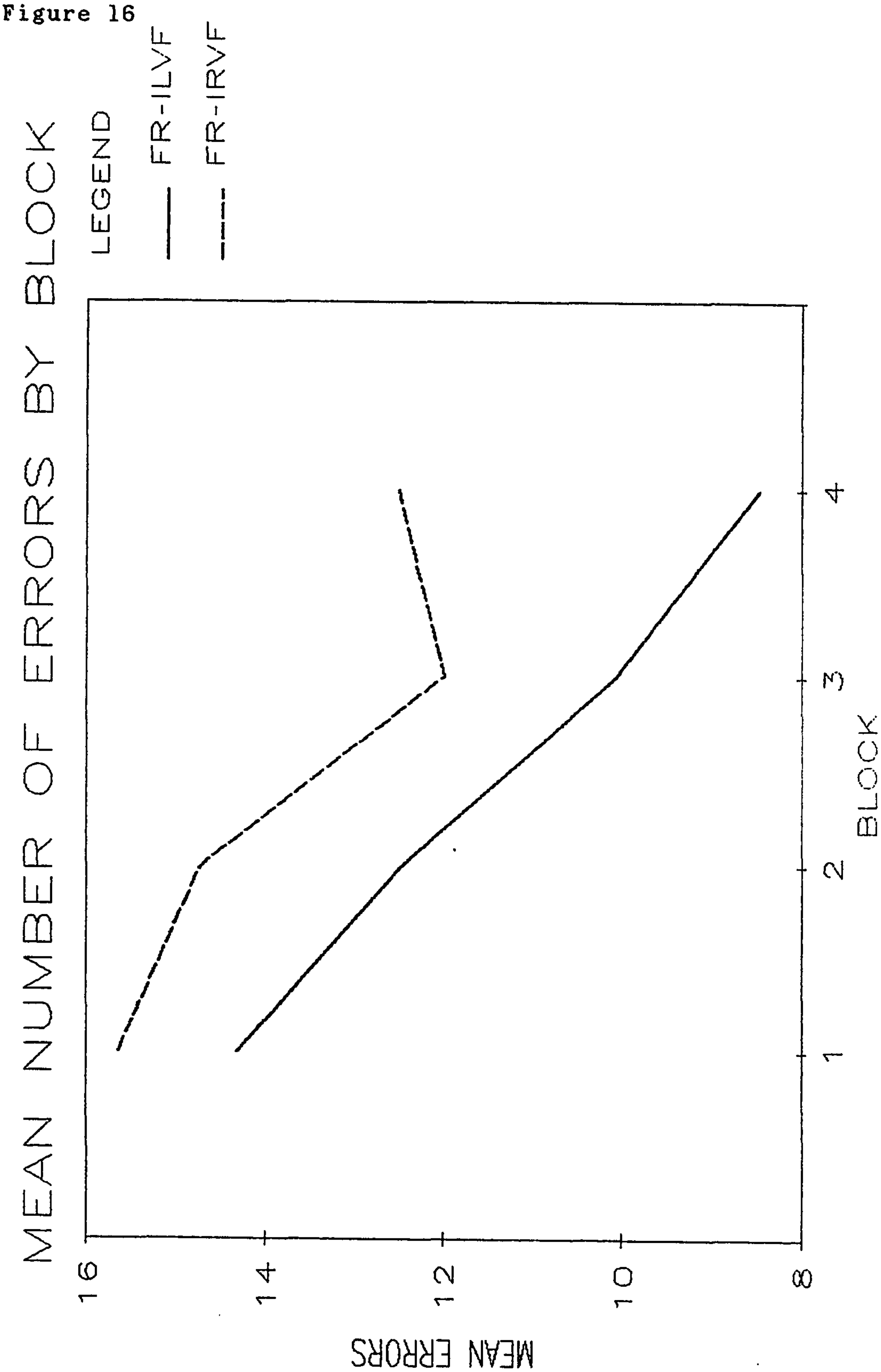

MEAN NUMBER OF ERRORS BY BLOCK
LEGEND
FR-ILVF
FR-IRVF
MEAN ERRORS
16
14
12
10
8
BLOCK
1
2
3
4

Figure 17

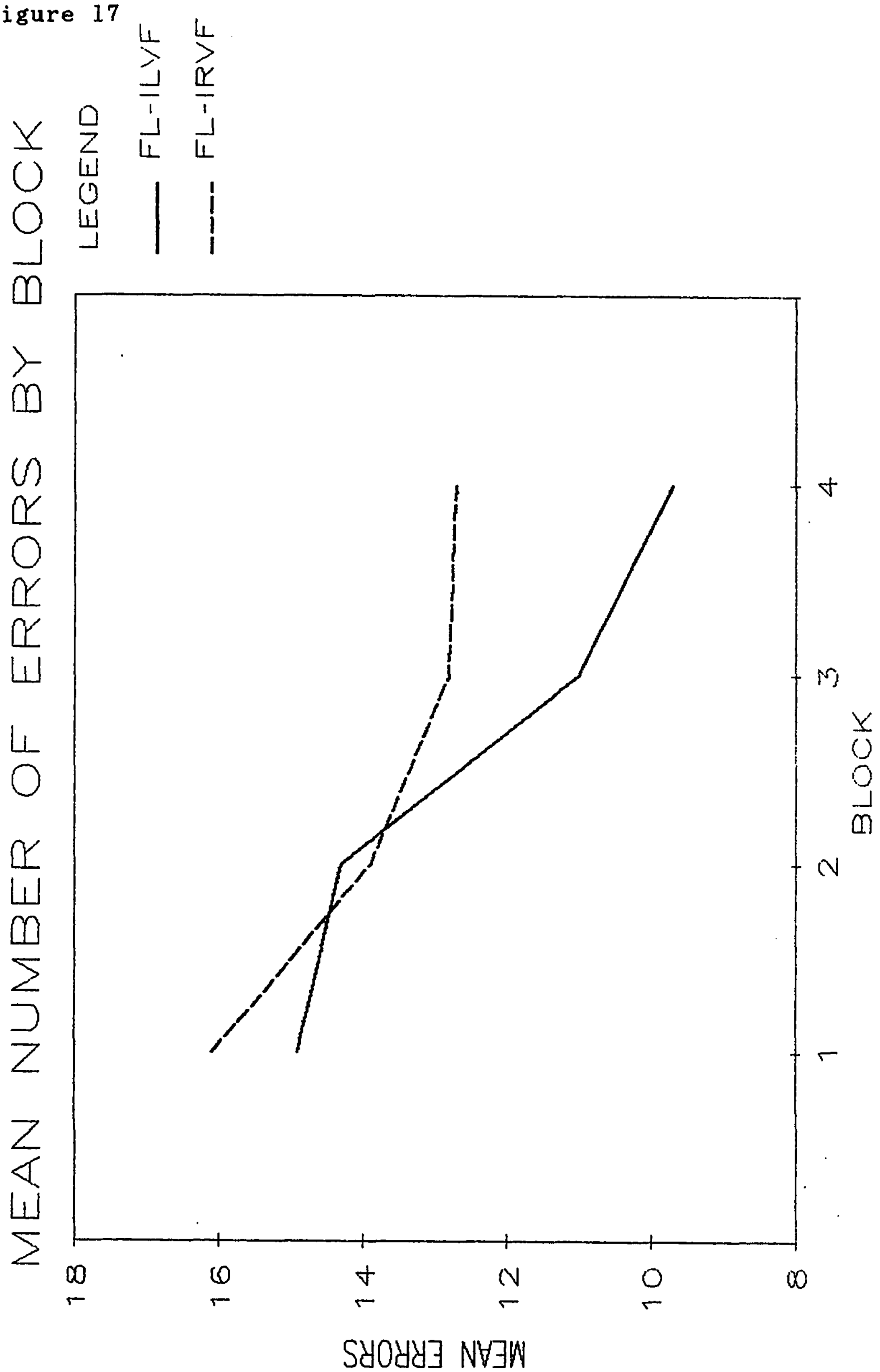

MEAN NUMBER OF ERRORS BY BLOCK
LEGEND
FL-ILVF
FL-IRVF
MEAN ERRORS
18
16
14
12
10
8
BLOCK
1
2
3
4

Figure 18

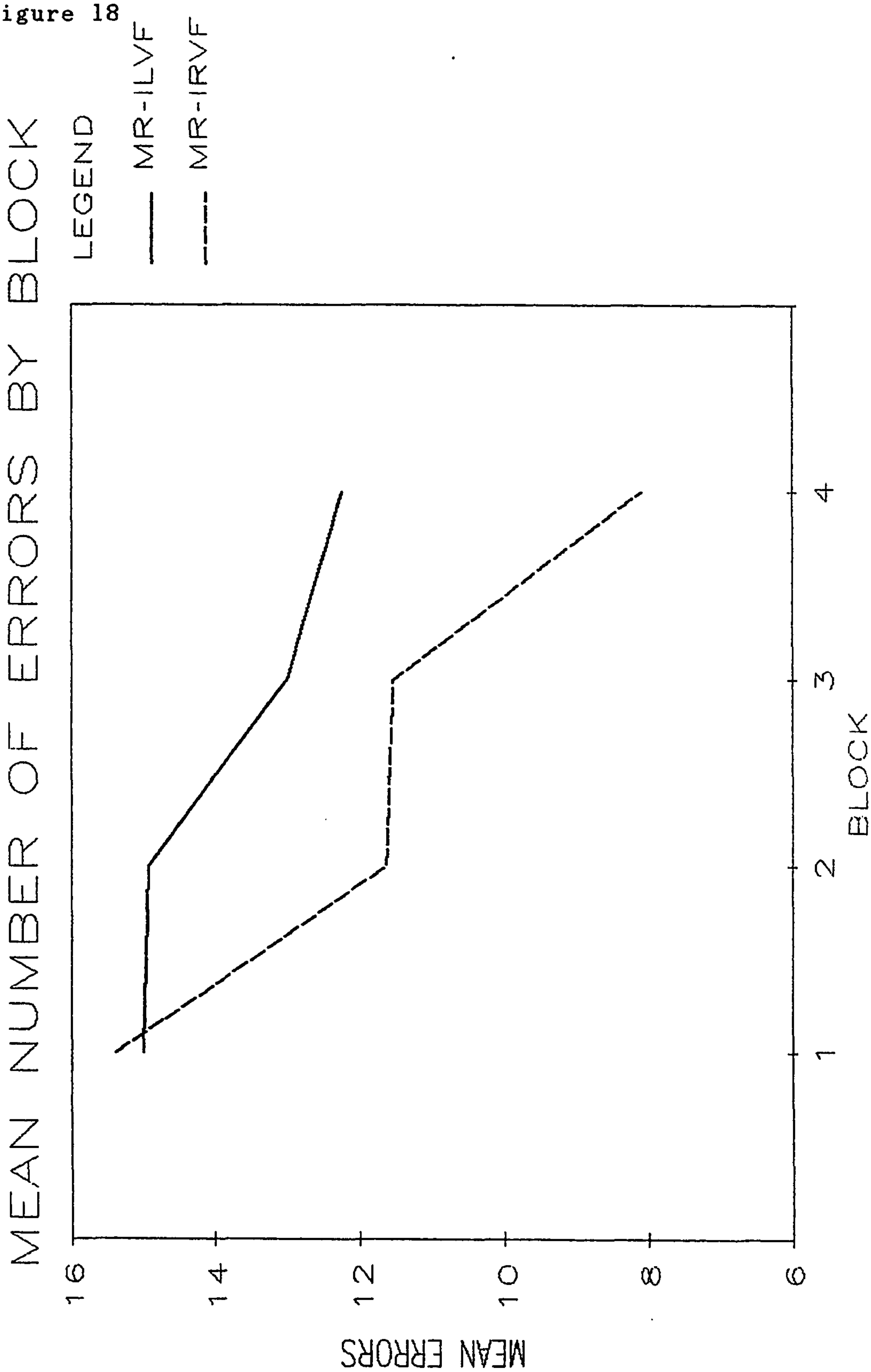

MEAN NUMBER OF ERRORS BY BLOCK
LEGEND
MR-ILVF
MR-IRVF
MEAN ERRORS
16
14
12
10
8
6
BLOCK
1
2
3
4

Figure 19

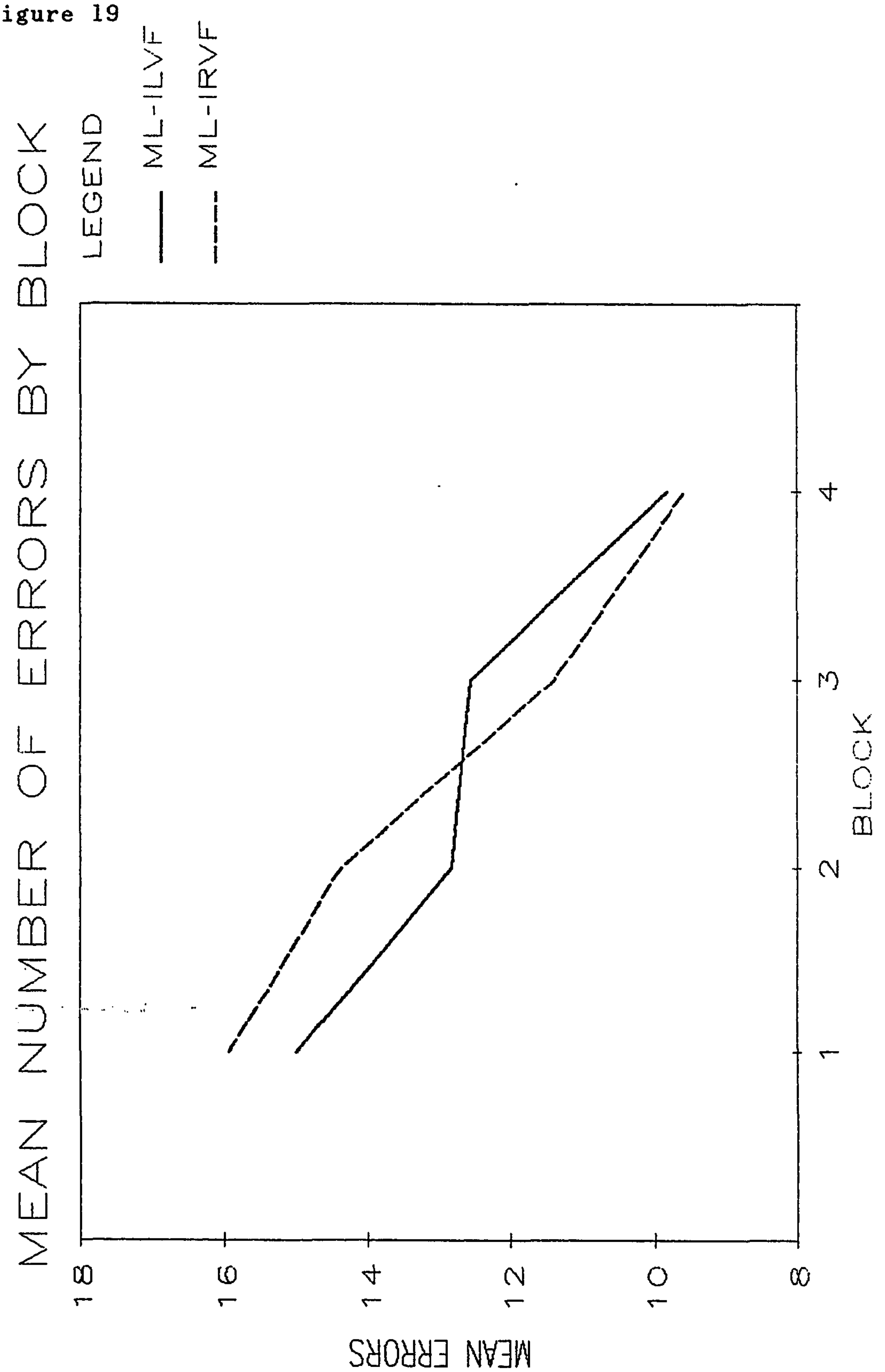

MEAN NUMBER OF ERRORS BY BLOCK
LEGEND
ML-ILVF
ML-IRVF
18
16
14
12
10
8
MEAN ERRORS
1
2
3
4
BLOCK

TABLE 3

MEANS, STANDARD DEVIATIONS AND STANDARD ERRORS

FOR ERRORS BY BLOCK

FOR SEX, HANDEDNESS AND IVFA GROUPS

	BLOCK 1	BLOCK 2	BLOCK 3	BLOCK 4
FEMALE				
MEAN	15.25	13.86	11.54	10.63
S.D.	3.12	3.05	3.44	3.92
S.E.	.41	.40	.46	.52
MALE				
MEAN	15.36	13.50	12.03	9.98
S.D.	2.82	3.47	3.53	4.07
S.E.	.37	.46	.46	.53
RIGHT-HANDED				
MEAN	15.32	13.45	11.72	10.38
S.D.	2.84	3.50	3.44	3.97
S.E.	.37	.45	.45	.51
LEFT-HANDED				
MEAN	15.38	13.93	11.87	10.22
S.D.	3.11	2.99	3.55	4.04
S.E.	.42	.40	.48	.55
ILVFA				
MEAN	14.79	13.62	11.66	10.09
S.D.	3.11	3.11	3.91	3.73
S.E.	.45	.45	.57	.54
IRVFA				
MEAN	15.75	13.70	11.85	10.57
S.D.	2.79	3.43	3.17	4.27
S.E.	.38	.48	.44	.59

TABLE 4

MEANS, STANDARD DEVIATIONS AND STANDARD ERRORS

FOR ERRORS BY BLOCK

FOR SEX/HANDEDNESS IVFA GROUPS

	BLOCK 1	BLOCK 2	BLOCK 3	BLOCK 4
FR-ILVFA				
MEAN	14.31	12.46	10.08	8.46
S.D.	2.98	4.05	4.31	3.38
S.E.	.83	1.12	1.20	.94
FR-IRVFA				
MEAN	15.64	14.71	12.00	12.50
S.D.	2.62	2.76	2.77	3.57
S.E.	.70	.74	.74	.95
FL-ILVFA				
MEAN	14.90	14.30	11.00	9.70
S.D.	4.36	1.77	3.97	3.92
S.E.	1.38	.56	1.26	1.24
FL-IRVFA				
MEAN	16.10	13.90	12.80	12.70
S.D.	2.38	3.03	3.77	3.68
S.E.	.75	.96	1.19	1.16
MR-ILVFA				
MEAN	15.00	14.92	13.00	12.23
S.D.	2.74	2.43	3.11	3.24
S.E.	.76	.67	.86	.90
MR-IRVFA				
MEAN	15.38	11.62	11.54	8.08
S.D.	3.23	3.99	2.33	3.75
S.E.	.90	1.11	.65	1.04
ML-ILVFA				
MEAN	15.00	12.82	12.55	9.82
S.D.	2.72	3.12	3.93	3.76
S.E.	.82	.94	1.19	1.14
ML-IRVFA				
MEAN	15.94	14.38	11.38	9.56
S.D.	3.00	3.46	3.79	4.44
S.E.	.75	.87	.95	1.11

To examine differences in numbers of errors made with LVF presentations versus RVF presentations, correlations were computed by Block for each subject group (See Table 5).

A low correlation between errors made with a LVF presentation versus a RVF presentation for a Block of trials would indicate the lack of a relationship between how the two hemispheres are functioning at that point in the familiarization process. Low correlations in Block 1 for males and right-handers may therefore reflect the importance of which hemisphere is processing the facial stimuli when they are unfamiliar. This interpretation is consistent with the greater degree of functional asymmetry generally attributed to these two populations.

On the other hand, the high correlations between LVF and RVF errors among females and left-handers indicate a strong association between how the two hemispheres are responding to the unfamiliar facial stimuli. The finding that the initial hemispheric advantage was less important among these two subject groups compared to males and right-handers is consistent with this interpretation.

As familiarization with the faces progressed, the correlations between LVF and RVF accuracy tended to increase so that by Blocks 3 and 4, correlations were significant for both sex and handedness groups.

TABLE 5

CORRELATIONS OF NUMBER OF ERRORS IN LVF

WITH NUMBER OF ERRORS IN RVF

Pearson r Values

BLOCK	FEMALE	MALE	RIGHT-HANDED	LEFT-HANDED
1	.327*	.146	.180	.304*
2	.245	.285*	.278*	.242
3	.358**	.380**	.363**	.367**
4	.363**	.642**	.510**	.505**

BLOCK	FR	MR	FL	ML
1	.212	.149	.435*	.164
2	.413*	.223	.075	.442*
3	.347*	.394*	.382*	.393*
4	.345*	.720**	.444*	.566**

* p<.05 (two-tailed)

** p<.01 (two-tailed)

In other words, information processing input from each hemisphere was integrated with increasing familiarization with the faces so that by the end of the task, the numbers of errors in each visual field were significantly correlated. This successive increase in the positive relationship between accuracy in the two visual fields is indicative of the dynamic nature of the involvement of the right and left hemispheres in the familiarization process.

The progression of increasing correlations was stronger for males and right-handers, which presumably reflects greater asymmetry among these two groups. A statistical analysis to determine the significance of the differences between correlations in Block 1 with correlations in Block 4 (Edwards, 1950) revealed that among males, right-handers, and MR, this difference was significant. For males, $z = 3.22$; for right-handers, $z = 2.03$; for MR, $z = 2.83$; all at $p < .05$.

Thus, evidence of the dynamic involvement of both hemispheres in the face familiarization process can be found regardless of sex or handedness but is much more pronounced among males and right-handers, both of which are considered to have relatively strong lateralization of function.

Relationship Between VFA and Accuracy

Previous research reported a relationship between patterns of VFA and proficiency on this face recognition task (Ross & Turkewitz, 1982; Ross-Kossak & Turkewitz, 1984; Turkewitz & Ross-Kossak, 1984). Among FR, it was found that: 1) During the early phases of facial processing, there was an advantage to having a strong LVFA; 2) During transitions in direction of VFA, a strong VFA was not advantageous; 3) Those subjects who evidenced two phases of right hemisphere processing, ending with a LVFA in the terminal Block, tended to outperform those subjects who did not shift in this manner; and 4) There was a significant negative correlation between magnitude of overall VFA and overall error rate.

Present findings indicate the following by comparison:

1) The initial processing strategy utilized when the faces were unfamiliar made an important difference among right-handers, both females and males, but was not related to accuracy among left-handers, regardless of sex.

Consistent with previous findings, a right-hemisphere mode of processing at the earliest stage of familiarization was advantageous for FR ($t = 2.58$; $df = 25$; $p < .05$). However, none of the other sex/handedness subject groups demonstrated such a relationship.

2) To examine the relationship between magnitude of VFA and accuracy during the course of familiarization, correlations between strength of VFA and errors were computed by Block and are shown in Table 6.

For FR and MR, it was advantageous to have a stronger VFA on the first and last Blocks when the faces were completely unfamiliar and after familiarization had taken place. This indicates both the importance of an initial strategy and the maximization of the integration of information from the two hemispheres by the end of the task. During the period between, a stronger VFA was not especially beneficial to performance.

Focusing on FR, who showed a tendency toward a right-left-right pattern of hemispheric advantages, it is interesting to note that strong VFA's were most beneficial to performance when either the initial LVF or second LVF was most likely to be utilized.

For FL and ML, a stronger VFA was only advantageous at the end of the task when the faces were no longer unfamiliar. The progressive increase in the relationship between

TABLE 6

CORRELATIONS OF VISUAL FIELD ADVANTAGE

(Absolute Indices)

WITH NUMBER OF ERRORS BY BLOCK AND OVERALL

BLOCK	FEMALE	MALE	RIGHT-HANDED	LEFT-HANDED
1	-.316*	-.378**	-.515**	-.145
2	-.304*	-.301*	-.346*	-.222
3	-.237	-.522**	-.396**	-.389**
4	-.520**	-.492**	-.380**	-.579**
OVERALL	-.234	-.270	-.228	-.279*

BLOCK	FR	MR	FL	ML
1	-.631**	-.431**	-.025	-.328
2	-.346	-.342	-.250	-.218
3	-.325	-.452*	-.109	-.586**
4	-.414*	-.424*	-.622**	-.568**
OVERALL	-.200	-.255	-.247	-.292

* p<.05 (two-tailed)

** p<.01 (two-tailed)

magnitude of VFA and accuracy across Blocks was evident for the left-handed subject group. For FL, in particular, there was a significant increase in the correlation of VFA with errors from virtually no correlation in Block 1 to a significant correlation in Block 4 ($z = 2.49$; $p<.05$).

3) To examine whether utilization of an initial right hemisphere advantage with a subsequent non-sequential right hemisphere advantage was a beneficial strategy, subjects were first divided into better-performing and poorer-performing groups based on overall error rates below or above the median error rate of 55%. A LVFA for this analysis was defined as an LVF minus RVF error difference of +2 or greater.

Without regard to sex or handedness, 15% of dual right hemisphere processors had overall error rates below the median of 55%, while 25% had overall error rates above 55%. When individual sex and handedness groups were analyzed, males, females, right-handers and left-handers had similar percentages of better-performing subjects among their dual right hemisphere processors (ranging from 33-40%). Of the four sex/handedness groups, only FR showed evidence of a benefit to performance, although sample sizes were insufficient to consider the data conclusive.

4) Magnitude of overall VFA was not significantly related to accuracy among FR as previously reported, nor among the other sex/handedness groups.

Instead, having a stronger overall VFA was significantly correlated with better performance only among left-handers ($r(53) = -.28$; $p<.05$), suggesting that given the weaker lateral asymmetry attributed to this population, maximizing the capacities of either hemisphere was an advantageous strategy for this face processing task.

Lateralization of Verbal and Visuospatial Functions

The hypothesis that differences between subject groups in direction and degree of cerebral lateralization of function would be reflected in the nature of shifts in hemispheric advantage, as well as the relationship of those shifts to accuracy on the face recognition task requires supporting evidence that the subject groups in the present sample demonstrate variations in direction/degree of asymmetry which are consistent with the existing accumulated body of data.

In order to obtain a comparative measure of the presence and extent of differences in direction and magnitude of functional lateralization across subject groups, a VFA index was computed for the Letter Identification and Dot Localization tasks in the same manner as for the face recognition data.

Sex

The effect of sex on degree of lateral asymmetry was expected to be manifested by a tendency toward greater asymmetry among males for the verbal task with no difference in direction of asymmetry. Both sexes showed a mean RVFA on Letter Identification, with the male mean RVFA being stronger than the female mean RVFA, although not significantly.

Mean VFA for Dot Localization did not differ among females and males. Although it is reasonable to expect evidence of a sex effect on the Dot Localization test as well, the fairly common insensitivity of visuospatial laterality tests to show significant sex differences might not support this expectation.

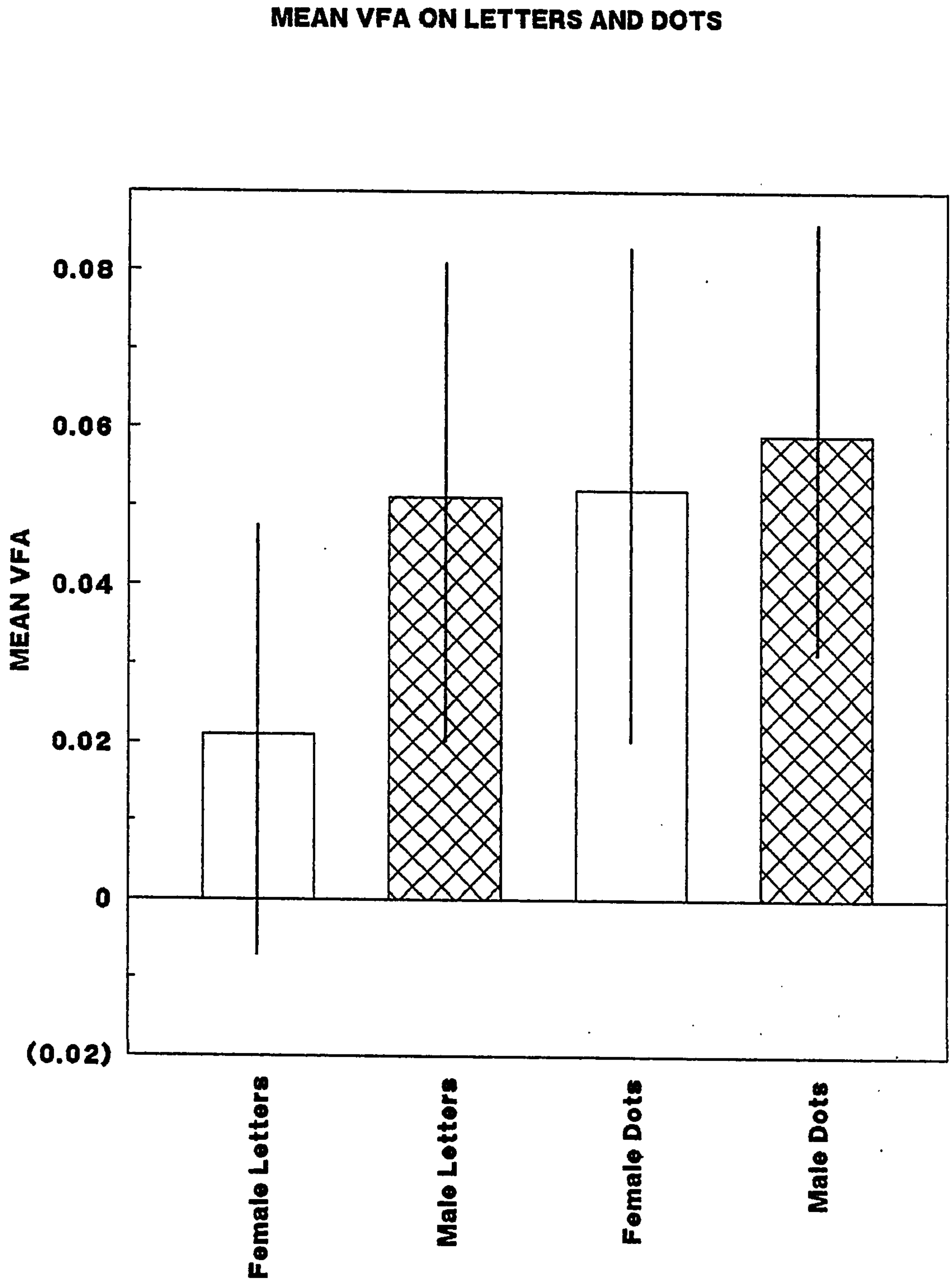
Although magnitude of VFA on the Dots was weak for both sexes, its direction was to the RVF. This result is unexpected, although other studies have reported it using dot localization (e.g. Pohl, Butters & Goodglass, 1972).

Mean VFA's on the Letters and Dots for females and males are shown in Figure 20.

Analyses of variance results revealed no main effects of sex on direction and degree of VFA for either the Letter Identification or Dot Localization tasks.

The percentages of females and males with reversed laterality (LVFA) on the Letters were similar (40% and 36%, respectively), which might be expected due to equivalent numbers of left-handers in each sex group. On the Dots,

Figure 20


MEAN VFA ON LETTERS AND DOTS
MEAN VFA
0.08
0.06
0.04
0.02
0
(0.02)
Female Letters
Male Letters
Female Dots
Male Dots

50% of females and 57% of males showed a reversed (RVF) lateral preference.

Handedness

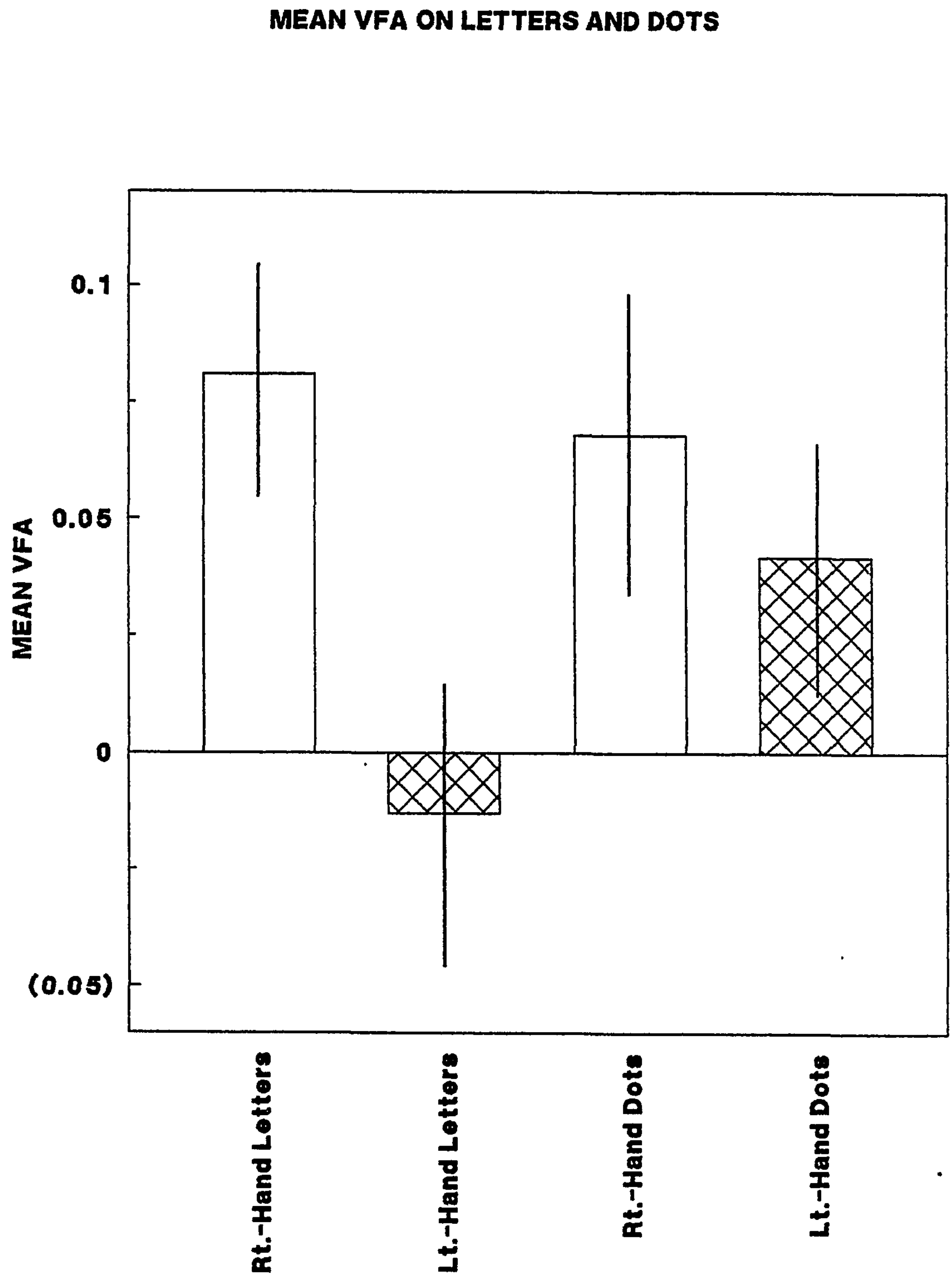
As predicted, handedness had a significant effect on both degree and direction of lateral asymmetry on the verbal task.

Analyses of variance results revealed a significant main effect for handedness on direction and degree of VFA for Letter Identification ($F_{hand} = 5.60$; $df = 1,99$; $p < .05$). Right-handers were more strongly lateralized to the RVF (mean VFA = .081), while left-handers were weakly lateralized to the LVF (mean VFA = -.013).

Both handedness groups showed a RVFA on the Dot Localization. An ANOVA on magnitude of VFA for Dots (without sign of VFA) revealed a handedness effect approaching significance ($F_{hand} = 3.31$; $df = 1,99$; $p < .10$). As would be predicted, right-handers had a stronger mean VFA (.188) than did left-handers (.141).

Mean VFA's for right-handers and left-handers on the Letters and Dots are shown in Figure 21.

Figure 21


MEAN VFA ON LETTERS AND DOTS
MEAN VFA
0.1
0.05
0
(0.05)
Rt.-Hand Letters
Lt.-Hand Letters
Rt.-Hand Dots
Lt.-Hand Dots

The prediction of substantially higher percentages of reversed lateralization for language among left-handers compared to right-handers was supported. Twice as many left-handers had reversed (LVF) lateralization on the verbal task than right-handers (51% versus 26%) ($X^2 = 8.23$; $df = 1$; $p<.01$).

On the visuospatial task, the percentages of reversed (RVF) laterality were similar (45% of left-handers and 59% of right-handers).

Because the percentages of reversed laterality for both verbal and visuospatial functions were relatively high, given estimates of right hemisphere language representation of about 5% among right-handers and 15-40% among left-handers (e.g. Satz, 1980), and given that a review of the divided visual field literature estimates 70% of individuals with left-hemisphere language specialization exhibit the predicted RVFA for verbal stimuli (Cohen, 1982), it was decided to investigate a possible confounding effect of task order on visual field asymmetries.

Specifically, did the direction of VFA on Block 4 differentially effect the direction of VFA on the Letters task which followed it; and, did the direction of VFA on the Letters task differentially effect the direction of VFA on the Dots task.

As Table 7 shows, just as many subjects who had a LVFA on Block 4 as had a RVFA on Block 4 evidenced the predicted RVFA on the Letters. There was only a slight tendency for subjects with reversed laterality for Letters (LVF) to have had a RVFA on Block 4.

This lack of task order bias might be expected given the fact that an interval of approximately 5 minutes separated the face recognition and Letter Identification tasks during which time subjects were given the writing posture test and the opportunity to stretch or walk about.

The possible influence of preceding the Dot Localization test with the Letter Identification test on VFA for the former is shown by the frequency of subjects with a RVFA on Dots who also had a RVFA on Letters compared to the number of subjects with a LVFA on Letters (See Table 8). However, X^2 analyses showed that the differences between these frequencies were not significant.

<u>Sex/Handedness Variables Combined</u>

The mean VFA's on the two laterality tasks for the four sex/handedness groups are shown in Figure 22. Consistent

TABLE 7

Frequencies of LVF, RVF, NVF Advantages
On Block 4 and on Letter Identification

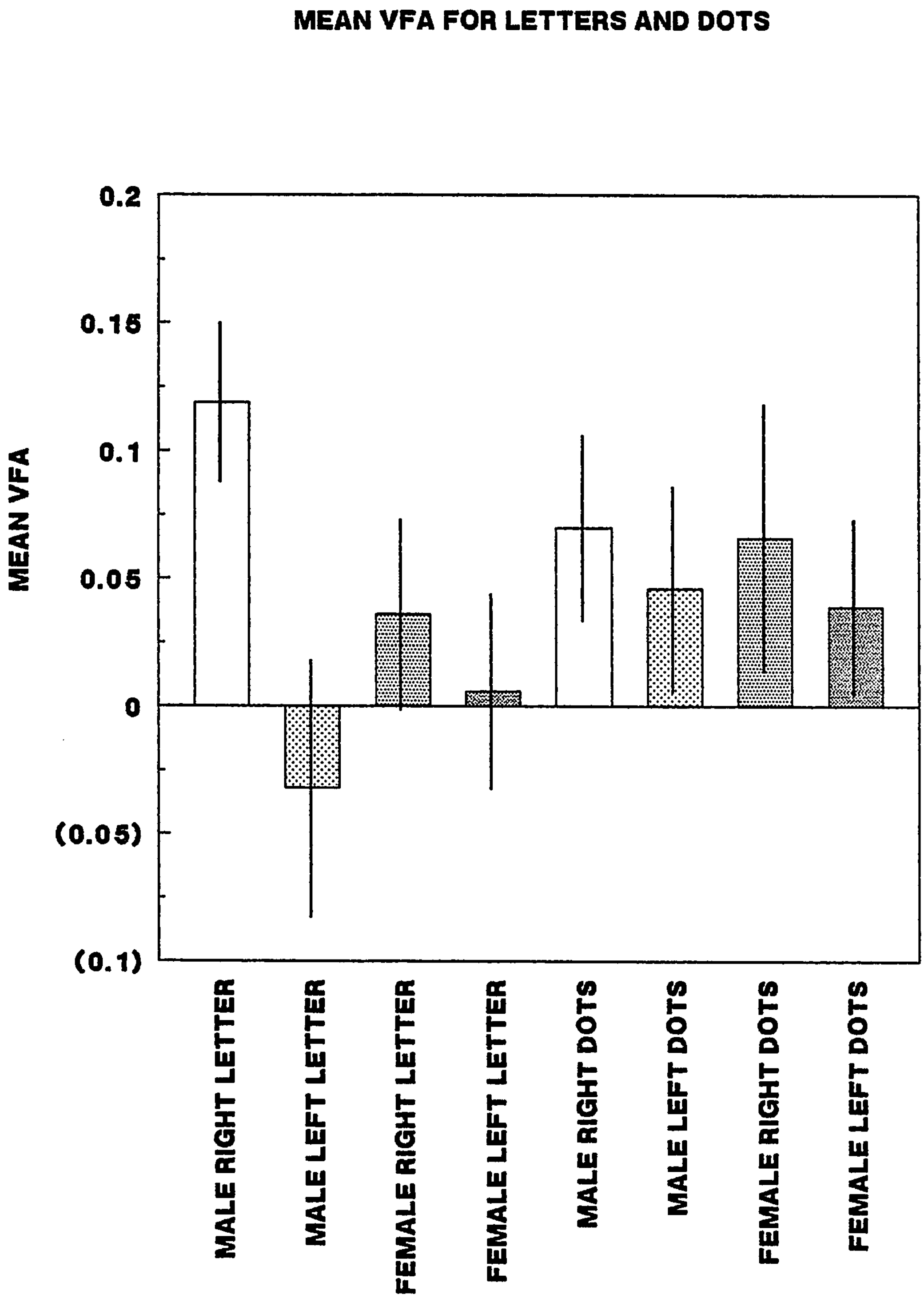
		LETTER ADV			
		LVF	RVF	NVF	Total
BL4 ADV	LVF	17	28	5	50
	RVF	21	27	3	51
	NVF	6	13	0	19
	Total	44	68	8	120

TABLE 8

Frequencies of LVF, RVF, NVF Advantages
On Letter Identification and Dot Localization

		LETTER ADV LVF	LETTER ADV RVF	LETTER ADV NVF	Total
DOT ADV	LVF	17	23	3	43
DOT ADV	RVF	21	41	4	66
DOT ADV	NVF	6	4	1	11
	Total	44	68	8	120

Figure 22


MEAN VFA FOR LETTERS AND DOTS
MEAN VFA
0.2
0.15
0.1
0.05
0
(0.05)
(0.1)
MALE RIGHT LETTER
MALE LEFT LETTER
FEMALE RIGHT LETTER
FEMALE LEFT LETTER
MALE RIGHT DOTS
MALE LEFT DOTS
FEMALE RIGHT DOTS
FEMALE LEFT DOTS

with lateralization data which in general show right-handers and males to have a greater degree of lateral asymmetry of function than left-handers and, to a lesser extent, females, the significant handedness effect on VFA for Letters revealed by the ANOVA was stronger among MR than FR, based on protected t-tests showing the MR mean VFA to be significantly greater than the mean VFA's for ML and for FL. (For MR and ML: $t = 2.80$; $df = 99$; $p<.01$. For MR and FL: $t = 2.09$; $df = 99$; $p<.05$.)

On an individual basis, MR had the lowest incidence of reversed (LVF) laterality on the Letters task (21%), while ML had the highest (54%). ML were the only group to show a mean LVFA on Letters.

On the Dots task, all sex/handedness groups showed a mean RVFA, with minimal differences between groups in magnitude of VFA.

Relationship Between Performance on Face Recognition and Dot Localization

Because face recognition and dot localization can be considered to represent assessments of lateralization of visuospatial function, performance in terms of VFA and accuracy on the two tasks were compared.

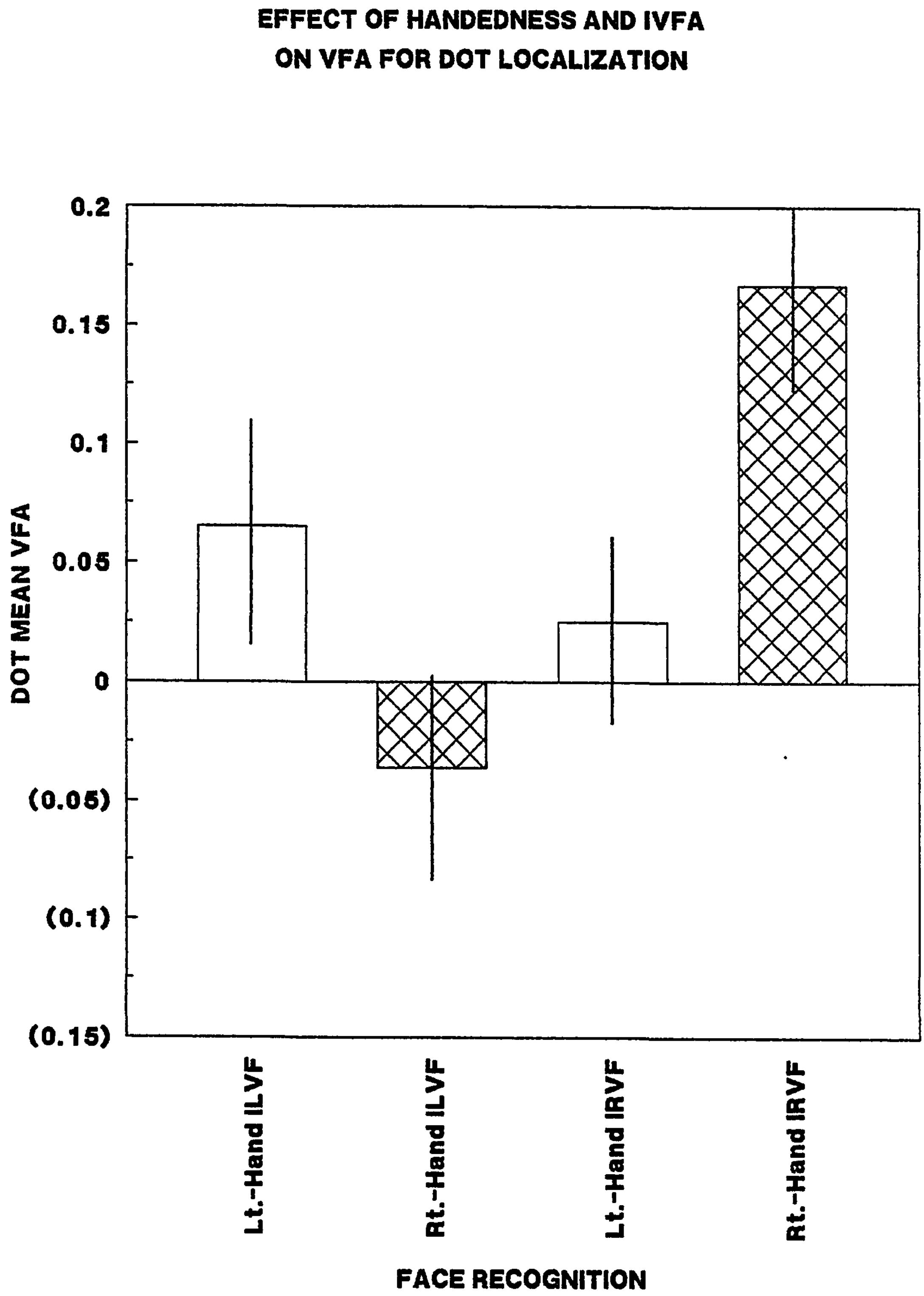
A 3-way ANOVA for the effects of IVFA on face recognition, sex and handedness on Dot Localization VFA revealed a significant main effect for IVFA (F IVFA = 5.01; df = 1,81; $p<.05$). Subjects beginning the face recognition task with a RVFA demonstrated a stronger RVFA (mean VFA = .099) on the Dots compared to subjects utilizing an ILVFA on the faces (mean VFA = .005).

This ANOVA also revealed a significant interaction effect of IVFA and handedness on VFA for Dot Localization (F IVFA X hand = 7.29; df = 1,81; $p<.01$). As shown in Figure 23, for right-handers, the direction of IVFA for faces was related to the same direction of VFA for Dots, while for left-handers, the direction of VFA for Dots was to the RVF regardless of IVFA used for the faces.

Thus, there was a tendency to use the same hemispheric advantage on both visuospatial tasks among right-handers, as indicated by direction of VFA, but such a tendency was not as clearly demonstrated among left-handers.

With regard to accuracy in performing the two visuospatial tasks, correlations of overall error rates on face recognition and Dot Localization were not significant for any of the subject groups.

Figure 23


EFFECT OF HANDEDNESS AND IVFA
ON VFA FOR DOT LOCALIZATION
DOT MEAN VFA
0.2
0.15
0.1
0.05
0
(0.05)
(0.1)
(0.15)
Lt.-Hand ILVF
Rt.-Hand ILVF
Lt.-Hand IRVF
Rt.-Hand IRVF
FACE RECOGNITION

Comparative Analyses of Letter Identification Data Using Other Laterality Indices

The VFA data for MR and ML for the Letter Identification task were converted to other indices of lateral advantage used by researchers studying performance asymmetries. This analyses was intended to: 1) Compare the nature of the lateral asymmetries reflected by each of these indices; and 2) Examine the relationship of the VFA index and these other indices to task accuracy. These two subject groups were chosen for comparison because MR showed a relatively strong RVFA and ML showed a weak LVFA on this task.

Mean laterality indices using VFA, Rc-Lc, POC, POE, f, and phi coefficient are shown in Table 9. As expected, the MR index values are generally higher than the ML values reflecting directional and magnitude differences in lateral asymmetry between the two subject groups.

Table 10 shows the correlations between the six indices as well as between each index and overall accuracy. All six indices were significantly intercorrelated for both MR and ML. POC for MR was the only index significantly (negatively) correlated with accuracy ($p<.05$). All other laterality index/overall accuracy correlations were low. Thus, consistent with Hellige et al. (1981) data, there was no consistent relationship between lateral advantage and accuracy for this task. This was true for both the strongly lateralized and weakly lateralized subject groups.

The relationship between accuracy and scores reflecting the difference between RVF and LVF correct responses discussed by Chapman and Chapman (1988) is shown in Figures 24 and 25. Although the highest individual difference score occurred at mid-range accuracy for MR and for ML, in general, the relationship between Rc-Lc and Rc+Lc does not appear to be curvilinear for either subject group, thus lending support for a minimal artifactual influence of accuracy level, according to Chapman and Chapman's model.

Finally, with respect to the range of overall accuracy for the two groups, the frequency polygons shown in Figures 26 and 27 show a fairly even dispersion of accuracy levels as opposed to a clustering around 50%. Conceivably, such a dispersion might tend to minimize a possible artifactual effect of heightened difference scores around the 50% level mentioned by Chapman and Chapman (1988).

TABLE 9

Mean and Standard Deviation (S.D.)

for Laterality Indices Applied to

Letter Identification Data

Male Right-handers

	VFA	Rc-Lc	POC	POE	f	phi
Mean	.119	3.00	.571	.560	.152	.128
(N=29)						
S.D.	.165	3.66	.086	.082	.194	.157

Male Left-handers

	VFA	Rc-Lc	POC	POE	f	phi
Mean	-.032	-.50	.494	.484	-.030	-.022
(N=24)						
S.D.	.244	6.33	.163	.122	.339	.271

TABLE 10

Intercorrelations of Overall Accuracy and Laterality Indices for Letter Identification

Male Right-handers (N=29)

	VFA	Rc-Lc	POC	POE	f	phi
Accuracy	-.12	-.24	-.40	-.12	-.32	-.26
VFA		.97	.85	.99	.93	.96
Rc-Lc			.95	.97	.97	.99
POC				.85	.97	.96
POE					.93	.96
f						.98

Male Left-handers (N=24)

	VFA	Rc-Lc	POC	POE	f	phi
Accuracy	-.24	-.16	-.12	-.24	-.19	-.17
VFA		.98	.93	.99	.96	.98
Rc-Lc			.98	.98	.99	.99
POC				.93	.99	.98
POE					.96	.98
f						.98

Figure 24

Relationship Between Overall Accuracy

and Rc-Lc for Letter Identification

Male Right-handers

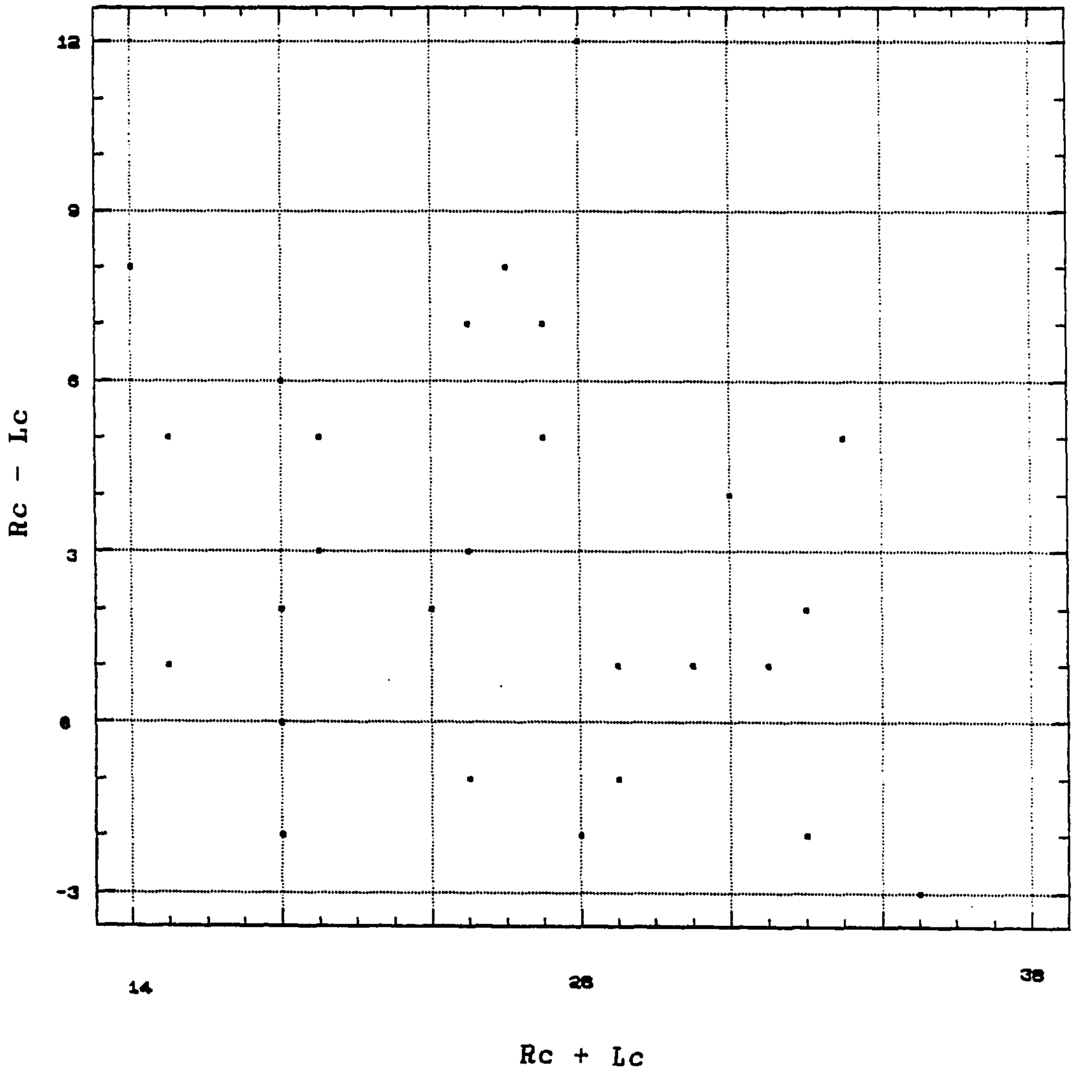


Figure 25

Relationship Between Overall Accuracy

and Rc-Lc for Letter Identification

Male Left-handers

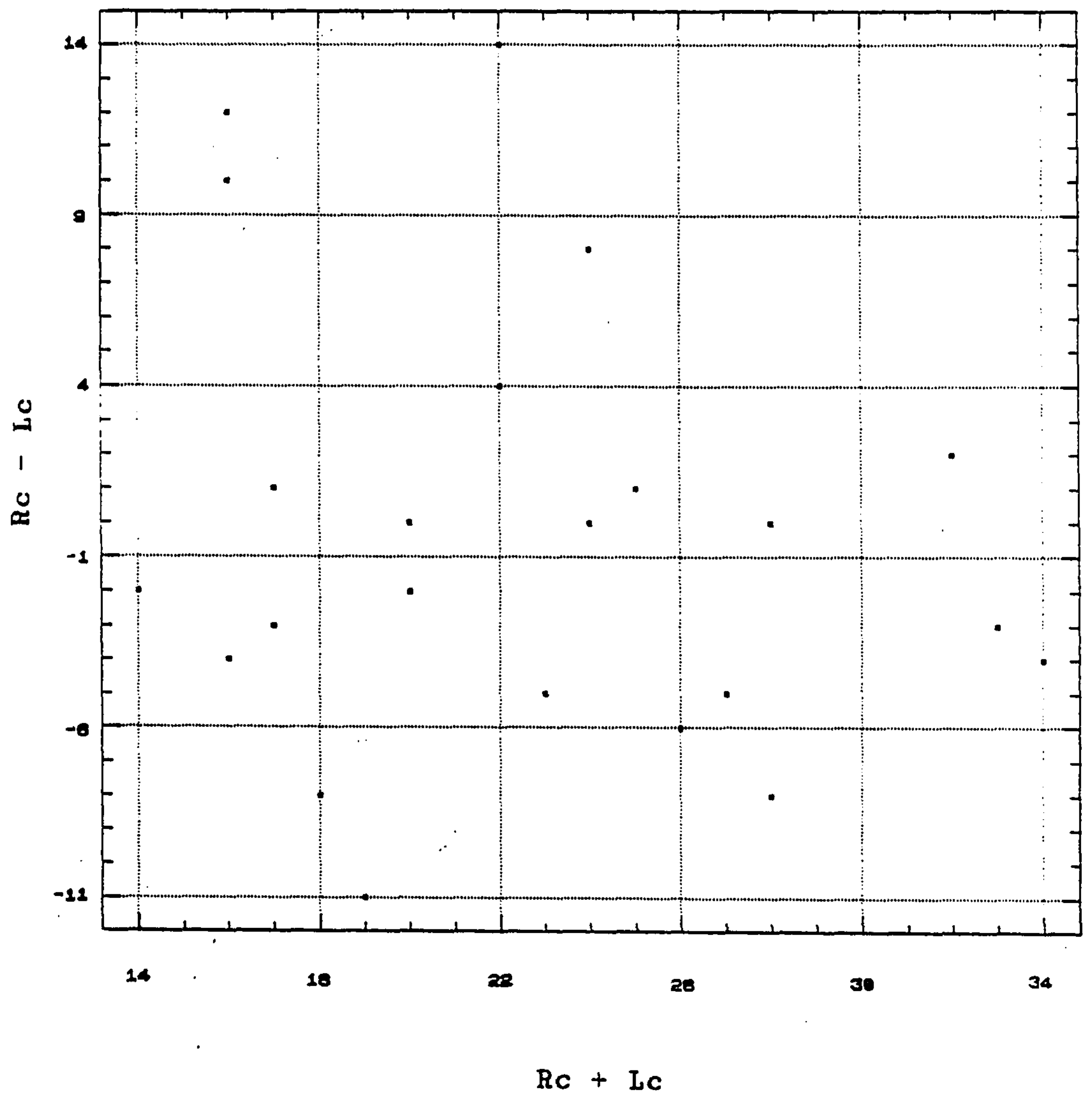


Figure 26

Frequency Distribution of Overall Percent Correct

for Letter Identification: Male Right-handers

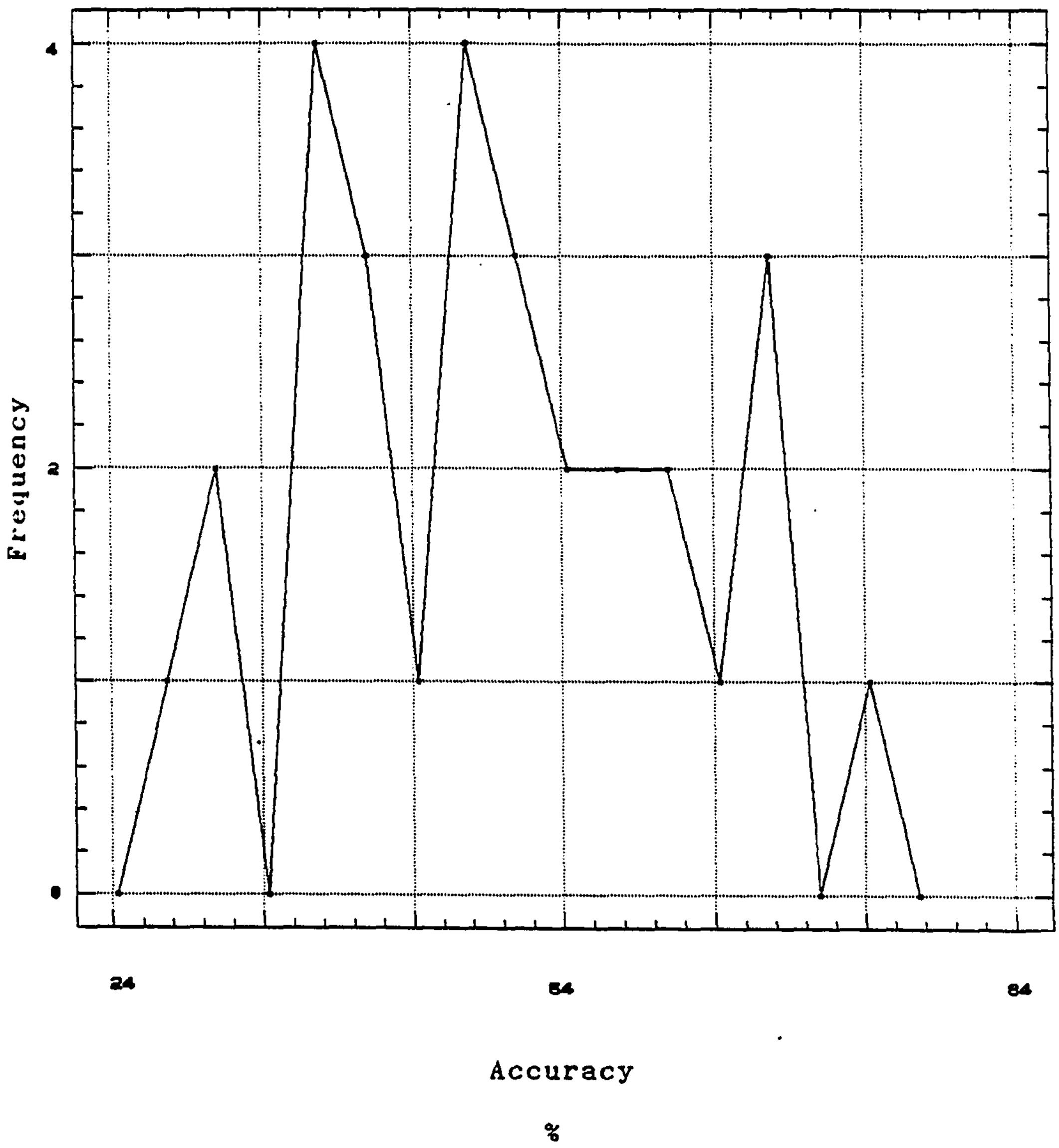
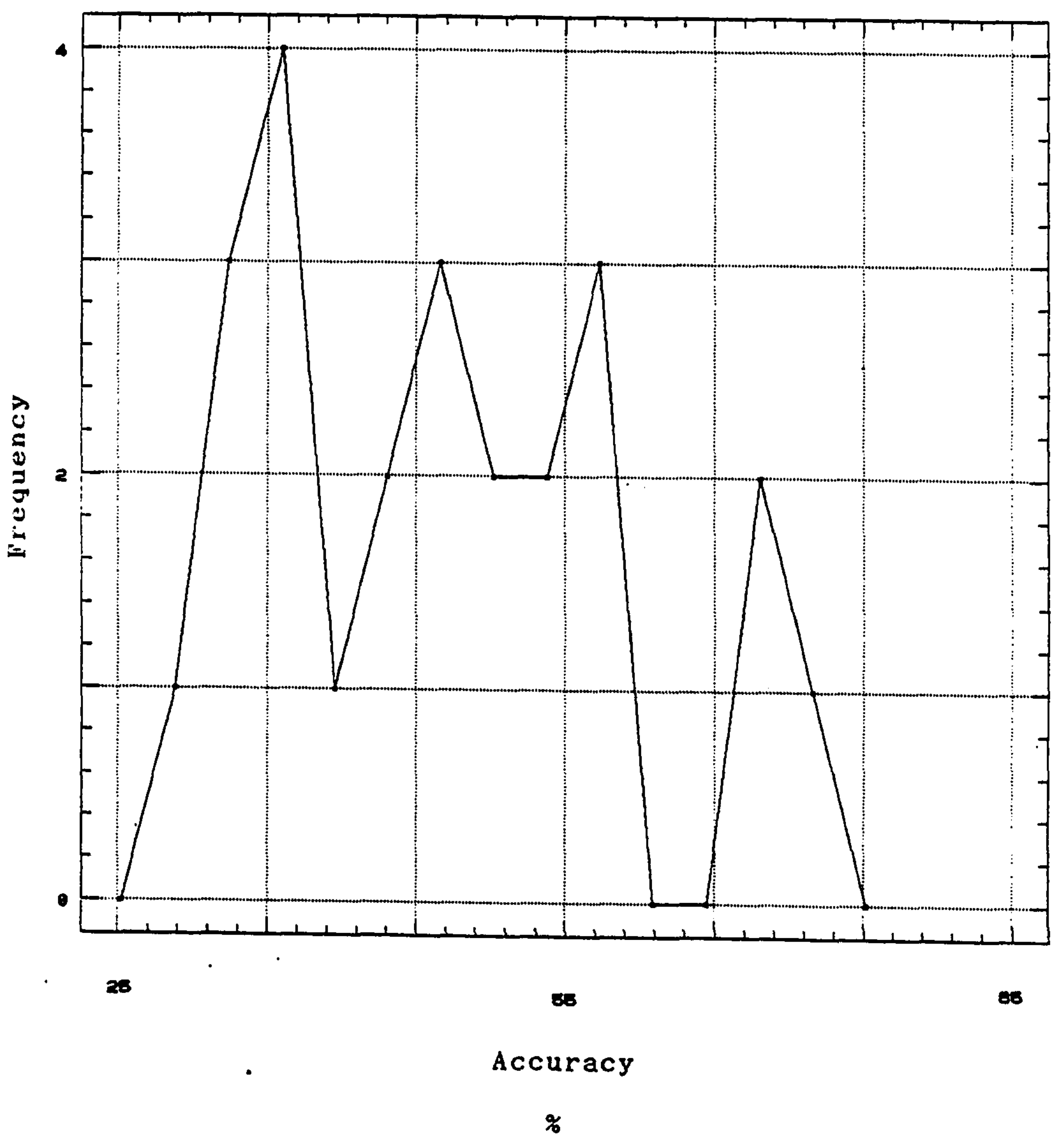


Figure 27

Frequency Distribution of Overall Percent Correct

for Letter Identification: Male Left-handers



Writing Posture

The data on writing posture were collected as an additional correlate of direction of lateralization. Previous research provides some evidence that inverted left-handers are more likely to show direction of lateralization similar to right-handers, whereas non-inverted left-handers are more likely to have right hemisphere superiority for verbal-type tasks and left hemisphere superiority for spatial-type tasks (e.g. Levy & Gur, 1980; Levy & Reid, 1978). Writing posture data were collected in part to determine whether such a pattern would be upheld in the present study.

Results show that writing posture did not successfully predict direction or degree of lateral asymmetry on either the verbal or visuospatial tasks. As Table 11 shows, of the 51% of left-handers with reversed (LVF) laterality on the verbal task, less than half (43%) had a non-inverted writing posture. Of the 45% with reversed (RVF) spatial lateralization, also less than half (47%) were non-inverters. These percentages indicate that the direction of lateralization on both tasks among non-inverters was opposite to the predicted direction.

TABLE 11

FREQUENCY TABLES

WRITING POSTURE AND DIRECTION OF VFA

LETTER IDENTIFICATION

	Writing Posture	
	Inverted (N=19)	Non-Inverted (N=30)
	%	%
RVF	31.6	46.7
LVF	63.2	43.3

DOT LOCALIZATION

	Writing Posture	
	Inverted (N=19)	Non-Inverted (N=30)
	%	%
RVF	42.1	46.6
LVF	31.6	43.3

It should be noted that cell sizes in the inverted writing posture groups were very small. Also, on the Letters task, there were four left-handed subjects with no VFA and on the Dot task, there were eight.

Sex differences in the incidences of inverted versus non-inverted writing posture were consistent with previous findings (e.g. Levy, 1984; McKeever, 1979; Searleman, Porac & Coran, 1984). Significantly fewer female than male left-handers were inverted (4 and 15, respectively) (X^2 = 9.78; df = 1; $p<.01$). Significantly fewer male than female left-handers were non-inverted (9 and 20, respectively) (X^2 = 16.00; df = 1; $p<.001$).

t-tests between sample means revealed no significant differences between inverters and non-inverters in magnitude of VFA on either task.

Writing posture was not related to magnitude of overall VFA nor to accuracy on the face recognition task.

Familial Sinistrality

In the present study, there was no consistent effect of familial sinistrality on degree of lateral asymmetry in the predicted direction.

Familial sinistrality had no significant effect on degree of lateralization on either task among left-handers.

Among right-handers, no effect of familial sinistrality on degree of lateralization for verbal function was noted. However, contrary to prediction, right-handers with familial sinistrality were significantly more lateralized than right-handers without familial sinistrality on the Dot Localization task ($t = 2.46$; $df = 52$; $p < .05$).

Only among right-handers, and again opposite to prediction, the presence of left-handers in the immediate family had a significant effect on both magnitude of overall VFA and overall error rate on the face recognition task. Right-handers with familial sinistrality had a significantly stronger overall VFA ($t = 2.72$; $df = 52$; $p < .01$) and a significantly lower overall error rate ($t = 2.36$; $df = 52$; $p < .05$) than right-handers without familial sinistrality.

Handedness Score

Possible scores on the handedness questionnaire were 15-75, with 15 being extremely right-handed and 75 extremely left-handed. Scores on the handedness questionnaire revealed minimal variation in degree of handedness among right-handers. Scores for this group ranged from 16-38, with a mean of 30.0, a median score of 30, and a standard deviation of 3.77.

Scores among left-handers reflected a greater heterogeneity of manual preference. The range was 42-72, with a mean of 54.0, a median score of 54, and a standard deviation of 6.91.

Although Dot Localization did not significantly differentiate sex groups as discussed above, when degree of handedness and degree of lateralization were correlated, there was a significant relationship for males on the Dot Localization task. Males who were more strongly right-handed (i.e., lower handedness score) were more strongly lateralized on the Dot Localization task ($r(51) = -.30$; $p<.05$).

DISCUSSION

Direction of Initial Visual Field Advantage

The finding of equivalent numbers of subjects with IRVFA's as with ILVFA's when faces were unfamiliar is consistent with previous data using this experimental design (Ross & Turkewitz, 1981, 1982; Ross-Kossak & Turkewitz, 1984; Turkewitz & Ross, 1983), although inconsistent with the most common finding of a LVFA for processing unfamiliar faces. It is important to note, however, that the direction of IVFA in the present study is based on only 24 trials which does not allow a direct comparison with face recognition data based on substantially greater numbers of stimulus presentations.

One possible interpretation of a relatively high percentage of RVFA's when the faces were unfamiliar is related to task difficulty. The particular experimental parameters used in the Ross & Turkewitz (1982) design and its replications consistently result in about half of the subjects demonstrating a RVFA for the unfamiliar faces which occurs with an error rate approximating 60%. Block 1 error rates for Ross & Turkewitz (1982), Turkewitz & Ross (1983), and the present research were 55%, 67%, and 63%, respectively. Klein, Moscovitch & Vigna (1976) and Young and Ellis (1976) obtained a LVFA in their face recognition experiments with unfamiliar faces and the error rates were approximately 44% for each study, based on 40 visual field presentations. Keeping in mind procedural differences between these studies and the present design, this percentage is considerably below the error rate for Blocks 1 and 2 combined (48 trials) of 60% for the present research.

There is data which indicates that using a stimulus set in which the faces are relatively difficult to discriminate may bias hemispheric asymmetry toward the RVF (e.g. Patterson & Bradshaw, 1975; Rhodes, 1985; Sergent, 1984b).

A contributing factor to the percentage of RVFA's obtained for unfamiliar faces other than task difficulty might be the use of verbal encoding as a discrimination strategy. Although the effect of verbal versus nonverbal response mode does not appear to significantly effect visual field asymmetry (e.g. Ellils & Shepherd, 1975; Hilliard, 1973; Umilta et al., 1978), the instigation of labeling a distinctive feature of a face to distinguish it from the other faces (such as bushy eyebrows, long nose, etc.) could influence the type of processing strategy used. The use of such semantic codes would reduce right hemisphere involvement if utilized early in a recognition task and would serve to aid processing by reducing stimulus uncertainty (Rhodes, 1985).

Such verbal encoding has been suggested by Benton (1980) as a possible component of face recognition which is consistent with his clinical findings that face recognition is a language-dependent task. Sergent (1986) also calls for more careful attention to the possible effects of a mnemonic strategy on resulting visual field asymmetries when subjects are first presented with the stimulus faces.

Kinsbourne (1973) reports that concurrent subvocalization induces a RVFA in recognizing visuospatial material among right-handers. Subjects were asked to remember six words while performing a nonsense shape recognition task and a strong RVFA was found although without such a concurrent task, no lateral asymmetry was demonstrated.

On the other hand, a high incidence of IRVFA would not be predicted based on the argument that the use of a left hemisphere analysis would not be advantageous when faces are unfamiliar because specific feature identification is likely to require high frequency spatial information. Evidence exists that at early stages of complex information processing, low spatial frequency information is attended to, which would best be served by the right hemisphere (Sergent, 1982, 1983).

Goldberg and Costa (1981) present support for the relative inefficiency of the left hemisphere in processing novel stimuli based on differences between the hemispheres in neuroanatomical organization, with specific reference to the interregional organization of the right hemisphere versus the intraregional organization of the left hemisphere. The right hemisphere is superior in dealing with informational complexity and has a greater ability to process many types of information within a single cognitive task. Therefore, the right hemisphere would be of maximal effectiveness in situations where no relevant descriptive system is immediately available to the subject.

Although Goldberg and Costa would apply their model to face recognition, in the strictest sense it may not apply to the same extent for faces as in other task situations. For example, in face recognition, all individuals have equivalent levels of experience in recognizing faces from birth whereas descriptive systems such as those for math or music entail considerable experiential variability.

Sex Effects

Direction of IVFA

One of the main differences between females and males in hemispheric advantage and its relationship to proficiency was in the direction of the IVFA. When the faces were unfamiliar, females utilized a LVFA, while males began with a RVFA. Starting out with a right hemisphere advantage was related to a lower overall error rate for the task among females whereas the same result was true for males starting out with a left hemisphere approach to the faces.

The opposite direction of visual field advantage would not be accounted for by differences in neuroanatomy or differences in degree of lateral asymmetry for nonverbal processing. Preferential use of a particular cognitive strategy by females versus males when confronted with a task with the constraints imposed by the present design must therefore be considered as a possible explanation.

While there is no consistent evidence to support the conclusion that males are more likely to use a left hemisphere approach to visuospatial tasks, or even specifically face recognition, and females are more likely to use a right hemisphere approach, an interaction of sex and certain experimental conditions could result in the different initial hemispheric advantages used by females and males in the present study.

Specifically, it is possible that females would be more likely than males to use some form of verbal encoding to help with a difficult face discrimination task. This strategy would result in a greater likelihood of a LVFA among females compared to males. In the Umilta et al.

(1978) study of familiarity and naming, the only significant VFA shown by females was a LVFA when subjects were asked to attach a name to the unfamiliar faces.

Initial processing approaches might also be differentially effected by the sex of the stimulus face. Brouwers, Pim, Mononen & Stefanatos (1980) found that for males and females, presentation of the same-sex face to the LVF resulted in fewer errors than when presented to the RVF. Extrapolating to the present study which used female faces, the results are consistent: females beginning with a LVFA showed greater overall accuracy on the task compared to males beginning with a LVFA.

Jones (1979) found that when female and male subjects were asked to classify tachistoscopically presented faces as either female or male, male subjects showed a strong RVFA while females showed no significant laterality. Further, males did not perform more accurately in either visual field than females, suggesting a differential cognitive approach by the sexes to the unfamiliar faces.

Based on such evidence which might suggest a VFA bias effected by the sex of the stimulus faces, a replication of the present paradigm using male faces, similarly photographed, would be informative.

For face recognition involving unfamiliar faces, it has been reported that males show a greater degree of visual field asymmetry than do females (Zoccolotti & Pizzamiglio, 1986), but the direction is generally to the LVF (e.g. Umilta et al., 1978). However, Young et al. (1985) using a categorization task of familiar/unfamiliar faces found that males tended to be less accurate in the LVF and females less accurate in the RVF.

Benton (1980) makes reference to a preference for left hemisphere mechanisms in mediating face recognition among certain right-handed subjects. Studies indicating either no VFA or a RVFA among females when processing nonverbal stimuli other than faces are fairly numerous (e.g. Kimura, 1969; McGlone & Davidson, 1973). A RVFA among females is opposite to the present results, but the nonverbal stimuli used in such studies are simple compared to the complexity and meaningfulness of the face as stimulus.

When cognitive strategy differences were specifically investigated in terms of their effect on lateral asymmetry for face recognition, results have shown a LVFA for field independent subjects and either no VFA or a weak RVFA for field dependent subjects (Pizzamiglio & Zoccolotti, 1981; Pizzamiglio, Zoccolotti, Mammurcari & Cesaroni, 1983). Since males are generally more field independent than females, the present findings for direction of IVFA are inconsistent with these results. However, it would be necessary to replicate the present design, particularly with reference to degree of familiarization and number of trials, and include the assessment of field independence/dependence to determine whether the current findings are in conflict with these data.

The present results suggest that the effects of sex on IVFA were made significant primarily by FR and MR. It is interesting to note what would appear to be the same directional preference among ML and FL: ML who began with a RVFA did not shift to a LVFA for any subsequent Blocks and FL who began with a LVFA did not shift to a RVFA during the task.

Although it has been maintained that cerebral lateralization develops progressively along a maturational gradient (e.g. Buffery & Gray, 1972), others have argued that lateralization is present from birth and only abilities and the expression of lateralization through performance develop over time (e.g. Kinsbourne, 1976). The fact that males in the present study showed an IRVFA whereas females had an ILVFA could be due to a greater handedness effect among males as well as the evolution of generalized cognitive strategies for information processing over the course of development and into adulthood which are sex-related.

Evidence for developmental differences in the utilization of a more advanced right hemisphere processing mode would also support such an explanation. For example, Turkewitz and Ross-Kossak (1984) found that by age 13, females showed evidence of a second advanced right hemisphere mode of processing for face recognition whereas males did not.

Since the present study is the first replication of this particular experimental design comparing adult males and females, further related research may generate new possible explanations for these sex effects.

Effects of IVFA on Overall VFA and Accuracy

The finding that an ILVFA was more advantageous than an IRVFA among females is not inconsistent with previous data using this paradigm. Turkewitz and Ross-Kossak (1984), using the same facial stimuli with children, found that FR with a LVFA performed better than FR with a RVFA, whereas the reverse was true for MR.

Patterns of Shifts in Hemispheric Advantage

With the exception of the direction of IVFA, patterns of VFA across Blocks did not differ significantly between females and males. Although the two sex groups showed opposite VFA's on Blocks 1 through 3, both ended the task with a right hemisphere advantage. Neither sex group evidenced significant changes in VFA across Blocks.

Relationship Between Magnitude of Hemispheric Advantage and Accuracy

Females and males did not differ in the degree to which a stronger VFA was advantageous to proficiency throughout most of the task. However, for females on Block 3, a strong RVFA was not correlated with better performance whereas for males, a LVFA on Block 3 was significantly correlated with lower error scores.

A RVFA after the faces had been familiarized might not be particularly advantageous. A more optimal strategy would be the proposed second right hemisphere processing mode of integrating previous input from the two hemispheres. It may be that males and females differed in the amount of familiarization necessary for the integrative right hemisphere processing mode to emerge. Direct testing of the mode of processing utilized at specific intervals during the familiarization process would therefore be informative.

Dynamic Involvement of Right and Left Hemispheres

A sex difference indicated by the data was the degree to which both hemispheres were dynamically involved in the familiarization process. Males showed a significant increase in the correlations between LVF errors and RVF errors from Block 1 to Block 4. For females, the correlations did not build in the same manner but were moderately high on the initial Block and the last half of testing.

These results may be considered to reflect differences in lateral asymmetry. Both sexes showed involvement of the specialized capacities of each hemisphere during the process, but for males this involvement began in Block 1 which would be expected given a stronger degree of lateral asymmetry, while for females the performance of both hemispheres was more related at the beginning of familiarization, reflective of a weaker degree of lateral asymmetry.

Presence of a Second Right Hemisphere Mode of Processing

On the basis of sex alone, when individual subjects were analyzed, there were no differences between males and females in evidencing the second mode of right hemisphere processing proposed by the dynamic shift model. When handedness was considered along with sex, however, differences did emerge.

The fact that MR were twice as likely as FR to demonstrate the right-left-right pattern of hemispheric advantages is not incongruous with a greater degree of lateral asymmetry among males and is consistent with the more dynamic involvement of the two hemisphere during the course of familiarization among MR, as discussed above.

Handedness Effect

Support for the hypothesis that underlying differences in direction and degree of lateral asymmetry of function would be associated with differences in patterns of hemispheric advantages as well as the relationship between such hemispheric advantages and proficiency comes from the differences between right-handers and left-handers in their performance on this task.

Direction of Initial Visual Field Advantage

Whereas among right-handers direction of IVFA had a significant effect on magnitude of overall VFA as well as overall accuracy, the data indicate no such effects among left-handers. This finding could suggest that left-handers do not have a consistent strategy for approaching a task of this nature, or that individual consistencies exist but due to the heterogeneity of cerebral lateralization patterns among the left-handed population, are masked.

It is suggested that the lack of effect among left-handers of the hemispheric advantage shown at the beginning of the familiarization process on overall accuracy is due to a greater degree of bilateralization of verbal as well as nonverbal information processing among left-handers compared to right-handers. Among left-handers, either hemisphere is more likely to contribute similar types of input derived from the facial stimuli and the association between hemispheric advantage and accuracy is therefore more variable among left-handers than right-handers.

Patterns of Shifts in Hemispheric Advantage

While right-handers showed a nonsignificant tendency toward a right-left-right sequence of hemispheric advantages, left-handers began with the opposite hemispheric advantage and showed a significant shift in the second half of the task to end with a RVFA in Block 4.

If right-handers were following a pattern of holistic/configurational analysis, followed by a feature analysis, and ending with an integrative, advanced strategy, it is conceivable that the opposite pattern of shifts among handedness groups at the beginning and end of the familiarization process could reflect the utilization of the same processing strategies by these two subject groups if the percentage of reversed lateralization among left-handers (51% in the present study) is taken into account.

The presence of a significant change in VFA among left-handers, unlike right-handers whose pattern of VFA's showed no significant changes, is contrary to previous face recognition studies. Investigations of the effect of handedness on lateralization of face processing have been few and results are inconclusive. Either no difference in hemispheric advantage between handedness groups (Gilbert, 1977), or the lack of a significant asymmetry among left-handers (Lawson, 1978; Piazza, 1980) has generally been demonstrated.

Thus, there is no previous direct empirical evidence to explain the shifting patterns of left-handers on this task. As Annett (1982) points out, differences between handedness groups on divided visual field studies must entail a structural factor at some level in the perceptual processes which lead to lateral asymmetries. The hypothesis proposed to account for the seemingly discrepant results compared to the meager face recognition data available for left-handers is based on both the dynamic nature of this task in terms of necessitating different kinds of analysis, as well as the differences in direction and strength of asymmetry among the two handedness populations.

When the task at hand requires both right hemisphere and left hemisphere types of processing, it might be predicted that movement from one mode of processing to another would result in different visual field asymmetries among the left-handed population than among the right-handed population because of the greater incidence of functional bilateralization or reversed lateralization in the former group.

It is further suggested that a right-left-right sequence of shifts can be translated to any subject population if it is assumed that a right hemisphere processing mode tends to be lateralized to the hemisphere opposite to the hemisphere specialized for language. The resulting pattern of shifts that would occur among left-handers during familiarization, would be left-right-left hemispheric advantages.

Turkewitz (1988, in press) proposes a model for the development of facial recognition specialization which is consistent with this hypothesis. A right hemisphere specialization for recognizing faces in the neonate is related to the early specialization of the left hemisphere for speech processing. Exposure of an infant to faces is likely to occur at the same time as he/she is being spoken to. At that point in time, the left hemisphere would be engaged in processing speech but the right hemisphere would be available to process facial information. The basis for this conclusion is that since interhemispheric connectivity and myelination are not fully developed, each hemisphere is more likely to act as a unit. Thus, activation of one hemisphere by a particular type of input would make that hemisphere less accessible to other concurrent input. Further, the nature of this initial right hemisphere processing would be global and diffuse due to the limitations of the neonate's visual system. Presumably, if prior specialization for language had developed in the right hemisphere, the left hemisphere would then become specialized for initial face processing which would be global and diffuse in nature.

In order to test the hypothesis that among individuals with right hemisphere specialization for language, face recognition using a global analysis would be lateralized to the left hemisphere, it would be necessary to introduce manipulations to the facial stimuli during the familiarization process in such a way as to discriminate whether a holistic or analytic type of analysis was being applied and correlate the results with handedness.

Relationship Between Magnitude of Hemispheric Advantage and Accuracy

Neither a strong RVFA nor LVFA was advantageous to performance among left-handers until the end of the task when the faces had been sufficiently processed by either the right hemisphere or left hemisphere for a strong VFA to maximize performance. Among right-handers, however, a strong VFA on Block 1 resulted in better overall performance, and the correlations representing this association did not increase significantly across Blocks.

The low initial correlation between magnitude of VFA and accuracy among left-handers, as well as successive increases in this correlation from Block 1 to Block 4, indicate that a strong VFA was most advantageous only towards the end of the task when the faces had been somewhat familiarized. Only among left-handers was there a significant progression of correlation values from Block 1 to Block 4.

Differences between right-handers and left-handers in the relationship between magnitude of hemispheric advantage and accuracy suggest underlying differences in the information processing approach to the task. The present results could be interpreted to reflect a relatively high degree of bilateralization of functional specialization of the hemispheres among the left-handed sample; i.e., either hemisphere might be effectively using an analytic or holistic processing strategy, particularly when the faces were yet unfamiliar.

It might also be hypothesized that left-handers show less consistency in applying a right hemisphere versus left hemisphere type of processing strategy when presented with unfamiliar visuospatial stimuli. The finding in the present study that left-handers tended to show less consistency in direction of hemispheric advantage when presented with two classes of visuospatial stimuli (faces and dots) than did right-handers is consistent with such a hypothesis.

Only for left-handers was there a significant association of overall magnitude of VFA with overall accuracy. This finding could be interpreted to indicate that for left-handers, having a stronger VFA, regardless of direction, resulted in optimal performance, whereas for right-handers, successive processing by both hemispheres was a more beneficial strategy. In other words, compared to right-handers, having a stronger overall VFA was relatively more advantageous to left-handers as a compensation for the relatively less important dynamic contribution of both hemispheres to the familiarization process.

Dynamic Involvement of Right and Left Hemispheres

Indications of differences in degree of lateral asymmetry between the handedness groups can be found in the correlations of LVF errors with RVF errors progressing from Block 1 to Block 4. A significant correlation in Block 1 for left-handers suggests a strong relationship between how each hemisphere was dealing with the facial stimuli. Based on the interpretation that the hemispheres were performing similar functional analyses, these findings may reflect greater bilateralization of functional specialization.

Conversely, the low correlation among right-handers in Block 1 might suggest that the right and left hemispheres were performing different functions. A low correlation between visual field errors might also be the result of either hemisphere performing a particular type of processing less efficiently than the other hemisphere.

Only for right-handers, presumed to be more strongly asymmetrical, was the progression of correlation values from Block 1 to Block 4 significant, indicating that for these subjects in particular this task involved a dynamic interchange of the processing strategies for which each hemisphere was particularly efficient. Likewise, the pattern of results among left-handers could be reflective of weaker lateral asymmetry, or the relative efficiency of either hemisphere to process the faces utilizing more than one type of strategy.

Presence of a Second Right Hemisphere Processing Mode

Not unexpectedly, left-handers were less likely than right-handers to demonstrate a second right hemisphere advantage. In fact, left-handers showed a significant shift in VFA from the LVF to the RVF for the final Block.

Accuracy

The fact that there were no significant differences in error rates based on sex or handedness brings into discussion theories which may have predicted that females would outperform males or that left-handers would perform more poorly than right-handers.

Females have been considered more adept at facial recognition (Ellis, Shepherd & Bruce, 1973; Goldstein & Chance, 1971), although in a review of this research, Fairweather (1982) notes that only one-fourth of the investigations involved significant sex differences and half of them required naming the faces which may have confounded the findings. Also, clinical assessments of face recognition performance typically do not show sex differences (Benton & VanAllen, 1968).

As far as the lack of a handedness difference is concerned, the neural competition model proposed by Levy (1969) that predicts greater bilateralization would lead to poorer performance on right hemisphere type tasks has not generally been supported (Beaton, 1986). Large scale studies of the effect of handedness on accuracy on tests of lateral asymmetry have not confirmed that left-handers show deficits compared to right-handers (Hardyck & Petrinovich,1977). As far as the higher incidence of reversed lateralization for speech among left-handers is concerned, Kinsbourne (1980) maintains that as long as the individual is engaged in one task at a time which requires only one mode of processing, there would be no reason for the part of the brain doing the processing, or how diffusely about that area the activation spreads, to make a difference.

Utilization of the right-left-right sequence of shifts in hemispheric advantage did not seem to benefit performance for the sex or handedness groups as predicted by the dynamic shift model. However, although subgroup sample sizes were small, the higher incidence of an advantage to such a pattern among FR compared to the other sex/handedness groups not only supports previous findings for FR, but also suggests that sex and/or handedness may influence the optimal sequence of shifts required for maximizing proficiency on this task.

Assessment of Lateral Asymmetry

The assessments of cerebral lateralization of function obtained in this study are generally consistent with precedent findings and may therefore represent an appropriate basis for the interpretation of the face familiarization data.

Right-handers and MR, in particular, tended to be more lateralized than the other subject groups on the verbal task. In addition, left-handers showed a weak LVFA on the verbal task which was related to a high incidence (51%) of reversed language asymmetry among the left-handed subjects.

On the measure of visuospatial lateral asymmetry there were no sex differences. Right-handers, however, were significantly more lateralized than left-handers.

The failure to demonstrate a significant sex effect on a visuospatial task such as dot localization is not without precedent (e.g. Allard & Bryden, 1979; Bryden, 1976; Pohl, Butters & Goodglass, 1972). With dot detection/localization/enumeration experimental designs, only five of the 23 studies reviewed by Fairweather (1982) yielded significant sex differences. In general, significant differences in lateral asymmetry are more difficult to demonstrate for visuospatial function and may require subtle differences in task design for sex effects to emerge (Kinsbourne, 1970). In his review of dot localization results, Davidoff (1982) also states that studies which fail to show a right hemisphere superiority for such stimuli are not hard to find.

Present results showed all subject groups had a RVFA on dot localization. Bryden's (1979) review of dot localization studies indicates that approximately 65% of males compared to 57% of females show a LVFA. This suggests that, at least among females, a relatively high percentage of subjects would show a RVFA on such a task. A study of McGlone and Davidson (1973) found that females had a higher incidence of RVFA on dot enumeration. These authors also reported a trend for more left-handers to show higher RVFA's or no VFA compared to right-handers, consistent with the present results.

Effect of Individual Variation in Hemispheric Arousal on Visual Field Advantage

Inferences about differences in the nature of hemispheric specialization between subject groups have been drawn in the present study based on performance asymmetries on laterality tasks. It is important to note, however, that the relationship between hemispheric specialization for a particular function and hemispheric superiority in performance on such laterality tasks is not necessarily direct. Individual differences in hemispheric activation may have a significant influence on cognitive performance.

EEG data show that arousal asymmetries both within-subject and between laterality tasks for individual subjects are consistent (Ehrlichman and Wiener, 1979). In addition, EEG asymmetry also reflects stability of lateralization of cognitive process which occurs without external stimuli (Ehrlichman & Wiener, 1980).

The relative amount of cerebral blood flow to the right and left hemispheres also indicates asymmetrical activation and has been correlated with performance on a laterality task (Gur & Reivich, 1980).
Lateral eye movements (LEM's) in response to experimenter questioning have been proposed to indicate differences in hemispheric activation (Gur, 1975). The Gur and Reivich (1980) study also showed that classifications of subjects into "left-movers" and "right-movers" were corroborated by differences in cerebral blood flow, with "left-movers" having relatively more blood flow in the right hemisphere and "right-movers" relatively more blood flow in the left hemisphere.

In addition to physiological indices of asymmetric hemispheric arousal that vary by individual, there is also evidence that a high level of right hemisphere arousal is associated with positive affect and low right hemisphere arousal is associated with negative affect.

Left-right asymmetry of function of the nigrostriatal system has been demonstrated in the rat (Glick, Jerussi, & Zimmerberg, 1977). This major pathway for the neurotransmitter dopamine is critical for maintaining arousal and activity. Such asymmetry has implications for dopamine-related psychopathology in humans and is directly relevant to states of depression.

In a study using induced mood states to compare relative hemispheric activation, Tucker, Stenslie, Roth and Shearer (1981) found that auditory attentional bias indicated a shift in attention toward the right ear during the depressed condition. In addition, EEG measurements showed that the depressed condition resulted in greater activation of the right frontal lobe compared to the euphoria condition.

Differences in personality style have also been correlated with measures of asymmetric hemispheric activation. Smokler and Shevrin (1979) reported that among subjects tested as having hysterical personality tendencies, leftward eye movements were significantly more likely than among subjects tested as having obsessive-compulsive personality tendencies. Charman (1979) found that extroverted subjects processed tachistoscopically presented letters more efficiently in the right hemisphere whereas introverted subjects showed the reverse tendency.

Given evidence of individual variation in hemispheric activation which may influence cognitive functioning, Levy, Heller, Banich, & Burton (1983) argue that standard measures of performance asymmetry cannot provide completely valid indications of hemispheric specialization unless individual differences in characteristic patterns of asymmetric hemispheric arousal are taken into account. They propose that a considerable amount of variance amongright-handed subjects in perceptual asymmetries as measured by laterality tasks is due to such individual variation.

The Levy et al. study examined the dimensions of optimism versus pessimism in relation to direction of visual field advantage (VFA) on a syllable identification task. Pessimists had strong RVFA's and optimists had weak or no asymmetry. These findings were linked to evidence that arousal level of the right hemisphere is related to affective mood.

Taken a step further, the authors' arousal hypothesis predicts that subjects demonstrating weak asymmetry on a syllable identification task are just as specialized for left hemisphere language as strong asymmetry subjects, but that the lack of performance asymmetry shown by the former group is due to characteristically high right hemisphere arousal.

Levy et al. related affect as an indication of hemispheric arousal to demonstrated lateral asymmetry by having subjects rate their performance. Pessimism was correlated with stronger RVF asymmetry while optimism was correlated with weak or LVF asymmetry. Thus, positive affect reflecting higher right hemisphere arousal was related to demonstration of increased left hemisphere involvement (weak or no RVF asymmetry).

Levy et al. also tested their model by measuring perceptual asymmetry for facial stimuli and correlating those results with VFA's for syllables. They found that with increasing leftward perceptual asymmetries for faces, RVFA's for syllables diminished. Thus, higher characteristic right hemisphere arousal led to increased leftward asymmetry for faces. Subjects with negative versus positive bias in affect also differed in laterality for faces in the direction predicted by the arousal model.

Thus, it can be argued that hemispheric specialization has variants not only in direction and degree of specialization, but also in the extent to which a particular hemisphere becomes active during a cognitive task. Determining whether a particular task is specialized to the right or left hemisphere in a population may be obscured if, in addition to sex and handedness, the extent to which the task is susceptible to individual differences in hemispheric activation is ignored (Gur & Reivich, 1980).

Indeed, the existence of such individual variation may account for inconsistent or contradictory laterality results often reported among the normal population. In a normal brain, cortical areas that subserve a specific function may inhibit other areas potentially capable of that same function (Kinsbourne, 1974). The arousal model addresses the discrepancies in degree and/or direction of demonstrated lateralization of function between split-brain or clinical populations and demonstrated perceptual asymmetries in laterality studies conducted with normal subject groups.

Levy et al. note that a distinction must be made between variations in hemispheric arousal which would influence general problem-solving strategies and variations in hemispheric utilization which would occur on a laterality task. An individual with characteristically higher right hemisphere arousal may predominantly utilize nonverbal types of processing strategies in everyday life. Under the forced viewing conditions of lateralized stimulus presentation, however, processing must be initiated by the hemisphere contralateral to the field of presentation.

Expanding the present experimental paradigm to include a measure of hemispheric activation or arousal and determining the extent of the relationship of such a variable to the laterality results obtained would certainly be instructive in light of the findings discussed above.

Writing Posture

A non-inverted writing posture among left-handers was not predictive of a right hemisphere asymmetry on the verbal task nor of left hemisphere asymmetry on the visuospatial task. The tendency instead was for an inverted posture to be associated with reversed laterality for language. This tendency among non-inverters opposite to the direction predicted by Levy and Reid (1978) was found by Lawson (1978) and a failure to find any relationship between writing posture and visual field asymmetry on a word recognition task was noted by McKeever (1979), and by Smith and Moscovitch (1979) on a dot localization task. In one of those studies, writing posture was determined by self-report (Lawson, 1978) and in another (Smith & Moscovitch, 1979), sample sizes were relatively small. Either condition could have precipitated failure to obtain a significant relationship in the predicted direction. In the present study, care was taken to follow the criteria for definition of writing posture specified by Levy and Reid (1978), but the incidence of inverted writing posture was relatively infrequent which could have precluded significant findings.

Familial Sinistrality

No significant effects of familial sinistrality on the verbal laterality task were found. Right-handers with familial sinistrality showed a significantly stronger visual field asymmetry on the dot localization task. No explanation is apparent for this result which is contrary to prediction.

The results of recent studies involving dichotic or tachistoscopic presentation have been less conclusive than previous research in terms of the relationship between familial sinistrality and lateral asymmetry (Hecaen, DeAgostini & Montes-Monzon, 1981). Inconsistent or absent effects of familial sinistrality are frequently found. For example, in a large scale study of familial sinistrality, Orsini, Satz, Soper & Light (1985) found no relationship between familial sinistrality and laterality on dichotic word recall among either left-handers or right-handers. Andrews (1977) found no significant correlation of laterality for nonsense trigrams with familial sinistrality.

Conclusions

The demonstration of shifts in hemispheric advantage during familiarization with facial stimuli was generalized beyond FR, the only group systematically investigated in previous research. Based on evidence for bilateral involvement in face recognition deficits as well as differences in anatomical correlates for recognizing unfamiliar and familiar faces, this generalization is not unexpected.

Sex affected the direction of the initial hemispheric advantage subjects employed when approaching this task. The direction of IVFA differentially effected proficiency with performance among females optimized by a right hemisphere advantage at the beginning of the process and performance among males optimized by utilization of an initial left hemisphere advantage. It has been suggested that variations in cognitive style between the sexes as well as differential effects of task difficulty based on similarity of test faces may have precipitated these differences in the way females and males approached this task.

Right-handers and left-handers tended to show opposing VFA's throughout the familiarization process, although changes in VFA for right-handers were not significant. The magnitude of the hemispheric advantages displayed by right-handers and left-handers had a differential effect on proficiency as familiarization with the faces progressed.

The lateralization data collected in this study, consistent with existing data, showed right-handers to be significantly more lateralized on both verbal and visuospatial measures than left-handers. The explanation for differences between handedness groups in their respective approaches to the face recognition task is related to these fundamental differences in functional asymmetry. Differences in VFA's between right-handers and left-handers, particularly in Blocks 1 and 4, are related to over half of the left-handed subject group demonstrating reversed lateralization for language. It is hypothesized that if a right-left-right sequence of hemispheric advantages is equated to global-analytic-integrative types of analyses, then a reversal of functional specialization would lead to the left-right-left sequence of hemispheric advantages shown by left-handers in this research.

The significant relationship among left-handers between overall magnitude of VFA and proficiency was not true for right-handers. It is hypothesized that having a stronger

VFA, regardless of direction, would maximize proficiency in a population with a weaker degree of lateral asymmetry, while the timely involvement of both hemispheres with their particular processing specializations would be more likely to maximize proficiency in a population with a stronger degree of lateral asymmetry.

Support for this interpretation comes from the progressive increases in the relationship between error scores in the LVF and RVF. These correlation values begin very low and increase significantly for the right-handers but do not show such successive increases for the left-handers. Two related hypotheses are offered to account for these findings: 1) Among right-handers more so than among left-handers the requirements of this face familiarization design involved the dynamic and cumulative involvement of the specialized processing strategies of both hemispheres; or 2) Among left-handers more so than among right-handers either hemisphere was more likely to be efficient at more than one type of processing strategy.

Additional support for a degree of laterality explanation for these handedness effects comes from the relationship between magnitude of VFA and error scores. These correlations among left-handers showed a progressive increase from a low correlation indicating that a strong VFA was not advantageous when the faces were yet unfamiliar to a strong correlation at the end of the task when the faces had been sufficiently familiarized for either hemisphere to be proficient at processing them. Among right-handers, a strong VFA was advantageous in the initial stages of familiarization, as well as at the end of the task, since degree of lateral asymmetry would result in each hemisphere having a specialized contribution to the process even at the start.

Differences in the degree to which both hemispheres were dynamically involved in the process, as well as differences in the benefit to performance of a strong VFA as the task progressed, showed a combined effect of handedness with sex. The same significant progression of the correlations between LVF and RVF errors shown for right-handers was also shown for MR but was not significant for FR. The same significant progression of the correlation between magnitude of VFA and proficiency shown for left-handers was also shown for FL, but was not significant for ML.

The demonstration of a second right hemisphere advantage proposed to be integrative and advanced in that it incorporates the initial right hemisphere and subsequent left hemisphere analyses preceding it can also be related to degree and direction of lateral asymmetry. MR, who showed the strongest degree of verbal lateral asymmetry and had the lowest incidence of reversed laterality on the verbal task, had the highest incidence of right-left-right shifters. Conversely, ML were the least likely to demonstrate a right-left-right pattern and evidenced the highest percentage of reversed laterality for language and were weakly lateralized. It should be noted that sample sizes used to compare incidences of right-left-right shifting were insufficient to draw firm conclusions from the present data.

The issue of whether or not face recognition represents a specific ability which can be discriminated from other visuospatial processing systems remains unsettled. Perhaps substituting other classes of complex visuospatial stimuli within the same paradigm and examining similarities/differences in the nature of hemispheric shifts is one way to address this issue.

As the body of evidence in support of systematic shifts in hemispheric advantage during the course of familiarization with faces grows, there would seem to be two avenues of investigation to be explored, both of which have already begun. First, examining the types of stimulus classes which elicit right-left shifts, as well as those which might also elicit the full right-left-right pattern of asymmetry; and secondly, examining individual differences and the effects of subject variables on the nature of these shifts and their relationship to proficiency. Once such subject differences have been demonstrated, dissecting various aspects of the task design and the effects of each aspect on individual differences would follow.

Based on the results of the present investigation, the hypothesis that sex and handedness differences in shifting patterns and their relationship to proficiency are a direct reflection of differences in underlying degree and direction of cerebral lateralization of function requires systematic replication. In addition, to what extent differences in direction of hemispheric advantage also reflect differences in information processing strategies used, and confirmation that these strategies may be classified as global/analytic/integrative, is a logical next step to the present set of results.

The interpretation of the present results has focused on differences between subject groups in the nature of processing strategies used in order to become familiar with the four faces used as stimuli. It should be noted that it is also reasonable to interpret these results as reflecting differences between subject groups in developing a more generalized task familiarization strategy. That is, familiarization with a specific set of faces may represent a subset of a more general task familiarization processing strategy.

Indeed, there is evidence which tends to support a more generalized interpretation of the data. The Turkewitz & Ross (1983) study using the same face recognition paradigm but substituting a different set of stimulus faces for the second two Blocks of trials provides evidence that shifts in VFA's and in corresponding processing strategies were based on the development of a generalized strategy for face processing rather than on increasing familiarity with the specific faces used as stimuli.

Also, changes in hemispheric advantage as a consequence of familiarization have been found using another class of stimuli as well as a different sensory modality. Kittler, Turkewitz & Goldberg (in press) used Japanese Kanji characters in a familiarization paradigm and found female right-handers demonstrated a right-left shift in hemispheric advantages which was related to accuracy. Devenny (1987) used a dichotic voice recognition task and also demonstrated a right-left sequence of hemispheric advantages during familiarization.

With respect to the dynamic shift model, the Turkewitz & Ross (1983) results did not support the interpretation of a second right hemispheric advantage as representing the integration of specific facial features learned in earlier trials. These results along with the lack of a second right hemispheric advantage in the Devenny (1987) and

Kittler et al. (in press) studies might be considered as evidence for the development of a more general task familiarization strategy. If a general strategy for processing repeatedly presented stimuli in a laterality paradigm is postulated, such a strategy might not necessarily include an integration of featural elements of the stimuli, but is more likely to include some form of both global and feature-specific types of analyses, represented by the right-left shift in hemispheric advantages which has been consistently demonstrated.

Appendix

HANDEDNESS QUESTIONNAIRE

DATE: ________

TIME: ________

Please indicate your preferences in the use of hands in the following activities by putting + in the appropriate column.

Where the preference is so strong that you would never try to use other hand unless absolutely forced to, put ++.
If in any case you are really indifferent, put + in both columns.

With which hand do you:

	LEFT	RIGHT
1. Draw?	______	______
2. Write?	______	______
3. Throw a baseball to hit a target?	______	______
4. Use a toothbrush?	______	______
5. Use scissors?	______	______
6. Use a bottle opener?	______	______
7. Remove the top card of a deck of cards when dealing?	______	______
8. Use a hammer?	______	______
9. Use a screwdriver?	______	______
10. Use an eraser on paper?	______	______
11. Use a tennis racket?	______	______
12. Hold a match when striking it?	______	______
13. Stir a liquid?	______	______
14. On which shoulder do you rest a bat before swinging it?	______	______
15. Carry your books or bookbag?	______	______

Are any members of your immediate family (mother, father, sisters, brothers) left-handed? ______

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