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INDIVIDUAL DIFFERENCES IN THE PATTERNING AND DEGREE OF CEREBRAL LATERALIZATION OF COGNITIVE FUNCTIONING

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INDIVIDUAL DIFFERENCES IN THE PATTERNING AND DEGREE OF CEREBRAL LATERALIZATION OF COGNITIVE FUNCTIONING

by

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Abstract

INDIVIDUAL DIFFERENCES IN THE PATTERNING AND DEGREE OF CEREBRAL LATERALIZATION OF COGNITIVE FUNCTIONING

by

Jane M. Healey

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Previous research has indicated that the pattern of specialization for certain verbal and nonverbal functions is such that in general, verbal material is processed more efficiently in the left hemisphere of the brain while nonverbal material is handled more efficiently in the right hemisphere. Models that are consonant with these patterns of brain organization have been developed and tested, but often cannot account for the range of individual differences in cerebral lateralization patterns that have been observed in some groups of individuals. The elaboration of new models requires a more precise delineation of the effects of those subject variables which have been shown to influence the pattern of perceptual, and thus inferentially, hemispheric asymmetry; such as sex, handedness, and presence or absence of a left handed family history (FH- or FH+).

64 subjects were divided on the basis of these three subject variables. The paradigm employed involved the study of laterality patterns over an extended period of time in the context of a verbal, tachistoscopic reaction time task. Since it is known that perceptual and motor performance change with experience, the usual procedure of employing procedures insensitive to these changes were replaced by measures designed to take into account individual differences in the role of experience on perceptual and motor behaviors.

The task used to study visual field differences was the Posner task, a task in which the presence of a physical identity (PI) or nominal identity (NI) has to be detected. A go-no go reaction time procedure measured speed of detection, and each subject received 8 equivalent and consecutive blocks of 32 trials each.

It was hypothesized that some of the variation in the laterality patterns observed would be accounted for by the three subject variables and performance on a number of cognitive tasks; therefore both the tachistoscopic laterality task and a cognitive test battery were administered to each subject. Correlations between differential cognitive abilities and patterns of cerebral laterality were computed, along with the association of all the performance indices with the three subject variables. Findings were as follows:

1) There were general regularities in the data across subjects; e.g. RT decreased in both fields over blocks for each type of stimulus match; and overall subjects' detection of NI matches was significantly faster in the right visual field (RVF); no field differences for PI matches was found. Additionally, scores on spatial tasks were positively and highly correlated with the field difference score for NI matches. 2) As far as individual differences were concerned, sex and family history (FH) acted to significantly reduce visual field asymmetries, while handedness had no effect. 3) Sex also affected cognitive test scores;females did better on verbal tests

and males did better on spatial tests. 4) FH was also found to have marked effects on other aspects of performance; FH+ subjects were slower across all conditions, and FH+ subjects had an attenuated practice effect, i.e., they showed an earlier asymptote in RT compared to FH- subjects. 5) Sex by FH interactions were obtained on both laterality and cognitive measures; presence of FH lowered the field difference score much more for males, and it significantly decreased spatial proficiency in males while increasing spatial proficiency in females. Handedness modified these interactions such that male right handers without FH had the most marked RVF asymmetry while the female left handers with FH had a reversed (LVF) asymmetry; these two subgroups also scored highest in spatial ability with respect to their sex grouping.

Findings argue for a strong genetic component in the lateralization of cognitive abilities, possibly tempered by maturational and hormonal factors. Presence of FH is viewed as a "marker" for a more diffuse brain organization which might be more potent in right handed males. Male right handers without FH and female left handers with FH are seen as representing opposite ends of a continuum of lateralization; their position on this continuum tends to enhance spatial abilities in both groups. Suggestions for a more flexible model of brain organization that takes individual differences in brain-behavior relationships into account were offered and discussed.

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For well over 100 years it has been known that in right-handed adults, discrete lesions of the left hemisphere of the brain result in impairment of many aspects of the language process, so that lesions to the speech zones in the frontal lobe produce deficits in expressive language functions, while lesions in language zones in the temporal and parietal areas result in deficits in receptive language functions (Geschwind, 1967; Goodglass & Geschwind, 1976). Posterior lesions, extending from the posterior temporo-parietal area into the occipital lobe can specifically disrupt reading and writing (Russell & Espir, 1961; Hecaen & Angelgues, 1964). Similar lesions in the right hemisphere in right handers produce at most, minimal linguistic deficits.

Although the evidence favors the view that most if not all aspects of language functioning are lateralized solely to the left hemisphere, many investigators have speculated as to whether lateralization for language is an all or nothing phenomenon occurring exclusively on the left side of the brain, or whether it can be conceived as a graded characteristic, varying in scope and completeness from individual to individual, with some aspects on the right side as well as on the left. For example, Broca showed that disturbances in speech production resulted from damage to the left frontal lobe, but believed that both hemispheres could decode speech (Broca, 1865).

Hughlings-Jackson spoke of the "leading hemisphere", the left, which was seen as having a more specialized involvement in language and skilled volitional motor acts. He maintained that although the left hemiphere was responsible for the production of propositional speech, the right hemisphere was capable of producing appositional speech, such as expletives and other more "automatic" speech. Nevertheless, with the clear demonstration of left hemisphere predominance in speech functions, the concept of the "leading" hemisphere gave way to that of cerebral dominance, implying a more complete control of one hemisphere relative to the other. The right hemisphere was referred to as the "minor" hemisphere because of the conspicuous absence of evidence that it played other than a minimal role in higher cortical functioning. This view cannot be said to have stood the test of time.

As early as 1935, Weisenburg and McBride had reported that patients with right hemisphere lesions, unlike those with left lesions, performed poorly on tests involving the manipulation and appreciation of forms and spatial relationships. In addition, right hemisphere lesions were found to produce greater deficits than left lesions on tests of visual perception, as well as on tests of visual memory (Milner, 1958, 1962; Kimura, 1961). The emergence of the Bogen and Vogel series (Bogen & Vogel, 1962) of split brain patients added new dimensions to the study of

left and right hemisphere capacities. In general, they found that the right hemisphere was indeed superior on tasks requiring nonverbal skills, and even more interesting, could also comprehend language to a certain extent, though not use speech.

Some investigators (Selnes, 1976) have argued that the linguistic ability of the right hemisphere of split-brain patients does not represent normal right hemisphere functions, but instead reflects reorganization as a result of the patients' past history of cortical dysfunctioning (i.e, epilepsy). It is well known that the right hemisphere can take over some and sometimes all language functions in the event of damage to the left, especially when this damage occurs early in development. There is now a good deal of evidence to suggest that the predisposition for the right hemisphere to develop language functions may vary from patient to patient (Luria, 1970) and it has been shown that this potential can be demonstrated in normal individuals without evidence of brain pathology (Satz et al., 1969). These individual differences in amount of potential right hemisphere participation in linguistic functions have been related to hand preference.

Individual Variations: Handedness

Almost as early as the idea of left hemisphere speech representation won acceptance, individual variations were noted. At the same time that Broca was proposing that the left hemisphere is dominant for language in right-handed people, he was also proposing the converse doctrine, which stated that the right hemisphere is dominant for language in left-handers. Cases of crossed aphasia (crossed aphasia at the time referred to left handers with a left-sided lesion and aphasia) reported during and after the studies of Broca, were in contradiction to his doctrine. Nevertheless, these cases were considered to be exceptions to the basic rule until 1936, when Chesher proposed that these cases were not simple exceptions, but rather that cerebral representation for language was basically different for left handers and right handers.

This early work was followed by several large-scale studies of language function in left handers with unilateral cerebral lesions (for example, Humphrey & Zangwill, 1952; Goodglass & Quadfasel, 1954; Penfield & Roberts, 1959; Russell & Espir, 1961; Hecaen & Ajuriaguerra, 1963), all demonstrating that cortical organization is indeed different in left handers. The conclusions of Goodglass and Quadfasel (1954) effectively summarized these reports. They stated that it was not correct to establish a direct and necessary correlation between handedness and cerebral

lateralization for language; for although the likelihood of language being controlled by the right hemisphere is increased in left handers as compared to right handers, right cerebral dominance for language is much less frequent than left handedness. A survey of most studies reveals that about 30% of left handed aphasics have only right hemisphere lesions, implying that at least some language functions are subserved by the right hemisphere in almost one-third of left handers.

Reversals of dominance, however, were more rarely met than variations in degree of cerebral asymmetry, and the suspicion that individuals may vary in their degree of hemispheric asymmetry has been repeatedly expressed in the literature (Zangwill, 1960; Hecaen & Ajuriaguerra, 1964). From observations of a large number of aphasic patients, Luria (1970) concluded that individual differences in degree of aphasic disturbance". . . cannot be entirely explained by the severity of the lesion . . . the degree of dominance of one hemisphere in relation to lateralized processes such as speech varies considerably from case to case (p. 89)."

The suspicion of individual differences in degree of asymmetry first arises in discussion of aphasia among left-handed individuals in whom the severity and duration of language disturbances tend to be reduced. For such cases, greater hemispheric equipotentiality has been hypothesized (Subirana, 1952), and the intracarotid sodium amytal test

has provided some support to this notion. With this test, Milner et al. (1966) studied cerebral dominance for language in a large group of right and left-handed epileptics. They found that more left handers than right handers manifested bilateral language (15% as compared to 1%). Converging evidence therefore supports the notion that lateralization of language may be less complete in a certain proportion of left handers; again, this evidence coming mainly from clinical studies of aphasics, where it has been observed that left handers more frequently than right handers become aphasic following a lesion to either hemisphere (Goodglass & Quadfasel, 1954; Hecaen & Sauget, 1971); aphasic symptoms are often less severe in left handers (Luria, 1970; Hecaen & Sauget, 1971); complete recovery is more frequent in left-handed aphasics (Luria, 1970); and, finally, that more left handers than right handers manifest bilateral language with injection of sodium amytal (Milner et al., 1966).

This notion of less complete lateralization in left handers is well demonstrated in the study by Hecaen and Sauget (1971) of left handers with verified unilateral cerebral lesions. They concluded that the left hemisphere syndrome in left-handed subjects consists of aphasic disturbance similar to those found in right handers with the exception that there is a lowered frequency of defects of verbal comprehension and writing and a higher frequency of disturbance of reading. However, some of the symptoms that

are seen with right-sided lesions in right handers are also observed (i.e., unilateral spatial agnosia). The right hemisphere syndrome in left handed subjects is characterized by a comparatively higher frequency (compared to right handers) of deficits in oral and written language, and especially alexia and spatial dyslexia. Disturbances of calculation, praxis and visual gnosis are similar to those seen in right handers with right hemisphere lesions. The comparison between the right- and left-hemisphere syndromes in left handers shows fewer differences than the same comparison in right handers; these differences are mainly in the realm of reading disturbances. It should be noted, however, that speech (expressive) defects are rarely seen with right-sided lesions in left handers (Hecaen & Sauget, 1971).

Individual Variations: Family History of Left Handers

Thus, comparisons show that unilateral cerebral lesions in left handers entail a lower frequency of symptoms specific for each hemisphere and some intermingling of left- and right-sided disorders. However, Hecaen and Sauget (1971) also showed that left handers do not represent a homogeneous group, but seem to differ depending on whether there exists other left-handed family members. The role of a family history of left handedness and the relationship of this history to cerebral organization for language was

first invoked by Kennedy (1916), who pointed out that right handers who developed aphasia after a right cerebral lesion were likely to be members of a left-handed family. In the Hecaen and Sauget study, right hemispheric lesions caused language disturbances such as oral language and reading only in familial left handers, those left handers who had at least one left hander in their immediate family. In this group, language disorders did not differ in intensity according to the hemisphere involved. This fact fits very well with the hypothesis that cerebral "bilaterality" is present only in familial left handers. However, the relative equality of deficits in oral verbal tasks and in reading found in the two groups of left handers with left-sided lesions does not conform perfectly to the hypothesis that cerebral bilaterality occurs in the familial group only. If this were the case, one would expect these deficits to be greater in the nonfamilial group, presumably because this group does not have the advantage of "bilateralization,' yet they are not.

In general then, the indications are that left handers do not seem to constitute a homogeneous group with regard to the lateralization of language functions; but that they do share some common characteristics that distinguish them from right handers as a group, mainly that they are less strongly and less rigidly lateralized. That they also seem to possess a neural plasticity not found in typical right-

handed adults was demonstrated in a study by Luria (1970) which looked at relative severity and recovery rates for left and right handers who suffered aphasia following damage to primary speech areas of the left hemisphere. Of 60 purely right-handed patients with no left-handed relatives, 51 initially became severly aphasic and none escaped aphasia entirely. In the residual period, 48 remained severly aphasic and only two showed no remaining symptoms. Of 23 left-handed and ambidextrous patients, 15 became severely aphasic in the initial period, four were slightly aphasic, and four showed no aphasic symptoms. In the residual period, only two remained severly aphasic, while 11 of the 19 patients who had initially become aphasic after a left hemisphere lesion showed no remaining aphasic symptoms. This suggests that even left handers with presumed left hemisphere dominance for speech differ in their functional brain organization from the majority of right handers, since they have a higher capacity to recover language functions in the event of brain injury.

One exception to this general difference between right and left handed patients was the subgroup of right-handed patients who had at least one immediate relative who was a left hander. These patients showed symptom severity and symptom recovery rates that were similar to the left handers. This neural plasticity, therefore, appears to extend beyond the left-handed condition itself, and suggests

a genetically based brain organization that is frequently associated with left handedness but is functionally independent of it, and that is characterized by some degree of equipotentiality between the two hemispheres of the brain.

A similar issue was discussed by Heilman (1979) in relation to apraxia. He notes that some right-handed patients with large lesions of the left hemisphere never manifest symptoms of apraxia, while others with small lesions become severely apraxic. Heilman postulates that different patients may have different recovery mechanisms, and in some people the right hemisphere may contain the engrams for motor skills. In this regard, it is interesting to note that apraxia is rare in left-handed patients and usually results from bilateral disease (Hecaen & Sauget, 1971). Heilman et al. (1973), in their studies of patients with apraxia, reached a similar conclusion to the one reached by Luria (1970) and Hecaen and Sauget (1971), that individual differences in recovery and symptomatology seem to be related to family history of left handedness. In other words, it is in those left and right handers with close left-handed relatives who demonstrate greater hemispheric equipotentiality.

Individual Variations: Sex Differences

Another variable that more recently has received empirical and theoretical attention is the possibility that sex differences affect cerebral organization. Many studies have shown that females tend to score lower than males on a variety of visual-spatial tasks (Wechsler, 1958). These findings have stimulated the construction of genetic theories of certain sex-linked traits (Stafford, 1961). Other investigators have reported morphological differences in cerebral asymmetry between males and females (Wada et al., 1975; Witelson and Pallie, 1973), with females often showing greater differences between the two sides of the brain.

The notion of sex differences in hemispheric specialization is also supported by clinical studies on the effects of cerebral lesions. Lansdell (1962) first reported that the nature of the cognitive deficit seen after temporal lobectomy depended not only on the side of excision but also on the sex of the patient. McGlone and Kertez (1973) administered the Block Design subtest of the WAIS to males and females with right hemisphere damage. Although visual spatial deficits were seen in general, the impairment was significantly greater in males. More recently, McGlone (1976) found that in men, left hemisphere damage impaired the WAIS verbal I.Q. much more than the Performance I.Q., while the opposite was true after right hemisphere damage. In women, however, Verbal and Performance I.Q.'s were not

different whether the lesion was on the left or on the right. McGlone suggested that the adult male brain is more asymmetrically organized compared to females; and that the latter may exhibit more equipotentiality between the two sides of the brain.

In summary, although there is ample evidence to support the notion that language processes are lateralized to the left cerebral hemisphere, both the pattern and the degree of cerebral lateralization for language can be affected by variables such as handedness, family history of left handedness and sex. Most of the evidence that bears upon patterns of cerebral specialization has come mainly from clinical studies of the aphasic sequaelae of unilateral cerebral lesions (Goodglass and Quadfasel, 1954; Zangwill, 1960), or from the disruption of language functions by electrical (Penfield & Roberts, 1959) or chemical (Branch et al., 1964) interference with cortical processes, or, finally, from the effects of cerebral commissurotomy (Sperry, 1968). The results of the split-brain studies particularly have stimulated a flood of investigations into the nature and function of cerebral lateralization. While the value of the clinical and commisurotomy studies can scarcely be overestimated, it is quite possible that generalizations made from patients who have suffered cerebral pathology may not be completely applicable to the normal population. This is because the extent of long-time

abnormalities and compensatory mechanisms is often unknown (Geschwind, 1970), and speech dominance has been defined in terms of interruption of the language process; the intact system may operate in a slightly different manner. In this context, the studies of visual-field differences in normal subjects stimulated by the studies of Sperry et al. (1979) in split-brain patients and the dichotic listening studies stemming from Kimura's applications of Broadbent's techniques (Broadbent, 1954; Kimura, 1963) are of particular interest because they provide data about cerebral specialization and lateralization in normal people.

Perceptual Asymmetries:

The main idea behind visual half-field and dichotic listening experiments was that stimulation arising from the right visual field or from the right ear arrived at the contralateral, or left, cerebral hemisphere for initial processing (and vice versa for left visual field or left ear stimulation). That is because the visual field-cerebral hemisphere connection and the ear-cerebral hemisphere connection is predominantly a crossed one, which gives the contralateral hemisphere a time advantage in receiving the stimulus. If that cerebral hemisphere that first receives the stimulus happens to be more efficient (because of its cognitive specialization) at processing the particular stimulus, then recognition or reaction to that stimulus should be

better or faster than when that stimulus arrives at the other hemisphere first. It is one more inferential step to the assumption that a reaction time or recognition advantage for a particular visual field (or ear) is related to the cognitive specialization of the contralateral cerebral hemisphere, and thus related to functional cerebral lateralization. This assumption forms the basis of the "direct access" model of Kimura (1961) who first popularized it. This model states that perceptual or visual field asymmetries are related to functional cerebral specialization or lateralization in a direct way.

The possibility of studying language specialization in normal subjects with the technique of lateralized tachistoscopic presentation has been pursued by many investigators (Bryden, 1965; McKeever, 1971; MacKavey, Curcio, & Rosen, 1975, and others). Differences in efficiency of visual field recognition in either the right visual field (RVF) or the left visual field (LVF) have been measured, often in relation to handedness (Bryden, 1973), eyedness (Gur & Gur, 1977), reading ability (Bryden, 1970; McKeever & Huling, 1971) presence or absence of familial sinistrality (Hines & Satz, 1971; McKeever et al., 1973), and a host of other variables. Although there is now ample evidence that a right visual field superiority for language related stimuli (and, by inference, a left hemisphere superiority) whether accuracy of report or reaction time is being

measured, is obtained in a majority of normal subjects, the inference that this reflects left cerebral language laterality has not been without its critics (White, 1969, 1973). Other variables, such as left to right reading habits (White, 1969), attentional bias resulting from selective activation of the language dominant left hemisphere (Kinsbourne, 1970), strategy and experience (Hellige, 1976; Hellige, 1980) and other task and performance variables have been invoked as contributing to left or right superiorities in visual half field experiments. A discussion of some of those variables that may affect the direction and/or magnitude of visual field asymmetries will be provided in later sections and can also be found in White (1973) and Hellige (1980). To date, the possible contribution of practice, stimulus qualities, task complexity, selective attentional shifts, and cognitive strategies and abilities to the outcome of tachistoscopic laterality tasks has not been systematically investigated. Nonetheless, considerable evidence for the "direct access" model of Kimura (1961), has accumulated, and most tachistoscopic laterality experiments are done within this general framework.

Tachistoscopic Procedures:

The most commonly used measures of performance in tachistoscopic research are accuracy of verbal report and manual reaction time. A verbal report necessitates the use

of the language hemisphere, which is usually the left. Stimuli presented in the left visual field must cross the corpus callosum in order to be verbally reported. White (1972) points out that it may be far better to employ a response measure that is not dependent on mechanisms lateralized solely to one hemisphere. A good candidate is manual reaction time. Although the cortical control of finger movement is predominantly crossed (contralateral), studies with split-brain subjects (Gazziniga, 1970) have demonstrated that the difference in reaction time between the two hand extremities is only two to three msec. Such slight differences should not affect hemispheric differences in stimulus processing. Another good reason for employing reaction time is that both speed of response and accuracy of response can be measured.

Practice Effects:

That performance on laterality tasks, whether it be absolute performance or relative asymmetries in performance, can and do change as a function of practice, experience or ability has been demonstrated. Several investigators have attempted to look at laterality changes as a result of practice (Hardyck et al., 1978; Hellige, 1976; Perl & Haggard, 1975; Ward & Ross, 1977; Holtzman, 1979). Hellige (1976), using the Posner task paradigm, found an initial LVF advantage for letter matching over the first two blocks

of trials, which was reversed by the third block. By the sixth block, no advantage was noted in either field. The direction and extent of visual field asymmetry thus changed over the course of the experiment, as the subjects gained more experience with the task. Perl and Haggard (1975), Hardyck et al. (1978), and Holtzman (1979) found that a significant RVF advantage for verbal stimuli was obtained only after some practice with the task. However, Ward and Ross (1977) observed a decline in the RVF advantage over time. All of the researchers also observed an improvement in performance over time.

Ward and Ross (1977) offered two possible interpretations for the practice effects observed, the first, that the subjects showed a nonspecific adaptation to the experimental situation and the second, that subjects developed specific strategies for processing the presented information more efficiently. With regards to the latter interpretation, it is interesting to note that Perl and Haggard (1975) found a small correlation between improvement in performance and the magnitude of the right ear advantage. In other words, more asymmetry towards the right side was somewhat associated with better accuracy over time. Both Hellige (1976) and Holtzman (1979) stressed the role of the right hemisphere in the initial stages of letter processing, which may be more visual-spatial in nature. Holtzman (1979) also implicated the right hemisphere in the orientation and

adaptation to the experimental situation. Whatever the case may be, it seems important to look at observed differences in performance over time in order to better elucidate the functional relationship between lateralization and cognitive functioning.

Reading and Visual Asymmetries:

Attempts to establish the relationship between lateralization and cognition have focused mainly on aspects of language. One major focus of these attempts has been on relations between lateral dominance and reading ability or disability. A half century ago, Orton (1937) suggested that there was a relationship between reading ability and lateral dominance. Attempts to establish the nature of the relationship between reading difficulties and dominance were hampered by major difficulties in assessing dominance. Handedness and consistency of hand and eye preference were the measures used to assess dominance, but research in the past 15 years has generally failed to show a consistent relationship between left handedness or deviant hand-eye preference and specific reading disability (Belmont & Birch, 1965; Sparrow & Satz, 1970; Zurif & Carson, 1970; Hardyck et al., 1976). With the advent of special laterality

assessment procedures in audition (dichotic listening) and vision (visual half-field perception), a more direct test of this hypothesis could be made. Results, however, have been contradictory. Using dichotic listening procedures, investigators have found a larger right ear/left hemisphere advantage among normal readers than among less able readers (Satz et al., 1971; Zurif & Carson, 1970; Witelson & Rabinovitch, 1972). Tachistoscopic studies have not consistently shown any relationship between reading ability and visual field advantage. Marcel and his colleagues (Marcel, Katz, and Smith, 1974;) reported a significant left hemisphere advantage for both good and poor readers. In their second experiment which used faces to assess right hemisphere specialization, they concluded that visual-spatial functions did not relate to reading proficiency. Witelson (1976) reached the opposite conclusion after examining lateralization for three modalities in normal and poor readers. Her normal male readers showed a right hemisphere advantage for processing figures of people, while her poor readers showed no advantage. Since her normal male readers were also more accurate in this task, she concluded that poor readers have poorly specialized spatial processing systems. Another study by Yeni-Komshain et al. (1975) found a similar right hemisphere deficiency for numbers presented tachistoscopically to poor readers. The implication here is that visual spatial

functioning may be more related to reading proficiency than what is normally assumed.

A discussion of some of the variables that have been found to be related to direction and/or magnitude of visual field asymmetries has been presented, but by far the three variables that have been of most interest to researchers in the past 15 years are handedness, family history of handedness and sex. Evidence that individual differences in tachistoscopic laterality effects and in cognition are related to these three variables has accumulated, and it is this evidence to which we will now turn.

Perceptual Asymmetries: Handedness and Family History of Handedness

In order to tease out the importance of handedness in the overall scheme of cerebral laterality, it is relevant to ask how important a factor is handedness in human performance. It is a variable about which individuals are highly aware. Provins (1956) showed that differences between the hands became apparent where "timing" or serial organization was important. Sersen (1976) found the preferred hand to be superior in terms of a variety of sensory and performance measures, as did Barnsley and Rabinovitch (1970). A variety of specific tasks and skills have been studied which show a superiority of the preferred hand in tasks requiring fine motor control. The importance of the

hand employed in a simple response in relation to the visual field of stimulation (stimulus-response compatibility) has been shown by Umilta et al. (1972), and recognition performances in the visual fields have been shown to differ between handedness groups (McKeever & Gill, 1972; McKeever et al, 1973; and others). More specifically, evidence from tachistoscopic tests of verbal recognition has suggested that as a group, left handers show a smaller degree of visual field asymmetry, and inferentially, lessened languaged lateralization (Zurif & Bryden, 1969; McKeever et al., 1973). However, some studies have found little to no difference between handedness groups (Hines & Satz, 1974). When family history of left handedness has been taken into account (presence or absence), interesting differences have emerged between those individuals with left-handed relatives and those without such relatives; these differences not always being consistent (Hines & Satz, 1971; Zurif & Bryden, 1969; McKeever et al., 1973; Briggs & Nebes, 1976). As noted previously, the evidence from clinical studies has been more consistent in suggesting that a positive family history of left handedness is often associated with less dependence upon the left hemisphere for language processing, and thus more equipotentiality between the two hemispheres (Hecaen & Sauget, 1971; Luria, 1970). Tachistoscopic studies have also indicated a higher proportion of left handers with

a greater degree of right hemisphere involvement in language processing compared to right handers, but only when a left-handed family history was present (Bryden, 1965; Hines & Satz, 1971, Zurif & Bryden, 1969). Zurif & Bryden (1969) interpreted their data as supporting the notion that left handers with left-handed relatives (familial left handers) show greater hemispheric equipotentiality as well as more variability with regard to side of dominance for language. The finding that even in right handers, the presence or absence of left-handed relatives affects laterality differences in a similar direction lends additional support to this notion (McKeever et al., 1973).

Some studies, however, have not found family history of left handedness to be a relevant factor (Briggs & Nebes, 1976; Bryden, 1973) while others have found the presence of a left handed family history to be indicative of more rather than less dependence upon the left hemisphere for language processing (Newcombe & Ratcliff, 1973). Although findings have been inconsistent when relating handedness and genetic history of handedness to laterality differences, some general comments can be made. First of all, the variability shown by left handers in general is striking; for while right handers usually display a clear-cut pattern of lateral specialization, left handers often do not, but usually show smaller interhemisphere differences. Secondly, atypical lateralization patterns (i.e.,

bilateralization of language functions or right hemisphere specialization for language functions) have not been found to be characteristic of all left handers but mainly for left handers with a left-handed family history (for review, see Hardyk, 1977). The differences that have been found between familial and non-familial left handers lend powerful support to genetic models of brain organization, such as that proposed by Annett (1972).

Variability in the assessment procedures used to ascertain handedness and presence or absence of a family history of left handedness may be one of the reasons for inconsistent findings in this area of research. Assessment of these variables may seem elementary but in fact is not, owing to the many different criteria for measuring handedness, and for ascertaining the presence of a genetic history of left handedness. It is a much simpler task to assess right handedness than it is to assess left handedness since right handers are more consistent in their hand preference. The choice of how to measure handedness has not been agreed upon, although most researchers now employ one of the many handedness questionnaires (Annett, 1970; Oldfield, 1971). Assessing the presence of a family history of left handedness is also difficult, should just the immediate family be included, or all relatives? Most researchers use just the immediate family, but the likelihood of left handers in the immediate family varies with the

number of siblings. A subject may have no left handers in his immediate family but may have a number of left-handed relatives outside the immediate family (e.g., grandparents, uncles, aunts, cousins). The risk here is that there indeed may be little difference between the family history positive subjects and the family history negative subjects if just the immediate family is used for designation purposes. McKeever & Van Deventer (1977) discuss the advantages of including all relatives in the family history designation, and requiring two of those relatives to be left handed.

Perceptual Asymmetries: Sex Differences

The failure to routinely assess possible sex differences in studies of laterality and individual differences may be another reason for the inconsistency of findings. A number of studies using tachistoscopic procedures have uncovered possible sex differences in hemispheric processing. McGlone and Davidson (1973) found that the majority of males showed a left visual field superiority on a dot enumeration task while an equal number of females demonstrated both left and right visual field preferences in response to the dot stimuli. This suggests that males are more consistently lateralized to the right hemisphere for visual spatial functions. In another study looking at sex differences, Hannay & Malone (1976a) studied visual field

effects and short-term memory for verbal material in males and females. Males exhibited a right visual field superiority, and inferentially, a left hemisphere advantage, while the females failed to exhibit a visual field superiority. This suggests that both hemispheres were involved in receiving and retaining verbal material in females. Hannay (1976) studied the relationship between WAIS Block Design performance and visual field superiority for random shapes in females. Hannay found that the females with low Block Design scores showed a right visual field preference while the subjects with high scores demonstrated a left visual field preference. However, some investigators have shown females to be more strongly lateralized for both verbal and nonverbal functions. For example, Buffery (1976) found that females exhibited more asymmetric responding toward the right visual field in a verbal matching task and toward the left visual field in a spatial same-different matching task when compared to males. Buffery also found that the more asymmetric responding on the verbal task was associated with better performance on that task, while more symmetrical responding on the spatial task led to better performance and was more characteristic of the men. Moore and Haynes (1980) measured EEG alpha asymmetries while subjects were engaged in a verbal and a nonverbal task and also assessed performance on WAIS Vocabulary and WAIS Block Design. Females showed more left hemisphere

involvement during the verbal task and more right hemisphere involvement for the nonverbal task as measured on the EEG. These findings indicate that females are more, rather than less lateralized for these functions. Further, no association was found between scores on the two cognitive tests and amount of alpha asymmetry. The authors concluded that the reason for the contrary findings may have to do with the nature of the tasks that are used, leading to the employment of differing strategies for their solution.

With regard to cognitive strategies (i.e., strategies one uses for problem-solving), the results of Davis and Wada (1978) are of some interest. They measured average evoked potentials to clicks and flashes in male and female left and right handers. All subjects in the study showed a basic left speech dominant pattern, but sex and handedness tended to modify response magnitudes, though not reverse the general organization that was observed. The results suggested that right handers and males tend to emphasize or respond more to the left hemispheric (nonverbal, spatial) characteristics of visual stimuli. Left handers and females tend to reverse this pattern. Handedness and sex were found to independently affect lateralization since no interaction occurred between them. Davis and Wada (1978) went on to suggest that the effect of unilateral hemispheric lesions might be modified but not reversed between subjects of differing handedness or sex. Right handers and males

would respond more asymmetrically than left handers and females and thus be more affected by unilateral lesions. In conclusion, both right and left handed males and females have a matrix of varying magnitudes of responses overlaid upon a basically left language dominant organization. Within this framework, the treatment of temporal or verbal information on the one hand, and of spatial, more visual information information on the other hand, may differ depending on the person's handedness or sex.

These findings are important in two respects: first, cognitive strategy or "style" (or the ways in which a person takes in and processes information) if you will, may be an important determinant of laterality findings, and second, that the strategy may differ between males and females and between left and right handers. This is not surprising, for there is some evidence to suggest that variations in performance on certain cognitive tasks may be related to sex and to handedness.

Cognitive Abilities: Handedness and Sex

Females have often shown superior verbal ability on word fluency and articulation measures compared to males, but usually demonstrate poorer spatial abilities when compared to males (Maccoby & Jacklin, 1974). Developmental studies indicate that girls show earlier and stronger lateralization of speech, motor and sensory functions

compared to boys (Buffrey & Gray, 1972), while boys seem to show earlier right hemisphere specialization for spatial processing (Witelson, 1976).

Handedness has been linked with a variety of disabilities. Research efforts over the past 40 years have attempted to link left handedness with speech defects (Bryngelson, 1939), mental retardation (Burt, 1958), reading disability (Orton, 1937), and other difficulties. However, as many studies have shown no relationship between handedness and cognitive abilities (Hardyck et al., 1976), it has been suggested that the raised incidence of left handedness in pathological populations can be explained by the phenomenon of "pathological left handedness," whereby some factor, either genetic or environmental, causes both the left handedness and the pathological state to co-occur (Satz, 1972). More recently, the hypothesis that left handedness is systematically related to certain types of deficit in cognitive performance has its principle support in recent studies comparing right and left handers on tasks requiring visual-spatial processing. The impetus for this notion seems to have been provided by Levy (1969) who showed that left-handed graduate students did less well on the Block Design subtest of the WAIS compared to right handers. Levy explained these findings by suggesting that since left handers seem to be more "bilateralized" for language functioning, the fact that the right hemisphere

as well as the left hemisphere is occupied by language functions limits the capacity of the right hemisphere to process spatial information. A similar result with left handers was reported by Miller (1971). Further support was provided by Nebes (1971) who examined left and right handers performance on a measure of part-whole relations.

Attempts to replicate Levy's findings have not been successful. Newcombe and Ratcliff (1973) found no relation between WAIS performance scores and handedness in adults, and Hardyck and his associates found no difference attributable to handedness when comparing Performance IQ and scholastic aptitude scores in school children (Hardyck et al., 1976). Also attempts to replicate Nebes study have not been successful (Kutas et al., 1975; Hardyck, 1977). It appears that the data indicating that left handedness is associated with cognitive deficit is speculative and interesting, but far from compelling.

However, it is ironic that both females and left handers have been hypothesized to have poorer spatial abilities, for both groups have also shown evidence of more "bilateralization" of cognitive functions as evidenced by smaller absolute field differences on tachistoscopic tasks. This does raise the question of whether certain patterns of brain lateralization may be correlated with certain patterns of cognitive abilities. More specifically, the question arises as to what type or pattern of cerebral

organization is most optimal for performance on certain cognitive tasks, and whether indeed a more asymmetrically organized brain is the most optimal for performance in humans. This question has arisen in the psychological literature many times (Orton, 1937; Kinsbourne, 1975; Kinsbourne and Hiscock, 1978). This notion probably stems from Orton's (1937) theory that dyslexia or inability to read, was due to incomplete cerebral dominance. Although numerous investigations of "mixed" or inconsistent hand and eye preference, and other indirect measures of laterality have failed to conclusively test this hypothesis; there still appears to be an underlying assumption to much of the research on laterality that evidence of left or right hemisphere "superiority" is evidence of functional maturity. As Kinsbourne (1975) has noted, "two assumptions . . . were that the rate of lateralization in some way represented the rate of language development, and the ultimate extent of lateralization its ultimate level of excellence." This view, that of a correspondence between lateralization and development of higher symbolic functions (language), has also been expressed in Lenneberg (1967) and in Brown (1977), but may be an unwarranted assumption.

Developmental studies of motor asymmetries however, have suggested that younger normal, and older brain-damaged, right-handed children show skills excessively asymmetrical to the right (Touwen and Prechtl, 1970;

Reitan, 1972; Denckla, 1974), in other words, they are "hyper-lateralized." Right-handed children with developmental learning disabilities frequently show excessively show, clumsy left-sided coordination (Denckla, 1974). These studies suggest that normal motor development proceeds toward lesser asymmetry between the two sides over time. Of course, there is no necessary reason to conclude on the basis of the foregoing results that development of other functions (i.e., language) also proceed in this fashion; but since motor asymmetries have traditionally been linked to language asymmetries (Hughlings - Jackson, 1874; Zangwill, 1960; Gazzinga, 1970 to name a few), there is some reason to assume that progressive development of language does not necessarily follow from increasing cerebral lateralization (see Kinsbourne, 1975).

However, the possibility that spatial ability may be related to increasing cerebral lateralization has not been as well investigated, although it has been found that right hemisphere participation in certain aspects of spatial-configurational abilities is not well established until an older age, especially in females (Carey & Diamond, 1979; Broman, 1978; Rudel, Denckla & Hirsch, 1977; Rudel, Denckla & Spalten, 1974). Perhaps the establishment of a clear right hemisphere superiority for spatial-configurational tasks is an important factor for

performance on such tasks. In this regard, the findings that females and left handers may have poorer spatial abilities becomes more interesting, for both groups have also shown evidence of "bilateralization" of cognitive functions. Perhaps "bilateralization" is fine for language abilities but less optimal for spatial abilities.

This concludes a summary of the data base from which numerous theories of brain laterality have evolved. A discussion of some theories and models relevant to an understanding of brain laterality and the role that individual differences play in its organization follows.

II

Theories and Models of Human Laterality

Those individuals who have endeavored to generate a model of human laterality invariably seek to determine the relationship between the two most common indices of human laterality: cerebral laterality and manual laterality (handedness). This seems like a natural place to start, since both indices of lateralization are unique to the human species and on the basis of evolutionary and developmental evidence, can be viewed as two aspects of an overall adaptive scheme with a variety of possible functions. Models of this relationship have generally been founded, at least in part, on the differential specializations of the two cerebral hemispheres. Methods recently developed for the independent study of the two cerebral hemispheres in the normal intact human brain, such as dichotic listening and tachistoscopic hemifield presentation, having provided an opportunity for the study and elaboration of such models. Since the literature on handedness is of considerable proportions, any attempt to generate a broadly based model of individual differences in hemispheric lateralization related to differences in manual

preference will meet with a variety of problems; including the extent of the work, the great variety of assessment procedures that are used, and the many criteria used to define "left", "right", and "mixed" handedness.

It seems clear from the large scale studies which have been undertaken (Bakwin, 1950; Karpinos and Grossman, 1953) that in Western society between 5 and 12% of the population are, or consider themselves to be, significantly left handed. There have been many attempts to provide an explanatory basis for handedness which have called upon a wide variety of factors, both genetic and environmental in nature.

Handedness has been studied in relation to other body asymmetries, such as ocular dominance and vascular blood supply. Recent research, however, has failed to confirm any consistent relationship between eye dominance and handedness (McKinney, 1967; Gur and Gur, 1977). Differences in the vascular supply of the two hemispheres was a popular theory which fell into disrepute, to be revived by Carmon and Gombos (1970), who showed differences in pressure in the right and left opthalmic arteries related to handedness. Perinatal factors seem to be somewhat related to handedness. The speculation that fetal position is related to later handedness has received some empirical support from the recent work of Grapin and Perpère (1968). It is interesting to note in this regard that both identical

and fraternal twins are often discordant for handedness (Collins, 1968, 1969), and this may be related to fetal position.

Heredity seems to play an important role in handedness, although the exact mode of inheritance is still uncertain. There is some correlation between the handedness of children and that of their parents such that children are more likely to be right handed if both parents are right handed, and least likely to be right handed if both parents are left handed (Rife, 1940). Two very popular genetic theories are those of Annett (1967) and of Levy and Nagylaki (1972). Since both of these researchers have linked their models to asymmetries in cerebral organization, their theories will be discussed in a later section.

Neurological Models:

Little detailed study was made of the functional differences between the two grossly similar hemispheres of man until the middle of the last century. It is in relating aspects of handedness to such features of cerebral organization that the study of handedness has been most useful. We have seen that information regarding cerebral organization can be obtained from many sources; such as pathology of the cerebrum, experimental and clincal studies of the split-brain, and laboratory investigations of the normal human subject. While the evidence from all these

approaches has led to some fairly coherent picture of brain organization, there have been some major discrepancies revolving around questions as to whether cerebral lateralization for language is an all or nothing phenomenon occurring exclusively on the left side of the brain, whether handedness is the cause or effect of cerebral lateralization, and whether cerebral or manual laterality is inherited or environmentally determined.

Hughlings-Jackson (1874) discussed the relation of the "leading" hemisphere and handedness. Jackson did not support the complete lateralization of speech to the left hemisphere as had been proposed by Broca (1865) but thought that it must be located at different levels in the functional hierarchy of the CNS. He felt that the higher levels mediated cognitive functions in a more finely tuned and differentiated way, while lower levels were more involved in "automatic" or "involuntary" behaviors. Jackson saw this as a general rule governing all aspects of development, including development of fine motor control and of speech. One implication of Jackson's work is that cerebral dominance is a relative concept; the degree of dominance being dependent on the particular function or behavior under examination, and the level of organization to which the behavior pertains or is relevant.

Brain (1945) provided an introduction to what might be regarded as the central line of thought on cerebral

dominance and handedness, that the appearance of a motor speech center in the left hemisphere in man made that the dominant hemisphere and the right hand the dominant hand. Zangwill (1960) thought the hemispheres to be equipotential at birth, hence the plasticity of speech functions with early brain insult, but that cerebral dominance seemed to evolve with the development of speech. He considered that cerebral specialization varied widely between both individuals and functions, and that indeterminant cerebral dominance was associated with temperamental instability and undue sensitivity to stress. Cerebral dominance, together with handedness, was seen as a graded characteristic according to Zangwill. Hecaen (1968) adopted a similar view to Zangwill, suggesting that different arrangements of cerebral control might exist for different functions, thereby challenging the extent or importance of any overall "dominance" in cerebral organization. Russell et al. (1970) however, assumed that the dominant hemisphere must be the one associated with the dominant hand, and that this hemisphere also contained speech. They concluded that motor dominance is a complicated matter and not always unilaterally localized, but that dominance for speech was almost without exception within the left hemisphere.

Gazziniga (1970) has developed a line of thought similar to Zangwill in that he believed the child to be born with an equipotential brain, which is even a

"split-brain". As the child manipulates more with the right hand, then the left hemisphere develops a lead, which in turn reinforces hand use, until the dominant relationship is established.

Gazziniga implies that left hemisphere dominance is secondary to the use of the right hand for fine motor activities. He fails to explicate how this initial right hand preference develops; whether it is environmentally or genetically determined. If it is genetically determined, then how does one really know which came first, the right hand preference or the left hemisphere dominance? If environmentally determined, it fails to account for the observed relationship between handedness and speech, that is, that most right handers and a majority of left handers posess left hemisphere dominance for language. Additional evidence for and against genetic versus environmental explanations for handedness will be presented.

An alternative view of brain organization, one that is not linked to hand use, has been proposed by Semmes (1968). Semmes suggests that studies of sensory and motor capacities of brain injured patients leads one to conclude that these capacities are represented differently in the two hemispheres, tending to be more focally represented in the left hemisphere and more diffusely represented in the right hemisphere. According to Semmes, such a structure would favor the integration of similar units within the left

hemisphere, the kind of integration needed for fine sensorimotor control in dexterity and in speech. The right hemisphere would be better at multimodal operations. These two contrasting modes of neural organization, according to Semmes, appear to be linked to the hemisphere rather than to the particular hand or function involved. Although an attractive model, it suffers from the same drawbacks as do other "static" models of brain organization in that it fails to take into account possible differences in arrangement that can occur in different individuals, and what the implications are for these different arrangements. Semmes points out this difficulty in a footnote (Semmes, 1968), but goes on to state that the individual differences observed in some people are simply exceptions to the general rule.

More recent approaches to the study of the relation of handedness to cerebral laterality have attempted to accommodate unusual patterns of cerebral laterality sometimes seen in the left handed. One unusual pattern is an ipsilateral rather than contralateral relationship between the "dominant" hemisphere for language functions and the preferred hand, in other words, the usual contralateral relationship between dominant hemisphere and preferred hand breaks down for many left handers. A more difficult pattern to incorporate into models of hemispheric processing, also observed in left handers, is the "bilateralization"

of language functions, that is, that many left handers seem less completely lateralized for language functions, and often evidence language processing on both sides of the brain. The evidence for this notion has already been presented and can be summarized here. Use of the sodium amytal technique has shown that more sinistrals than dextrals manifest bilateral language (Branch et al., 1964), left handers more frequently than right handers become aphasic following a lesion to either hemisphere (Goodglass & Quadfasel, 1954), but their symptoms are often less severe (Hecaen & Sauget, 1971), and recovery from aphasia is more frequent and occurs more rapidly in left handers (Luria, 1970). Finally, in lateralization tests with normal subjects, field and ear differences tend to be smaller for left handers (Staz et al., 1965; Zurif & Bryden, 1969). Converging evidence therefore supports the notion that lateralization of language is less complete in a certain proportion of left handers, a phenomenon that should be accounted for in any model purporting to explain hemispheric laterality patterns in the normal human.

Dimond (1971, 1972) has criticized traditional concepts of cerebral dominance, and asks why it must be assumed that dominance for any function resides in only one hemisphere. He has also emphasized that the hemispheres are not isolated units, that the control of a hand is not exlusively from the contralateral hemisphere, that contralateral motor

control need not imply contralateral cerebral control, and that the right hemisphere must be involved in most higher cortical functions. His model of brain organization is that the brain works as a unit, with specialized abilities located within hemispheres, but with the capability of sharing functions. Dimond suggests that right handers possess more focal representation of functions, while left handers possess a more diffuse cerebral organization. He speculates that the diffuse system of the left hander carries an advantage for complex, integrative tasks, but a disadvantage for rapid simple communications; and presents some data to support his notion. Dimond's criticism of traditional concepts of cerebral dominance merits consideration, and his model is interesting but speculative, since he presents only a small amount of evidence in its support.

Genetic Models:

Levy (Levy & Nagylaki, 1972) has proposed a genetic model of cerebral and manual asymmetry involving two genes; one gene determines which hemisphere will be the dominant one for language, while the second gene determines whether hand control will be contralateral or ipsilateral to the dominant hemisphere for language. This model thus can incorporate the ipsilateral arrangement of dominance and handedness seen in many left handers but has difficulty accounting for "bilateralization" of language. Levy

accounts for bilaterality by postulating that the presence of the recessive gene serves to weaken the full expression of the dominant gene, resulting in incomplete lateralization of language functions. If the right hemisphere is invaded by language, then according to Levy, this limits the capacity of the right hemisphere to process visual spatial information. This should result in a relative deficit at perceptual tasks for left handers. Both Levy's genetic theory, and Levy's hypothesis of perceptual deficits in left handers, have been found lacking in strong empirical support (Hudson, 1975; Hardyck, 1977; Hardyck et al., 1976).

Annett (1967) has postulated a single gene controlling both cerebral dominance and handedness, and has related her model to performance on various psychomotor tasks. A major aspect of her theory is that the heterozygote can shift both dominance and handedness under certain conditions (as in cases of brain damage). Her model has found recent support from Satz et al. (1969), who have argued that partial penetrance of the recessive gene in the heterozygote may manifest itself even in the absence of brain insult. In other words, the heterozygote may be unstable in terms of both cerebral dominance and handedness, and may manifest partial bilateralization and ambidexterity under normal circumstances. In a more recent discussion of her model, Annett (1972) concludes that what is inherited is really a "right-shift" factor, which inclines most people to be

right handed and left brained. This genetic tendency is accentuated by cultural influences. Some individuals however, lack this "right-shift" factor, and therefore handedness and cerebral lateralization are determined at random. These individuals can be right handed, left handed, or ambidextrous, and exhibit a range of lateralization patterns. In the absence of the "right-shift" factor, the main factor at work is random variation. This implies that right handedness is inherited but left handedness is not. Left handedness then, according to Annett, is due to a recessive condition, that is, the absence of a "right-shift" factor, which combines with environmental influence to produce ambilateral tendencies in both dominance and handedness. Annett recognized still another source of left handedness, that is, early brain-insult can reverse the handedness of those otherwise predisposed to be right handed. Annett thus identified at least two groups of left handers, those in whom left handedness comes about as an interaction of genetic or familial influences and environmental influences, and another group in which the left handedness is purely environmental. We might expect then, that in the former group, there will be other left handers or ambidexters in the family, while in the second group, there is no need to postulate familial inheritance.

Annett's theory helps to explain the somewhat "atypical" laterality patterns often seen in left handers, especially

those left handers with a family history of left handedness (familial left handers). There is now a lot of evidence to suggest that left handers are a very heterogeneous group. Several studies have suggested (Bryden, 1973; Hecaen and Sauget, 1971; Hines and Staz, 1971; McKeever et al., 1973; Zurif and Bryden, 1969) that left handers with a positive family history of left handedness are different in many ways from the left handed with no such history. Left handers with no family history of left handedness tend, paradoxically, to be the most strongly left handed and more often show a pattern of cerebral lateralization that is characteristic of the right handed. The left handed with a positive family history of left handedness range from those with strong left hand preferences to those who are approximately equally skilled with either hand (Satz et al., 1967). These individuals have most frequently shown the "bilateralized" cerebral organization, and show aphasic symptoms equally often with both right and left hemisphere lesions (Hecaen and Sauget, 1971). In addition, as Luria (1970) has shown, individuals with this bilateral organization also recover function following brain damage much more quickly and show fewer lasting after-effects from lesions than do the more lateralized right-handed. It is interesting to note in this regard that right handers with a positive family history of left handedness also recover language functions following brain injury more quickly than

do right handers without such history (Luria, 1970). Studies using normal subjects have also shown differences between familial and nonfamilial left handers, but the pattern of the findings has not always been consistent. It is clear however, that presence or absence of a genetic history of left handedness is an important variable to be taken into account when comparing the lateralization patterns of left and right handers.

According to Annett's genetic theory then, we might expect the absence of consistent or strong cerebral lateralization patterns to be more characteristic of those left handers who lack the "right shift" factor, and it is these left handers who would be most likely to have other left handers in the family who also lack the shift factor. If the above findings on the differences between familial and nonfamilial left handers hold up with additional experimentation on normal subjects, it would lend powerful support to this parsimonious model.

Based on findings cited above, Hardyck (1976) has proposed a model of individual differences of brain organization that views cerebral lateralization as existing on a continuum, with a high degree of lateralization on one end and a high degree of bilaterality on the opposite end. An individual's position on this hypothesized continuum with regards to his brain organization depends in large part on hand preference and presence or absence of a family

history of left handedness. A right hander with no family history of left handedness was the best representative of one extreme of the continuum (high degree of lateralization), while a left hander with a family history of left handedness was represented on the other extreme of the continuum (high degree of bilateralization). Most individuals were seen as falling somewhere in between these two extremes. According to this model, a right hander with a negative family history of left handedness should do better at handling verbal material in the left hemisphere and spatial material in the right hemisphere. The bilaterally organized person achieves the same level of solution to problems that the lateralized person attains by employing both hemispheres to work on problems in a parallel manner and then combining the two efforts in order to reach a solution.

Hardyck cites as evidence for his model clincial and experimental findings showing that both hand preference and type of genetic history interact to produce different variations of lateralization. He notes that most models of brain organization do not allow for variations in the patterning and degree of cerebral lateralization, which seems necessary in view of the findings indicating a wide range of individual patterns of brain organization. He also notes that studies of split-brain, hemispherectomized, and aphasic patients suggest that the right hemisphere is capable of comprehending, and even producing language.

Hardyck suggests that the predisposition for the right hemisphere to develop language functions may be gentically determined and vary from individual to individual. In short, he makes a strong case for a flexible model of cerebral organization which can account for wide variations among individuals, and an even stronger case that these individual variations are gentically determined.

Environmental Factors:

Perhaps the principal proponent of a non-genetic explanation of laterality is Collins (1968, 1969) who has argued that handedness can be accounted for without any recourse to genetic considerations. Collins' criticism of genetic theories stems mainly from the known fact that identical twins are often discordant for handedness. Nonetheless, there is relatively little data on the sociocultural effects on handedness. Social and cultural influences are considered by most writers to operate, to a greater or lesser degree, to modify congenital and manual preference. In summarizing this area, the most appropriate conclusion seems to be that a genetic model is a more probable explanation (see Hardyck & Petrinovich, 1977 for review). Otherwise, it would be difficult to understand why such a consistent percentage of children over the years have strongly resisted pressures to use the right hand and decided to use the left hand instead. Harder to explain on

an environmental basis would be the strong, though imperfect, correlation between handedness and cerebral dominance. Thus we know that language and speech mechanisms are almost always localized to the left hemisphere in right handers, while their localization in left handers is more variable. On the other hand, there is no doubt that the environment can cause left handers to use their right hands much more than they would otherwise. It seems then, that the environment could act to conceal the true incidence of non-right handedness. Perhaps the most compelling evidence against the purely environmental interpretation is the systematic behavioral differences in hemispheric lateralization that have been reported between familial and nonfamilial left handers (Hacaen & Sauget, 1971; Zurif & Bryden, 1969). As Hardyck states, "if, as Collins argued, an unspecified environmental mechanism is adequate to explain the fact that offspring resemble their parents in handedness, such a mechanism would have to work in a rather strange manner, since it would be in effect for the familial left handed but not for the nonfamilial left handed" (Hardyck & Petrinovich, 1977, page 396).

A recent approach to the study of the relationship between manual and cerebral asymmetries is of interest here, because it incorporates both biological and environmental factors (Corballis and Morgan, 1978). Although similar on the surface to Annett's genetic model, Corballis and

Morgan's model has characteristics which resemble the more environmental approaches. The essence of this model is that there exists an innate maturational left-right gradient favoring earlier development on the left side of the brain. This gradient, which underlies both cerebral laterality and handedness, is coded in the spatial structure of the oocyte rather than in the genes, implying that laterality is innate but not inherited. They argue that the direction of asymmetries (i.e., left versus right) cannot be coded in the genes, but whether an asymmetry will exist or not is probably genetic. In the absence of this gradient, determination of laterality and handedness is essentially random. Again, as in Annett's model, we are left with the conclusion that right handedness is biologically determined while left handedness is environmentally determined.

The existence of a maturational gradient in Morgan and Corballis' model is meant to imply that the difference between the two sides of the brain is not a rigid one; in other words, the difference may be more quantitative, rather than qualitative. It is suggested that the effects of handedness could be to weaken, or sometimes even reverse, the usual gradient favoring faster growth on the left side of the brain. The implication is that differential use of the left hand can affect the development of the right hemisphere in such a way that it can be "primed"

to develop engrams for fine sensorimotor actions and eventually for speech and language. This could explain why a small proportion of left handers seem to have speech represented in the right hemisphere, while a larger proportion of left handers exhibit "bilateral" language mechanisms.

Aims of Experiment

1) To look at inferred hemispheric processing as it takes place over trials in the acquisition of a naming and matching letter task.

2) To contrast the pattern of hemispheric processing in different groups of individuals purported to differ in both their patterning and extent of hemispheric lateralization.

3) To ascertain whether certain patterns of hemispheric processing are correlated with: (a) demographic (subject) variables, and (b) cognitive (intellectual) variation.

4) To evaluate existing models of individual differences in cerebral organization and how these individual differences have been related to performance. If possible, a more plausible model can be generated if existing models are found to be lacking in explanatory power.

Design of Experiment

The methods of analysis that have been used to look at performance in tachistoscopic laterality research have generally been restricted to the comparison of two means, one for the RVF and one for the LVF, in a number of individuals. These means are computed by summing over many blocks of trials given over an extended period of time. The development of a response or performance curve is often overlooked within subjects, leading to generalized conclusions concerning cerebral lateralization mechanisms. More importantly, by comparing just a grand mean of performance in different groups of people (for example, left handers versus right handers), a large amount of information relevant to individual differences in both degree and pattern of cerebral asymmetries is lost. In the realm of laterality research, considerations of this kind can aid in refining relationships between laterality, performance, and individual differences.

The design employed in this thesis involves the study of laterality patterns of different groups of individuals over an extended period of time in the context of a verbal, tachistoscopic, reaction time task. Since it is known that perceptual and motor performance change with experience, the usual approach of employing measures that are insensitive to these changes will be replaced by measures designed to take into account individual differences

in the role of experience on perceptual and motor behaviors. In addition, a finer discrimination between subgroups divided on important subject variables can be achieved.

The choice of the stimulus or the stimuli to be used in tachistoscopic reaction time experiments has been an important consideration. Alphabetic material such as letters has been used most often in manual reaction time paradigms. Often in studies of this kind, there is a confounding of stimulus qualities with the cognitive demands of the task. One would like to have two or more concurrent measures of performance, especially in laterality research, to distinguish between processing capabilities of the two cerebral hemispheres compared to each other, or to compare a task that produces asymmetrical responses with another task that either hemisphere can perform equally well. Rarely can the same stimulus materials be used for two different tasks, but Geffen et al. (1972) and Cohen (1972) achieved this end by using a lateralized version of the "Posner" task. This task, devised by Posner and Mitchell (1967) involves judgments as to whether two simultaneously presented letters are the same or different. These researchers found that when a pair of letters are physically identical (e.g., BB or bb), reaction time is about 70 msec faster than when the stimuli share the same name, that is, are nominally identical but are physically dissimilar (e.g., Bb). Posner et al., (1969) has hypothesized that the

matching of letters based on nominal identity requires the use of a verbal transformation of visually presented letters, and thus requires additional processing time. Cohen (1972), Geffen et al. (1972), and Davis and Schmidt (1973) all used the Posner task and found a speed advantage for right visual field presentation when the match required naming, and either a small left visual field advantage or no visual field advantage when the match could be accomplished on the basis of physical identity only. This task has been used in studies looking at individual differences such as handedness (Cohen, 1972) and sex (Segalowitz & Steward, 1979) and was found to produce reliable and consistent differences between groups. The Posner letter matching task is thus an improvement over previous tachistoscopic tasks because stimulus factors are more easily controlled, and performance on the task can be contrasted in a number of different ways.

The paradigm that will be used to study information processing differences of the two cerebral hemispheres will therefore involve judgments about whether two simultaneously presented letters are the same letter. This task, called the Posner task, will be presented unilaterally to the left and the right visual fields via tachistoscopic means, and manual reaction times will be elicited.

It will be hypothesized that some of the variation in the laterality patterns thus observed can be accounted for

by reference to a number of subject and performance variables.

Biographical and handedness questionnaires are included to provide some of the information which will aid in forming homogenous subgroups of subjects and also in explaining variation within groups. Other potentially useful information, such as major in school, eye dominance, and hand position when writing, will also be obtained. Subjects grouped on the basis of the three independent variables of sex, handedness, and presence or absence of a family history of left handedness will be administered the tachistoscopic reaction time task and a number of other ancillary cognitive and performance tasks. It is hypothesized that performance on this ancillary battery of tasks will help explain some of the variability on the RT task within sub-groups. Correlations between differential cognitive abilities and certain patterns of cerebral lateralization can thus be computed, along with the association of all these indices with sex, handedness, and family history of left handedness.

The independent variables of sex, handedness, and family history of handedness have been found to affect laterality and cognition in complicated and often ambiguous ways. With regards to laterality indices, right handed males with no left handed relatives have most consistently shown a left hemisphere superiority for verbal materials and a right hemisphere superiority for nonverbal

materials. The findings for females have been less clear, although it has been suggested that they show more equipotentiality between the two hemispheres. The lateralization patterns of left handers are also unclear but there is some consensus that as a group they are quite variable and show more equipotentiality between the two hemispheres for language functions. It seems that at least some of the variability among left handers has been found to be associated with presence or absence of a family history of left handedness. A positive family history of left handedness has been found to be associated with a more rapid recovery following brain damage and with lesser asymmetries on laterality measures; two phenomena often observed in left handers. Thus, a genetic history of left handedness can be an important determinant of the extent of the laterality differences found in both left and right handers.

With regards to cognition, studies have shown that certain cognitive abilities may be related to sex and hand preference. It's been suggested that both females and left handers have relatively poorer spatial ability. Both groups also evidence more "bilateralization" or equipotentiality between the two hemispheres of the brain. This raises the question of whether certain patterns of brain lateralization may be correlated with certain patterns of cognitive abilities. This question will be tested empirically by looking at associations between performance on a battery of verbal and spatial tasks and performance on the tachistoscopic laterality task.

HYPOTHESES AND THE PROCEDURES FOR TESTING HYPOTHESES

General Experimental Effects

1) There will be faster reaction times to physical identity (PI) matches as compared to nominal identity (NI) matches. Theoretically, matching letters that are physically identical is a simpler task than matching letters that have the same name but do not look the same. Posner and others (Posner & Mitchell, 1967; Posner et al., 1969) have hypothesized that the nominal match requires the use of a verbal code while the physical match has no such requirement. This requires the translation from a visual representation to a verbal representation before a nominal match can be made; this translation would not be required for the physical matches. This additional processing takes up additional time; as Posner and others have shown (Posner et al., 1969; Cohen, 1972).

2) There will be faster reaction times to nominal matches presented to the right visual field as compared to the left visual field. Rationale: Theoretically, the process of naming letters is one for which the left hemisphere is more specialized to perform. Letters flashed tachistoscopically in the right visual field arrive in the left hemisphere of the brain faster than letters flashed in the left visual field. Therefore, reaction times to letters that have to

be named should be faster when they are presented to the left hemisphere first. Empirically, Cohen (1972), Geffen et al (1972), and Davis and Schmidt (1973) found a speed advantage for the RVF when the match required naming.

3) Reaction times to left and right visual field stimulation for both NI and PI matches will decrease over blocks of trials; in other words, there will be progressive improvement in speed of RT as the experiment progresses, although the amount of improvement may differ depending on the field. Rationale: In the acquisition of any new task, performance will tend to improve with practice. Empirically, it has been shown that when letters are presented tachistoscopically (Hellige, 1976; Ward and Ross, 1977), reaction times tend to decrease over time.

Hypotheses Related to Individual Differences

1) If the phenomenon of left handedness alters cerebral lateralization mechanisms, then all left handed groups should show evidence of decreased lateralization compared to right handed groups. More specifically, if left handers as a whole are more "bilateralized" for language abilities, then all left handed groups will show a smaller visual field advantage for NI matches, or put another way, right handers

will show a greater RVF advantage for NI matches. Rationale: Both clinical (Hecaen & Sauget, 1971) and experimental (Zurif & Bryden, 1969; McKeever et al, 1973) studies have shown that left handers as a group exhibit a lesser degree of language lateralization.

2) If sex alters extent of cerebral lateralization such that females are more "bilateralized" for cognitive functions, then all female subgroups should show smaller visual field differences for NI matches. Put another way, males should show a greater asymmetry in response times to left and right visual field stimulation involving the naming of letters. Rationale: Clinical (Lansdell 1962) and experimental (McGlone & Davidson, 1973) studies support the notion that cognitive functions may be more lateralized in males than in females.

3) If genetic history of handedness is an important determinant of extent of hemispheric laterality; then differences in pattern or degree of response asymmetries should arise between those subjects with a positive family history of left handedness and those subjects without such history. More specifically, if presence of a left handed family history results in more equipotentiality between the two hemispheres of the brain, then individuals without left handed relatives should show a greater asymmetry in response time to left and right visual field stimulation compared to

individuals with left handed relatives. Rationale: Clinical studies of the comparison of symptomatology and recovery rates (Hecaen & Sauget, 1971; Luria, 1970) between subjects with and without left handed relatives have suggested that both left and right handers with left handed relatives tend to exhibit more equipotentiality between the two sides of the brain for cognitivie functions. Experimental studies (Hines & Satz, 1971, Zurif & Bryden, 1969) have generally shown smaller field effects for family history positive subjects.

3b) If a genetic theory of brain laterality is indeed plausible, then the presence of a family history of left handedness should reduce field asymmetries in all of the subgroups tested; although not necessarily in an equivalent way.

4) If the effects of sex, handedness, and family history of handedness are additive in their reduction of visual field asymmetries for language processing; then it can be hypothesized that male right handers without left handed relatives will show the greatest asymmetry in responses to LVF and RVF stimulation; while female left handers with left handed relatives should show the least asymmetry.

5) If a lesser degree of lateralization is associated with less optimal cognitive performance or with certain cognitive deficits; then those individuals showing lesser

response asymmetries on the laterality task should score lower on the cognitive tests than those individuals showing greater response asymmetries on the laterality task.

6) If a lesser degree of lateralization is associated with lowered spatial ability as has been proposed by Levy (1969), then those individuals showing smaller response asymmetries on the laterality task should score lower on spatial tasks compared to those individuals showing greater asymmetry on the laterality task.

METHOD

Subjects

Subjects were 64 undergraduates from the City College of New York without previous experience with this kind of experiment. All subjects signed informed consent forms. They were equally divided between males and females, and were additionally selected on the basis of their hand preference scores on the Annett Handedness Questionnaire, and their responses on the "family history" questions. Only those subjects who performed at least 11 of 12 unimanual activities with their right hand were retained for the right handed groups. Some allowance was made for the fact that some left handers who exhibit a strong preference for their left hand may nevertheless not reach this criterion of 11 out of 12 activities. Thus, an average of 10 out of 12 activities with the left hand was sought in the left handed groups. On the family history variable, only those subjects with at least one primary or two second-degree left handed relatives were included in the "family history positive" (herein referred to as FH+) groups. Those subjects included in the "family history negative" (herein referred to as FH-) groups were individuals with no primary

or second degree left handed relatives. A total of eight subgroups resulted, divided on the three independent variables of sex, handedness, and family history.

Each subject was either paid for his or her services or given class credit for participation. Each subject attended three one-hour sessions on three separate days. Stipulations were that sessions were at least one day apart but not more than a week apart.

Each subject was given an eye acuity test during Session 1, and was excluded from the study if acuity in either eye was worse than 20/25, or if the difference between eyes was greater than two points on the Snellen chart. Additionally, any subject who was unable to perform up to criterion (less than 10% error rate) on the tachistoscopic reaction time task after two practice sessions had been run, was excluded from further testing.

Apparatus

Stimuli was presented in a three-field Gerbrands tachistoscope (Model T-3B-10). One field was used for fixation while a second field was used to present the stimulus material. Both fields were illuminated at four foot lamberts (4 fL). Duration of the fixation field was set at 1.5 seconds; offset of this field was followed immediately by the onset of the stimulus field. Pilot work for this experiment had demonstrated that exposure

durations of less than 100 msec for the stimulus material resulted in over 10% error rates, so the exposure duration of the stimulus field was set at 100 msec and remained constant for all subjects.

Stimuli were viewed binocularly by the subject. A Gerbrands digital timer (Model #G1271) recorded subjects' manual reaction times. This timer was triggered by the onset of the stimulus field and was stopped by releasing a microswitch situated by the subject.

Two microswitches, one on the left side and one on the right side, were mounted on a wooden board situated in front of the subject. Each subject used only one of the microswitches depending on his or her handedness; right handed subjects used their right hand only and released the key on the left side of the board. Left handed subjects used their left hand only and worked with the microswitch on the right side of the board. Thus, each hand-microswitch combination was a crossed one. This was done to help rule out possible stimulus-response compatibility effects, which sometimes occur when both the stimulus and the reponse occur on the same side of physical space.

Stimulus Materials

The letter stimuli for the tachistoscopic task were adapted from the Posner task (Posner & Mitchell, 1967) and consisted of pairs of letters printed on 6 x 4 inch plain

white cards with Letraset, 24 point Helvetica Medium print. The letters were placed one above the other to eliminate horizontal scanning effects. The two letters appeared 3 degrees of visual angle to the left or to the right of the center of the field and a digit was placed at the center of fixtaion. Pilot work had demonstrated that a distance of 3 degrees right or left of fixation was far enough from foveal vision without being so far as to fall in an area of insufficient acuity. Half of all letter pairs consisted of two letters that were the same letter, while the other half were different letters. The same letter pairs were further subdivided into pairs that were physically identical (like BB or bb), and pairs that were nominally (had the same name) but not physically identical (like Bb or gG). The different pairs were either both uppercase (like BG), both lowercase, or mixed in case; the number of uppercase and lowercase letters used and the combinations used were equated for both same and different pairs.

The letters selected as stimuli were B, F, G, and H. None of these letters form what Posner has called "analog" pairs, meaning that the uppercase and the lowercase version of each of these letters are not physically similar. This insures that nominally identical pairs can never be matched by physical cues alone. In addition, both the uppercase and the lowercase versions of the letters chosen as stimuli are the same size, so that the possibility of matches being

made on the basis of the size of the letters was minimized. All of these letters appeared equally often in all types of pairs.

A total of 128 stimuli were made up, half of which appeared in the right visual field (RVF) and half in the left visual field (LVF). The 128 stimuli were broken up into four blocks of 32 stimuli each. Each block consisted of 16 same and 16 different pairs; and of the same pairs, 8 were physically identical and 8 were nominally identical. Half of these were presented in the RVF and half were presented to the LVF. Field of presentation (RVF or LVF), type of respnse (same or different), and type of match (physical or nominal) were randomized within each block with the stipulation that no more than three stimuli pertaining to each of these groups occurred together. This randomization procedure was applied to each block separately, so within each block all relevant experimental variables were randomized, while across blocks all relevant experimental variables were equated. Blocks were presented in a fixed order, and all subjects received the same order. This same order was repeated on the second day of testing, so that all subjects received a total of 8 equivalent blocks of 32 trials each.

The other stimulus materials used in the experiment constituted the "ancillary" task battery. A description of each of these tasks follows:

1) Hand rotation task: The stimuli for this task consisted of 20 pictures from the Boston Parietal Lobe Battery. Each picture was of a left hand or a right hand and was mounted at the center of a 6 x 4 white card. Twenty such cards were presented in the tachistoscope at an exposure duration of 1000 msec. Half of the hands were right hands and half were left hands. Of these, half of the hands were pictured in a "normal" orientation (hand is facing in the same direction as the subject's own hand), while the other half were pictured in a "reversed" orientation (hand is rotated relative to the viewer). Subjects were instructed to indicate whether the hand was a right or a left hand by lifting their finger from the reaction time microswitch as soon as they had the right answer, which they then gave vocally. Thus, both latency to respond and the actual response given was recorded for each stimulus.

2) Street Closure Test: This is a test that involves the creation or unification of a figure from incomplete or fragmented parts. A set of 13 such closure stimuli were presented in full view for identification and scoring was standard.

3) EFT (Embedded Figures Test): The embedded figures test is a paper and pencil test designed to measure aspects of visual perception (ability to perceive a figure in a complex background). This 12 item version of the EFT is part

of the CAB battery of tests[1] and is a commonly used version.

4) WAIS Block Design and WAIS Similarities: These two subtests from the Wechsler Adult Intelligence Scale were administered and scored in the standard format.

5) Vocabulary Test: A 15 item vocabulary test was taken from the CAB battery. The subject is asked to choose the best synonym out of five alternatives.

6) Abstract Reasoning test: This 13 item reasoning test was taken from the CAB battery. For each item, five sets of letters were presented of which one set did not belong or go with the others. Subjects were asked to choose that set of letters that did not follow the same rule or pattern as the others.

7) Mental Rotation test: This test was taken from the CAB battery and is designed to measure aspects of visual-spatial perception. It involves the ability to see two objects as the same object even though one of them is rotated in a left-right plane.

8) Purdue Pegboard test: This is a test of fine motor coordination and was administered in the standard format,

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[1]The CAB is a factor analyzed series of short tests developed by R. Hackstein from the University of British Columbia.

that is, two trials were allowed for the right hand separately, for the left hand separately, and for both hands together.

8) Eye dominance test: The standard test for eye dominance was used (Miles, 1958).

9) Hand orientation when writing: Placement of writing implement relative to the line of writing will be observed for each subject, and a judgment will be made as to whether subject writes in a "normal" orientation or in an "inverted" (hooked) orientation.

Procedure

Administration of all tests and procedures took place over 3 one-hour sessions. The procedure for each session follows:

Session 1: All subjects were administered the Annett handedness questionnaire along with additional questions as to presence or absence of a family history of left handedness, a visual acuity test, and the tachistoscopic reaction time task (Posner task). A verbatim account of the actual instructions that were given to each subject is included in the Appendix. A few additional notes on these instructions are warranted here. Three sets of practice trials for the tachistoscopic tasks were given during the first session to insure that all subjects understood the task and

responded appropriately. The first set of practice trials (10 trials) involved responding as quickly as possible to a number which was presented foveally in the tachistoscope. This practice was done to get the subject acclimated to the tachistoscope and to the manual reaction time apparatus. The second set of practice trials (10 trials) involved responding to Posner stimuli presented foveally. This was done to insure that the subject understood the task requirements. A third set of practice (24 trials) involved responding to lateralized Posner stimuli. A digit appeared at the center of each stimulus card. These stimuli were the same as those that would be used in the experiment. The purpose of this practice was to ensure that the subject had indeed understood the task requirements and that he or she was able to respond to the lateralized stimuli, which were more difficult to see, and also to report the digit at the center of fixation.

Every effort was made to insure that all subjects understood the instructions in the same way. Also subjects were reminded all during the practice trials to respond as quickly and as accurately as possible. Finally, motivation was induced by reinforcing fast responses during practice (verbal reinforcement), by allowing a one minute rest period between each block of trials, and by reminding the subject that the session is only one hour long.

Session 2: Subjects were run on the same tachistoscope reaction time task that was presented during Session 1 with the following differences. Only the last set of practice

trials were presented, followed by the four blocks of test trials. The hand rotation task was then administered while the subject was still seated in front of the tachistoscope. At the end of the session, the subject was given an extended questionnaire form. Specific questions related to family history of left handedness, amount of schooling, major in school, and orientation of pen when writing, were included on this questionnaire. Subjects were allowed to take the questionnaire home to check with other family members if they were not certain about how to answer some of the questions.

Session 3: This session was devoted to the administration of the remaining ancillary tasks. The remaining tasks were given in the following order, eye dominance test, Street Closure test, WAIS Block Design subtest, WAIS Similarities subtest, Purdue Pegboard test, Embedded Figures Test (EFT), mental rotation test, vocabulary test, and abstract reasoning test. Each test was administered according to standard instructions. Subjects were told which tests were timed, and they were given a brief rest between each test.

At the end of Session 3, each subject was debriefed and was allowed to ask about any of the experimental procedures. Any subject requesting his or her scores on any of the tests were told to come back to the lab in a couple of weeks. Test scores were then given to the subject, and were interpreted if the subject requested an interpretation.

RESULTS

For the reaction time (RT) data, mean reaction times were computed for both physical identity (PI) matches and nominal identity (NI) matches for both the right visual field (RVF) and the left visual field (LVF) for all eight blocks of trials for each subject. Effects of practice on mean RT over time can be assessed by looking at the block effect which is essentially an analysis of change in RT over time. The block effect can also be conceived as a learning curve. The match effect, or difference in RT between PI and NI matches (NI-PI difference) can be viewed as the difference in processing time for a simple perceptual or template match versus a match that requires some transformation (linguistic?) beyond perceptual. Field effects, or differences in RT between the RVF and the LVF, can be interpreted as a measure of hemispheric differences; and therefore related to cerebral laterality. This relationship between the field effect and cerebral laterality need not be an isomorphic one, and will not be interpreted as such.

These data were subjected to a repeated measures analysis of variance (ANOVA) with three within factors (block, field, and match) and three between factors (sex,

handedness, and family history). This first analysis included all the subjects tested. Subsequent analyses were then performed on males only, on females only, on right handers only, on left handers only, on family history negative subjects, and on family history positive subjects. For these separate analyses, the only data presented will be those that did not appear in the first overall ANOVA or those that were discrepant with the first ANOVA.

Various transformations were then performed on the RT data. First log transforms were performed on mean RT to correct for possible skewness in the data and subjected to a repeated measures ANOVA using the same factors listed above. Next, left-right field difference scores were calculated for both NI and PI matches for each block of trials by subtracting the RVF mean from the LVF mean. These difference scores were subjected to a repeated measures ANOVA similar to the above. Another difference score was computed for only NI matches using the following formula:

$$\frac{\text{Left-right}}{(\text{Left} + \text{right})/2} \times 100$$

This "normalized" difference score (normalized in the sense that the score is corrected for mean performance) allows for the comparison of the difference scores between groups of subjects while controlling for performance level. (Shankweiler & Studdert-Kennedy, 1976). The normalized difference score for NI matches was subjected to a repeated

measures ANOVA with one within factor (block) and the three between factors. Finally, change in RT over blocks (improvement) over time was analyzed by calculating change scores for each day separately and for both days combined. Repeated measures ANOVA's (sex by hand by family history) were performed on each change score measure with match and field as within factors. For all the transformations, only new or discrepant information will be presented.

To conclude the analyses on the RT data, correlations and regression analyses using the forward step-wise procedure (SPSS) were performed on the block effect, field effect, match effect, total RT, and the normalized difference scores using the three independent variables of sex, handedness, and family history as predictors. This was done to ascertain the effects of the three independent variables separately and in combination while controlling for the intercorrelations among them.

Mean Reaction Time

A) General Experimental Effects Across Groups

A repeated measures ANOVA with three within factors (block, field, and match) and three between factors (sex, handedness, and family history of left handedness) was first performed on the raw RT data. Table 1 presents the summary table for this ANOVA. Major findings were as follows. An overall block effect was found ($F = 51.0$,

df 7,392, $p < .001$) indicating that RT decreased with practice in all conditions. This practice effect can be seen in Figure 1. Post hoc Scheffe analyses revealed that RT in blocks 1, 2, 3, and 4 ($\bar{x} = 591.5$) differed significantly from each other and from blocks 5 through 8 ($\bar{x} = 534.4$) ($p < .01$). Reaction times in these last four blocks did not differ significantly, in other words, there was no significant practice effect after Block 4.

PI matches ($\bar{x} = 575.6$) were performed significantly faster than NI matches ($\bar{x} = 650.3$) ($F = 552.6$, df 1,56, $p < .001$) in both fields for all eight blocks of trials, which accounts for the fact that there was no block by match interaction nor a block by field by match interaction. This match effect was remarkably robust and stable over the eight blocks.

Reaction times in the RVF ($\bar{x} = 607.6$) were significantly faster than RT in the LVF ($\bar{x} = 618.3$) ($F = 10.2$, df 1,56, $p < .003$), but this effect was due entirely to the difference in RT for NI matches between the two fields. This field by match interaction ($F = 10.5$, df 1,56, $p < .003$) was such that a RVF advantage in RT was found for Nl matches while no field difference in RT was found for PI matches. This interaction is picture in Figure 2.

This RVF advantage for Nl matches was preserved for all blocks of trials with the exception of the eighth and final block of 32 trials. Here there was no field

advantage, due to the fact that while RT in the RVF increased slightly, RT in the LVF decreased slightly.

Block interacted with the field effect ($F = 3.42$, df 7,392, $p < .002$) such that the difference between the RVF and the LVF is smaller in the first two blocks and in the last two blocks of trials compared to the middle blocks (Blocks 3 through 6). In other words, the RVF advantage in RT is very small at the beginning of the experiment and non-existent at the end of the experiment, but quite robust in-between.

B) Effect of the Subject Variables Taken Separately

The subject variables of sex, handedness, and family history of left-handedness individually affected the aforementioned general trends in the following ways.

Family History: Family history affected the findings in three major ways:

1) It was the only subject variable to produce a significant main effect ($F = 5.58$, df 1,56 $p < .022$); overall RT for family history negative subjects ($\bar{x} = 593.2$) was faster than that of family history positive subjects ($\bar{x} = 632.6$). A comparison of RT over blocks of trials between family history negative (FH-) and family history positive (FH+) subjects is shown in Figure 3.

2) Additionally, there was a significant history by block interaction ($F = 2.1$, df 7,392 $p < .04$). In general,

FH- subjects exhibited a larger decrease in RT across blocks of trials compared to FH+ subjects. To put in another way, FH+ subjects appeared to asymptote earlier than the FH- subjects and not exhibit any further decreases in RT after the fourth block of trials (see Figure 3). Post hoc Scheffe analyses revealed that for FH- subjects, there was a significant decrease in RT from Blocks 1 thru 4, and from Block 5 to Block 6 (there was no significant decrease from Blocks 4-5). For FH+ subjects, there was no significant decrease in RT after Block 4.

3) Family history also interacted with the field effect ($F = 4.37$, df 1,56 $p < .04$). FH+ subjects showed no significant difference in RT between the two visual fields, whereas the FH- subjects did. This effect in part was reflected in a marginally significant history by field by match interaction ($p < .08$). This interaction was such that while FH- subjects exhibited a substantial RVF advantage for NI matches, the FH+ subjects revealed little to no RVF advantage for NI matches. This relationship can be seen in Table 2.

The remainder of the family history by field effect was accounted for in a history by block by field interaction ($F = 3.60$, df 7,392, $p < .001$). This interaction revealed that the FH- subjects exhibited a RVF advantage in RT over all blocks of trials except for the first, but

the FH+ subjects exhibited a RVF advantage in RT over the first three blocks of trials and a nonsignificant LVF advantage in RT over the last three blocks, thereby cancelling out the field effect. This LVF advantage over the last three blocks of trials in FH+ subjects occurred because while RT in the LVF continued to decrease over the last three blocks, RT in the RVF actually increased over the same three blocks. This effect can be seen clearly in Figure 4, and implies that the slowness exhibited by the FH+ subjects, especially in the last half of the RT experiment, was particularly due to slowness in the RVF.

Sex effects

Sex interacted only with field ($F = 5.15$, df 1,56, $p < .03$). Females had a significantly smaller field difference compared to males. Further inspection of the data revealed why this may have been the case. Males had a significant RVF advantage for NI matches (Scheffe, $p < .01$), and a nonsignificant RVF advantage for PI matches as well. Females on the other hand had a nonsignificant RVF advantage for NI matches and a nonsignificant LVF advantage for the PI matches. Since these advantages in females were so small and in opposite directions, the field effect was cancelled out in females. A comparison of RT between males and females for each type of match in each visual field can be found in Table 3.

As can be seen in Table 3, males were also somewhat faster than females in all conditions, but this difference was not significant. Sex was not found to influence any of the other major findings, but it did interact with handedness and family history. These interactions will be described in the sections dealing with interactions of the three subject variables.

Handedness effects

Handedness was not found to significantly affect any of the overall experimental findings. Left handers were somewhat faster than right handers, but this difference in RT was only significant in Block 1 (Scheffe, $p < .01$). Handedness did interact with sex and family history, these interactions will be described below.

The effects of the subject variables taken separately can be summarized as follows: Family history had the most marked effect on performance in this experiment. It not only reduced field differences, but was found to have quite unique effects on other aspects of performance, such as overall RT, and amount of improvement in RT over time. Sex also reduced field differences, but in a slightly different way. Females had small and opposite field advantages for the PI and NI matches. These nonsignificant field advantages cancelled each other out. Handedness by itself did not significantly affect any of the overall findings.

C. Interactions of the three subject variables

The three subject variables of sex, handedness, and family history of left handedness (FH- or FH+) interacted with each other to produce the following effects on the major overall findings.

Sex by hand interactions

Sex and handedness together interacted with the block effect ($F = 5.36$, df 7,392, $p < .001$) in the following way. Male left handers and female right handers showed a progressive decline in RT over all eight blocks of trials, but male right handers and female left handers exhibited an increase in RT after Block 4. Over the first four blocks of trials, all right handers, both male and female, exhibited a similar performance curve (i.e. a sharp decrease in RT). Left handers too, all had a similar performance curve over the first four blocks, but different from the right handers. They started out faster than the right handers (by 32 ms), but showed less of a decline in RT compared to the right handers (63 ms decline for left handers and 94 ms decline for right handers over the first four blocks). Its only over the last four blocks that the difference between the two handedness groups breaks down according to sex. This interaction can be seen in Figure 5.

Handedness by family history interactions

Handedness and family history together interacted with the match effect ($F= 4.24$, df 1,56, $p < .045$). In FH- subject, left handers are faster on NI matches (620 ms) compared to right handers (642 ms), and left handers are also faster on PI matches (538 ms) compared to right handers (642), both differences were significant at $p < .01$. For FH+ subjects, the right handers were faster on both types of matches, this difference was not significant for NI matches (668 ms versus 672 ms) but was significant for PI matches (586 ms for right handers and 605 ms for left handers).

Sex and family history interactions

Sex and family history together interacted with block and field (sex by family history by block by field interaction, $F = 2.1$, df 7,392, $p < .04$) in the following way. Although RT was increased for both sexes with a positive family history, the RT of males was most affected by a positive family history compared to females. This was especially true in the RVF over the last four blocks, where

males with FH+ showed an 85 ms increase over males with FH- while females with FH+ showed a 36 ms increase over females with FH-. This effect of family history can be seen in Figure 6.

Sex by handedness by family history

There were no major three-way interactions of the subject variables.

Summary of overall analysis of the raw data.

A. Overall Experimental Effects

1. Block or practice effect, with an asymptote after Block 4.
2. Match effect-PI matches faster than NI.
3. Field effect - Faster RT in RVF compared to LVF.
4. Field by match interaction - RVF advantage for NI matches; no field advantage for PI matches.
5. Block by field interaction - RVF advantage nonuniform across blocks; smaller at beginning and end.

B. Individual differences

1. Family history: 1) FH - faster than FH+,
   2) earlier asymptote in FH+ subjects,
   3) no field advantage in FH+.

2. Sex: Females showed no field advantage.
3. Handedness - no major effects.
4. Sex by family history interaction - RT difference between males with FH+ and males with FH- was much greater than the same comparison in females (RT was increased for both sexes with FH+).

D. Analyses on individual groups

The previous sections dealt with analyses that were performed on all of the subjects taken together. Similar analyses were subsequently performed on males only, on females only, on FH- subjects, on FH+ subjects, on right handers only, and on left handers only. The analysis on males was compared to the analysis on females in order to see whether any effects appeared in one analysis that did not appear in the other, or whether any new findings emerged that were not in the overall analysis. This comparison was also done between right handers and left handers, and between FH- and FH+ subjects. The three comparisons are described below. Only new or discrepant data (relative to the overall analysis) will be presented here; the remaining data can be found in Appendix 2, section A.

FH-subjects versus FH subjects

As far as field effects were concerned, only FH- subjects had a significant field effect ($F = 15.3$, df 1,28,

[$p < .001$) and a significant field by match interaction ($F = 11.46$, df 1,28, $p < .003$). This meant that RT for the RVF was faster than RT for the LVF (584 versus 602 ms) in FH- subjects, and that there was a significant RVF advantage for NI matches (32 ms advantage) in FH- subjects. In contrast, FH+ subjects had no field advantage (3 ms difference in favor of the RVF) and no significant RVF advantage for NI matches (8 ms difference in favor of the RVF).

Sex and handedness significantly affected the field difference in FH- subjects only. Sex interacted with field for the FH- subjects ($F = 4.02$, df 1,28 $p < .05$) in that females had a significantly smaller field difference compared to males (8 ms versus 27 ms).

Handedness also interacted with the field effect in FH- subjects ($F = 4.2$, df 1,28, $p < .05$) but not in FH+ subjects. In FH- subjects, left handers had a smaller field difference (8 ms in favor of RVF) compared to right handers (27 ms in favor of the RVF).

Males versus females

Only males had a significant field effect ($F = 16.1$, df 1,28 $p < .001$) and a field by match interaction ($F = 11.3$ df 1,28 $p < .003$). Males had an overall RT advantage for the RVF (18 ms) and a RVF advantage for NI matches (31 ms). Females failed to show a field advantage (3 ms) mainly because RT increased over the males much more in the RVF

compared to the LVF, and because females had a nonsignificant RVF advantage for NI matches and a nonsignificant LVF advantage for PI matches, thus cancelling out any field effect in females.

As far as the effects of handedness and family history were concerned, the most interesting finding was the lack of an overall effect of family history in the females and the presence of one in males ($F = 5.85$, df 1,28, $p < .02$). In other words, overall RT was significantly affected by family history in males only. Further inspection of the females' data revealed that RT was affected by family history, but the effect was opposite with respect to handedness. In right handed females, presence of family history decreased RT (not significantly), while in left handed females, presence of a family history significantly increased RT ($p < .01$) in an equivalent way as it increased RT in males (both right and left handers).

Right handers versus left handers

Only right handers had a significant field effect ($F = 15.5$, df 1,28, $p < .001$) and a significant field by match interaction ($F = 8.97$, df 1,28, $p < .006$). Right handers exhibited an overall RT advantage for the RVF (14 ms) and a RVF advantage for NI matches (27 ms). Left handers failed to show a significant field effect (7 ms in favor of RVF) mainly because the RT in the LVF was lower in

left handers (RT in the RVF was the same for both handedness groups). Left handers showed a nonsignificant RVF advantage for NI matches (13 ms). Again, RT in the RVF for NI matches for the two handedness groups was similar, but RT in the LVF was 16 ms lower for left handers, thus leading to a smaller field difference for NI matches. Left handers exhibited a block by field by match interaction ($F = 2.02$, df 7,196, $p < .05$) such that they exhibited a significant RVF advantage for NI matches (21 ms advantage, $p < .01$) over the first four blocks of trials but a nonsignificant RVF advantage (5 ms) over the last four blocks of trials.

As far as the effects of sex and family history were concerned, the most interesting difference between the two handedness groups was the lack of an overall family history effect in right handers and the presence of one in left handers ($F = 6.27$, df 1,28, $p < .02$). This lack of a family history effect in right handers was probably due to the fact that the presence of a family history significantly increased RT in males ($p < .001$) but decreased RT in females (not significant). In left handers, presence of a family history increased RT for both males and females equally.

In summary, separate analyses of males, females, right handers, left handers, FH- subjects, and FH+ subjects revealed the following major trends.

Differences between the groups were observed mainly with respect to field effects. In general, FH- subjects, males, and right handers exhibited a significant field effect (RVF advantage) and a significant field by match interaction (RVF advantage for NI matches). FH+ subjects, females, and left handers failed to display a significant field effect or a significant field by match interaction. Figures 7 to 15 show the RVF and LVF reaction times for NI matches for all 8 blocks of trials first for all subjects combined (see Figure 7) and then for each individual subgroup of subjects. Visual inspection of these figures shows that the pattern of the field effects differs in each of the subgroups, and no one subgroup (except for male right handers with a negative family history) exhibits a consistent field advantage over all eight blocks. Additional findings related to field differences will be presented in later sections (see sections B and C below).

Transformation of the RT data

A. Log and square root transforms

A log transform (to the base 10) was performed for all data points and subjected to a repeated measures ANOVA with three within (block, field, match) and three between (sex, handedness, and family history) factors. This was done to ascertain whether possible skewness in the RT data significantly affected the obtained findings, and whether a

transformation that served to normalize RT scores would yield similar results (Hays, 1963). The results of the analysis on the log transformed scores were amazingly similar to those of the raw scores (see Appendix 2, section B). In fact, all of the findings from the analysis of the raw data emerged again when the data was transformed; with similar F values and significance levels. There emerged only one new finding with the log transformed scores, and that was a block by match interaction ($F = 2.7$, df 7,392, $p < .01$). This interaction showed that while RT for P1 matches continued to decrease over all blocks, RT for NI matches showed no obvious decline after Block 4. This interaction can be seen in Figure 16.

The fact that the analysis of the data after a log transformation was so similar to the analysis of the raw data was very surprising, since RT data in general is known to be positively skewed. A square root transformation was thus performed on the raw data to provide an additional check. This analysis yielded results similar to those obtained with the log transformed scores.

B. Mean left-right difference scores

Left-right difference scores were calculated for both the NI matches and the PI matches for each block of trials by subtracting the RVF mean from the LVF mean. A positive score thus indicates a RVF advantage in RT and a negative

score indicates a LVF advantage in RT. These difference scores were subjected to a repeated measures ANOVA with two within factors (block and match) and the three between factors of sex, handedness, and family history. Results were as follows.

There were significant main effects for sex ($F = 5.0$, df 1,56, $p < .03$) and for family history ($F = 4.56$, df 1,56, $p < .04$) such that females and FH+ subjects had significantly smaller field difference scores (3.04 and 3.4 respectively) compared to males and FH- subjects (18.0 and 17.6 respectively). There was a significant match effect ($F = 10.3$, df 1,56, $p < .003$); the left-right difference score for NI matches was significantly greater than the difference score for PI matches (20 ms versus 2 ms). There was also a significant block effect ($F = 3.46$, df 7,392, $p < .002$); the field difference scores tended to increase over the first three blocks (from 8.4 to 24 ms) and then decline over the last four blocks (from 18.6 to -6.6 ms). The highest difference score was in Block 3 (24 ms). A history by block interaction ($F = 3.58$, df 7,392, $p < .001$) revealed that field difference scores of FH- subjects started out <u>negative</u> (-3.4 ms), indicating an initial LVF advantage, increased positively to the third block (34.0 ms) and then decreased thereafter (down to 8.0 ms). FH+ subjects started out highly <u>positive</u> (20 ms) indicating an initial RVF advantage, and decreased thereafter, becoming

negative over the last three blocks (down to -21 ms). Sex contributed unequally to this effect which accounted for the presence of a sex by history by block interaction ($F = 2.1$, df 7,392, $p < .05$). FH- females start out negative (-17 ms), increase dramatically to the third block (38 ms), but decrease rapidly thereafter. FH- males start out positive (10 ms), increase more slowly than the females but remain with very high difference scores throughout the eight blocks. FH+ females started out with lower difference scores compared to FH+ males (13 versus 27 ms), and then decrease more sharply than the males. The difference score for FH+ females remains highly negative over the last three blocks ($\bar{x} = -19$ ms), while the score for the FH+ males becomes highly negative only in the last block of trials (-17.0 ms). A summary of the left-right field difference scores broken down by match for all subgroups of subjects summed over blocks can be found in Table 4. Notice in this table that all subgroups had a positive difference score for the NI matches (indicating a RVF advantage) except for left handed females with a positive family history. Males in general had higher field difference scores for NI matches compared to females, and FH- subjects had higher difference scores for NI matches compared to FH+ subjects. In right handers, males and females with a negative family history had positive difference scores for the PI matches as well; but the FH+ subjects had negative difference

scores (indicative of a LVF advantage) for the PI matches. In left handers, there was no clear-cut relationship between the difference scores for NI matches and the difference score for PI matches, except to say that the males had positive scores for both types of matches, while the females had negative scores for the PI matches. In general, males tended toward positive difference scores for both types of matches, while females tended toward positive scores for NI matches and negative scores for PI matches.

C. Normalized difference scores

In order to control for the differing performance levels of the subjects, another type of difference score was computed, this time for NI matches only (PI matches were excluded because of the low difference scores they engendered). The following conversion formula was used:

$$\frac{\text{Left-right}}{(\text{Left-right})/2} \times 100$$

This normalized difference score allows for the comparison of the different scores between subgroups of subjects while controlling for overall performance. The normalized difference score for NI matches was subjected to a repeated measures ANOVA with one within factor (block) and three between factors (sex, handedness, and family history). Results were as follows:

There was a significant sex effect ($F = 6.12$, df 1,56 $p < .02$) and family history effect ($F = 6.12$, df 1,56 $p < .02$) such that females and family history positive subjects had significantly lower normalized difference scores (1.2 and 1.2) compared to males and family history negative subjects (5.1 and 5.1). There was also a significant block effect ($F = 2.39$, df 7,392 $p < .02$), a history by block interaction ($F = 2.67$, df 7,392, $p < .01$), and a sex by history by block interaction ($F = 2.55$, df 7,392, $p < .02$), and these effects manifested themselves in similar ways to the ones previously described in Section B above for the left-right difference scores. The overall normalized difference score for NI matches (summed over blocks) for each subgroup of subjects is presented graphically in Figure 17. It can be seen clearly in this figure that males show larger asymmetries overall compared to females (only exception is male right handers with a positive family history), and family history negative subjects exhibit larger asymmetries than family history positive subjects (only exception is male left handers with a positive family history).

A three-way ANOVA (sex, handedness, and family history) was performed on the normalized difference score, and there were main effects for sex ($F = 6.1$, df 1,56, $p < .02$) and for family history ($F = 6.1$, df 1,56 , $p < .02$). Males and FH- subjects had significantly higher difference scores

compared to females and FH+ subjects (males 5.15, females 1.20, FH- 4.26, FH+ 2.09). A signfiicant sex by family history ($F = 5.81$, df 1,56, $p < .03$) interaction revealed that the effect of family history was much stronger in the males, in other words, the difference between the FH- and FH+ males was much greater than the same comparison in females. Table 8(b) presents the difference scores for all the subgroups of subjects. Notice that the largest difference between family history groups occurs for the male right handers, but the three-way interaction of sex, handedness, and family history did not reach significance ($p < .11$).

The normalized difference scores for each subgroup were then tested to see whether they were significantly different from zero and from each other. The difference scores for all male subgroups except the male right handers with FH+ were significantly different from zero ($p < .05$, one-tailed). For females, only the difference scores for the right handers and left handers without FH were different from zero ($p < .05$, one-tailed); the scores for the two FH+ female groups were not. Comparisons were then performed between all eight subgrups. The difference score for male right handers without FH was significantly higher than all other groups (Tukey, $p < .05$). The only other significant comparisons were between female left handers with and without FH and between male and female left

handers with FH (in both cases the female left handers with FH had a significantly lower difference score, $p < .05$). Although there was no three-way interaction of the subject variables with regards to the normalized difference score, it is clear from these results that the major effect of family history on field difference scores for NI matches was manifested in the difference between male right handers with and without FH; with the male right handers without FH exhibiting field difference scores way above all other sub-groups. The effect of family history is also evident in the female left handers, but to a lesser extent. Any major sex effects can be seen as primarily due to the difference between right handed males and females without FH, and between left handed males and females with FH.

In summary, as far as the field difference for NI matches was concerned, overall sex and FH effects were noted, as well as a sex by FH interaction. When individual comparisons were made, however, results supported the notion that the major findings with respect to these difference scores were primarily due to the unusually large deviation in the difference scores of the male right handers without FH compared to all other groups, especially when compared to the male right handers with FH. The female left handers with FH also deviated in a negative way from the other groups, but to a lesser extent.

Table 5 presents a breakdown of the number of subjects who exhibited a RVF advantage, a LVF advantage, or no visual field advantage, in each subgroup of subjects. In the last column of this table, the number of subjects in each subgroup who displayed a visual field advantage which was consistent with the subgroup average (maximum = 8) is shown. The cutoff scores for determining a left or right field advantage were determined as follows. Two frequency distributions were constructed for the normalized difference scores, one for the positive scores and one for the negative scores. A cutoff score in each distribution was found such that all scores higher than the cutoff were significantly different from zero at a probability of less than .05. The cutoff for the positive scores was 2.21 and for the negative scores was -1.92. Therefore, a normalized difference score of over 2.21 was considered a RVF advantage, and a difference score of less than -1.92 was considered a LVF advantage; all scores in between consituted no field advantage.

It can be seen in Table 5 that males more than females exhibited a RVF advantage. Male subgroups tended to differ more from each other in their distribution of visual field advantages, but were very consistent within subgroups (half or more of the male subjects within subgroups were consistent with their group mean). In contrast, the distribution of field advantages for the females was more

similar between groups, but females tended to be less consistent within groups (half or less of the female subjects within subgroups were consistent with their group mean). The distribution of visual field advantages was quite similar between handedness groups. Left handers did not have an increased number of subjects showing a lack of a field advantage, nor did they tend to show less consistency with the group mean. Females and FH+ subjects were most apt to show no visual field advantage. In general, 32 out of 64 (50%) subjects in this experiment showed a significant RVF advantage for NI matches.

As a final way of measuring variability and consistency of the difference scores within subgroups, the standard deviation of the difference score for each subgroup was compared and is shown in Table 6. Since the means in each subgroup differed, the standard deviations could not be directly compared, but were first divided by the mean of each subgroup and then multiplied by 10 to give a "corrected" standard deviation for each group. At the bottom of Table 6, the "corrected" standard deviation of the difference score for all male subjects, all female subjects, etc. is shown. Notice that the difference scores for females were most variable between groups (all females combined) and within each subgroup; while males were least variable between and within subgroups. FH+ subjects were more variable than FH- subjects within each subgroup and across

subjects. Finally, right handers tended to be less variable as a group compared to the left handers, and this trend was also observed within subgroups. In order to check whether the increased variability observed in some of the groups, especially the females and FH+ groups, was specific to the field difference score; the variability of Total RT was also noted for each group and corrected for mean performance. These corrected scores can also be found in Table 6 for each subgroup. Notice that females and FH+ subjects are <u>not</u> more variable with regards to their total RT compared to the other groups. This supports the notion that the increased variability of the difference scores for NI matches in these groups is not due to variable performance in general.

D. <u>Change Scores</u>

Change in RT over blocks of trials (improvement over time) was analyzed by calculating change scores for each day separately and for both days combined. The change score for Day 1 was calculated by subtracting the mean RT of Blocks 3 and 4 from the mean RT of Blocks 1 and 2. The change score for Day 2 was calculated by subtracting the mean RT of Blocks 7 and 8 from the mean RT of Blocks 5 and 6. The overall change score was calculated by subtracting the mean of Day 2 (Blocks 5-8) from the mean of Day 1 (Blocks 1-4). Change scores for Day 1, Day 2, and

overall change scores for each subgroup of subjects can be found in table 7.

A repeated measures ANOVA with two within factors (field and match) and three between factors was performed on each change score measure, and the results were as follows. For Day 1 change scores, there was a main effect for sex ($F = 4.66$, df 1,56, $p < .036$) and for handedness ($F = 5.92$, df 1,56, $p < .019$); females and left handers had lower change scores on Day 1 compared to males and right handers respectively (females = 65.0 ms, males = 93 ms, left handers = 63 ms, right handers = 94 ms). It could be noted that the change score for each visual field was almost identical (RVF = 80.0, LVF = 78.0). However, there was a family history by field interaction ($F = 10.1$, df 1,56, $p < .003$) which revealed that FH- subjects had significantly higher change scores in the RVF compared to the LVF (101 versus 77 ms, Scheffe post hoc test, $p < .05$) while FH+ subjects had higher change scores in the LVF compared to the RVF (79 versus 58, not significant).

There was also a trend ($p < .06$) for the handedness by field interaction. Right handers had higher change scores in the RVF compared to the LVF (102 versus 87) while left handers had slightly higher change scores in the LVF compared to the RVF (69 versus 57).

For Day 2 change scores, there were no significant main effects or interactions, and the same was true for

the overall change score (Day 1 minus Day 2). All change scores were then normalized by dividing by mean performance and then multiploying by 100. This was done so that the amount of change could be compared over different levels of performance. Repeated measures ANOVA's were performed on the normalized change scores, and the results obtained were similar to those obtained from the untransformed change scores. These results will therefore not be discussed.

E. Relationship of other subject variables to the RT measures

Four other subject variables (besides sex, handedness, and family history) were assessed, but not manipulated or controlled for, in this experiment. These four variables were number of left handed relatives, eye dominance, eye acuity, and hand position when writing (hooked or regular). The relationship of these variables to the RT measures were ascertained, and number of left handed relatives was found to have important and unexpected effects on some of the RT measures. These effects will be described here. The other 3 variables were not found to significantly affect the RT data. Breakdown by sex and handedness of these 3 variables can be found in Appendix 2, section C.

Number of left handed relatives: In previous sections, effects of the three subject variables separately and in interaction with each other were noted on the various

RT measures. More specifically, family history of left handedness, either alone or in combination with the other subject variables, was powerful in its effects on measures such as Total RT, the normalized difference score for NI matches, and overall change in RT over blocks of trials. In interaction with the other subject variables, family history of left handedness was shown to differentially affect the various subgroups of subjects in interesting ways. For example, family history was found to significantly affect total RT in males but not females and in left handers but not in right handers. A breakdown of total RT by subgroups shows why this was the case. Table 8 shows comparisons of family history negative and family history positive subjects on various performance measures. The first table on the left (Table 8a) shows the comparison for total RT. It can be seen from this table that FH- subjects are faster than FH+ subjects with the exception of right handed females where this finding was reversed. This reversal of the effect in right handed females is most probably responsible for the lack of an overall effect of family history in females and in right handers. Notice that family history affected the total RT of the other groups in a fairly equal way, i.e., it increased total RT by 60 to 65 ms (65 ms in male right handers was the largest difference). The second sub-table (table 8b) shows the same kind of comparison for the overall

normalized difference score for NI matches. Notice in this subtable that the effects of family history were to decrease the difference score but not in an equivalent way. It affected male right handers and female left handers more than it did the other two groups. For the overall change score, FH- subjects all had higher change scores compared to FH+ subjects, but some groups show larger differences between FH- and FH+ than others. These comparisons are presented to illustrate an important point, that the effects of a positive family history were not always the same in each of the groups. This fact led to the search for some other variable that might be accounting for these differential effects. It was discovered that not all subjects had the same number of left handed relatives, although each positive subject had to have at least one primary or two second-degree left handed relatives. Many of the positive subjects however, had more than one primary left handed relative and some had a number of second degree left handed relatives.

Creation of the variable "relatives"

A new variable called "relatives" was created, where one point was given for every primary left handed family member and a half a point was given for every secondary left handed family member, so that each positive subject was given a score on "relatives" which was simply the sum

of their points (all half scores were rounded upward). Scores on "relatives" ranged from 1 to 3, with an overall mean of 1.87. However, the four family history positive subgroups did not have an equal number of left handed relatives. The mean score on the variable "relatives" for each of the four family history positive subgroups is shown in Table 9, where it can be seen that male right handers and female left handers had more left handed relatives than male left handers and female right handers. The effect of "relatives" was therefore ascertained for a number of dependent measures.

One-Way ANOVA's

One-way ANOVA's with "relatives" as the independent variable were performed on Total RT, Total Difference Score (normalized difference score for NI matches), and the overall change score, since these were the three dependent measures that seemed to be most affected by family history. "Relatives" had no significant effect on Total RT nor on the overall change score, but it did significantly affect the Total Difference Score ($F = 4.25$, df 2,30, $p < .024$); subjects with a score of 1 on "relatives" had a difference score of 2.88 ($n = 10$), subjects with a score of 2 had a difference score of 2.43 ($n = 16$), and those subjects with a score of 3 on "relatives" had a difference score of -4.90 ($n = 6$). Post hoc Scheffe analyses revealed that Groups

1 and 2 did not differ significantly but did differ from Group 3 ($p < .01$). It is observed then that as score on "relatives" went up, the difference score went down and even became negative, which is indicative of a LVF advantage for NI matches. It should be noted that all of the data dealing with "relatives" should be interpreted with caution because of the unequal group sizes.

Convariance analyses with "relatives"

In order to try to determine more precisely the relationship of "relatives" alone and in interaction with the other subject variables, a number of ANOVA's and ANCOVA's (analysis of covariance) were performed. Major findings for these analyses are described below; other findings related to "relatives" can be found in Appendex 2, Section C. These analyses were done on the family history positive subjects only. Family history was therefore excluded as an independent variable and "relatives" was used in its place. It was felt that this analysis made more sense statistically because if all the subjects were combined, the ultimate effect of adjusting for the covariate "relatives" is to give all subjects a family history, thus cancelling out any effect of the family history variable. Separating out the family history positive subjects made sense for another reason as well. The use of a covariate assumes that the covariate is linearly

distributed among all the subjects (if all the subjects are being used in the analysis). Although this assumption might reasonably hold for the family history positive subjects, there was no strong reason to believe that having no left handed relatives compared to having one left handed relative was equivalent to a comparison between having one versus having two left handed relatives. In other words, the distance between zero and one on the hypothetical continuum "relatives" may not be the same as the distance between one and two or between two and three and so on. The results of these analyses on FH+ subjects only were as follows.

Analysis 1: When "relatives" was covaried out, the effects of sex and handedness on Total RT and Total Difference Score in the FH+ subjects were as follows. There were no effects on Total RT. The only effect on the Total Difference Score was for the covariate itself ($F = 5.37$, df 1,27, $p < .03$). This meant that the covariate "relatives" was significantly influencing the Total Difference Score, but the covariance analysis does not elucideate the type or pattern of this influence.

Analysis 2: "Relatives" as a separate independent variable

In order to ascertain the influence of "relatives" on the Total Difference Score in FH+ subjects more precisely, it was entered into the analysis as another independent

variable. Therefore, the effects of sex, handedness, and "relatives" on Total Difference Score was tested with the following results. There was a main effect for sex ($F = 4.5$, df 1,20, $p < .05$); males had a higher normalized difference score compared to females (2.33 versus 0.07). There was also a main effect for "relatives" ($F = 8.8$, df 2,20, $p < .002$), subjects with a score of 1, 2 and 3 on "relatives" had a normalized difference score of 2.88, 2.43, and -4.90 respectively. There was a handedness by "relatives" interaction ($F = 4.3$, df 2,20, $p < .03$); left handers showed a strong and progressive decline in Total Difference Score as number of relatives went up (4.71, 1.89, and -14.0), but this decline was not observed in right handers (1.05, 3.12, -0.35). In other words, the relationship between number of left handed relatives to the difference score is seen mainly in left handers. The relationship of "relatives" to the Total Difference Score in different subgroups of subjects can be found in Table 10. Notice that the difference between left handers and right handers lies mainly in the males; which accounts for a marginally significant sex by handedness by "relatives" interaction ($p < .07$). Male left handers show a progressible decline in the normalized difference score as number of left handed relatives goes up, but right handed males show relatively little effect; if anything, their difference scores go up slightly as the number of relatives goes up.

Analysis 3: Correlations with "relatives"

The differential effect of "relatives" in the two handedness groups can be observed when one looks at the correlation of "relatives" with Total RT and Total Difference Score in the two handedness groups. In all subjects combined, the correlation of "relatives" with Total RT was only 0.188, a nonsignificant correlation. In right handers only, the correlation was even lower ($r = 0.129$). However, in left handers, the correlation of "relatives" with Total RT was 0.498, which was significant ($p < .002$). In left handers then, as number of left handed relatives went up, Total RT also went up; this relationship was not observed in the right handers. As far as Total Difference Score was concerned, its correlation with "relatives" in all positive subjects was -0.41 ($p < .01$), the correlation in right handers was -0.358 ($p < .02$) and in left handers was -0.399 ($p < .002$). The correlations were similar, but it should be kept in mind that the pattern of the relationship between Total Difference Score and "relatives" was not the same for males and females within and between the handedness groups (see Table 10); and in male right handers there is very little relationship between number of relatives and the difference score while in the other groups it was negative.

The foregoing analyses bring to light some interesting effects of number of left handed relatives in the different family history positive subgroups. Data were presented that showed a strong relationship between "relatives" and the Total Difference Score. It will be recalled that family history had a differential effect on the difference scores of right and left handed males and females; it affected male right handers the most, and also the left handed females, and these two groups also had the highest number of left handed relatives (see Table 9). But a higher number of left handed relatives was not associated with lower difference scores in the male right handers (see Table 10); therefore, the effect of family history on the difference scores of right handed males can not be attributed to the fact that this group had the most left handed relatives. However, a higher number of left handed relatives was associated with a lower difference score in the left handed females, so this relationship may partially underlie the strong effect of a positive family history in this subgroup of subjects.

Can number of left handed relatives account for the differential effects of a positive family history on Total RT? Apparently not. As can be seen on the left side of Table 8 (Table 8a), the effects of family history on Total RT were virtually identical for three groups (male right handers, male left handers, and female left handers), yet

these three groups had a differing number of left handed relatives. The major difference in Total RT occurrrd between male and female right handers (family history significantly increased RT in the males but decreased RT in the females), but it will be recalled that "relatives" was not correlated with Total RT in right handers, only in left handers. Therefore, a differing number of relatives cannot easily account for these effects either. These examples help to point out that "relatives" may be an important variable to keep in mind when interpreting the effects of a positive family history on only some data, especially that of left handers. There is evidence to suggest that number of left handed relatives is related to field difference scores, but this relationship cannot easily account for the strong effects of family history on right handed males. There was also evidence that "relatives" was related to speed of RT, but only in left handers. "Relatives" was not related to the overall change score.

F. Intercorrelations and regression analyses

An intercorrelation matrix of many of the RT measures with each other and with other ancillary performance measures (which will be discussed in later sections) is shown in Table 11. Correlations of the RT measures with each other can be found in the lower right hand section of the matrix. Notice that speed of RT (Total RT) was

negatively correlated with the Total Difference Score (normalized field difference for NI matches), and with the match effect (overall NI-PI difference). In other words, as Total RT went up, the normalized field difference score and the NI-PI difference went down. Total RT was positively correlated with RT errors (total number of errors made in the RT experiment); as total RT went up, number of errors also went up. The match effect was negatively correlated with RT errors, as the NI-PI difference went up, RT errors went down. The Day 1 change score was not correlated with any of the other RT measures, but the overall change score was negatively correlated with Total RT, as the overall change score from Day 1 to Day 2 went up, total RT went down; certainly not an unexpected finding.

Regression analyses: Forward stepwise regression analyses (SPSS) were performed on a number of criterion variables using the variables of sex, handedness, and family history as predictors.

Four criterion variables were used in the regression analyses, and results will be discussed in order: 1) Field effect-raw score difference between the LVF and the RVF mean; 2) Total difference score-normalized field difference score for NI matches; 3) Total RT-overal mean RT; 4) Overall change score-normalized change score from Day 1 to Day 2.

1) Field effect: Sex was the first variable entered in the regression equation, because it accounted for the most variance in the field difference scores (7.3%). Family history was entered second, and it accounted for an additional 6.2% of the variance. Both variables together therefore, accounted for 13.5% of the variance in field difference scores. Handedness did not enter into the equation. A summary table of all the regressions to be discussed (including this one) is shown in Table 12. This table shows which predictors were entered into the regression analysis (first column), the Pearson r coefficient for that predictor with the criterion variable, Multiple R (the correlation of all the variables that have been entered up to that point with the criterion variable), Multiple R^2 (the amount of variance accounted for by all the predictors entered significantly into the analysis at that point), the amount of additional variance accounted for by each new predictor, the F statistic, degrees of freedom, and the signficance level for each predictor added.

2) Total difference score: The regression analysis for this field difference score was different in comparison to the raw difference score above. Family history was the first variable to be entered into the analysis, accounting for 8.6% of the variance, while sex was entered second, and accounted for an additional 7.8% of the variance.

3) Total RT: Only family history emerged as a significant predictor of Total RT (FH- subjects faster than FH+), and accounted for 8.3% of the variance.

4) Overall change score: None of the subject variables accounted for any significant proportion of the variance in this change score measure.

The variable "relatives" (number of left handed relatives) was substituted for family history in the above regression analyses to ascertain whether it would account for more or less variation. For Total RT and Overall Change Score, the variable "relatives" did not enter as a significant predictor. For the two difference score measures, "relatives" accounted for more variance than did family history. For the field effect (raw score difference in RT between the two visual fields), the variable "relatives" was entered first, and accounted for 9.2% of the variance (as number of relatives went up, difference score went down). Sex entered second, and added an additional 7.0% to overall prediction. Table 12 shows all the relevant regression statistics for this analysis. The biggest difference in predictive ability between family history and "relatives" occurred with the Total Difference Score (normalized difference score for NI matches). "Relatives" accounted for almost double the variance in Total Difference Score compared to family history (15.8% versus 8.6%).

Sex added an additional 6.2%. "Relatives" and sex together accounted for 22% of the variance in Total Difference Score (see Total R^2).

In summary, when sex, handedness, and family history were used as predictors, sex emerged as the most significant predictor of raw field difference scores while family history was more influential in predicting normalized field difference scores. "Relatives" however, was a better predictor of both field difference scores than any of the subject variables. Handedness did not significantly predict any of the RT measures.

Cognitive data

A. Methods of analysis used

The second part of the present experiment involved the assessment of a number of ancillary performance measures for the purpose of further explaining the variability in the RT measures within and between subgroups of subjects. These measures were selected mainly to survey particular aspects of verbal, spatial, and motoric abilities, and were not meant to be an exhaustive evaluation of all cognitive abilities. The cognitive tasks that were used are briefly described, and the means and standard deviations for each task of all the subjects collectively are given in Appendix 2, section D. These means were compared to standardized norms, if such were available. Three-way ANOVA's with sex,

handedness, and FH as independent variables were then performed on each task separately; and the results of these ANOVA's can also be found in Appendex 2, section D. A summary of these findings will be presented in the main text. An intercorrelation matrix of all the measures with each other and with the RT measures is presented in Table 11, following which a factor analysis was performed on the cognitive data in order to extract out major groupings of these measures. Two of the emerging factors, a Verbal factor and a Spatial factor, were then used in subsequent analyses in place of the cognitive tests' scores.

In order to assess the relationship of the cognitive measures with the laterality measures, the RT data was condensed and three variables were extracted. These three variables were Total RT, Total Difference Score (normalized difference score for NI matches), and the overall change score (Day 1 minus Day 2). These three variables, along with the two cognitive factors (Verbal and Spatial) and the subject variables, were entered into a number of stepwise regression analyses. This was done to ascertain whether any of the variability in the RT measures could be additionally explained by the cognitive factors alone or in conjunction with the subject variables. These analyses were also tried in reverse, i.e., to ascertain whether the RT measures alone or in conjunction with the subject variables were predictive of cognitive performance.

B. Summary of cognitive test findings: Effects of the three subject variables separately and in interaction

Sex effects: Males were significantly faster than females on the hand rotation task and made fewer errors. Difference in RT between the two hand orientations (normal and reversed) was smaller in males. Males attained higher scores on the Street Closure test and on the Mental Rotation test. Females had higher scores on the Vocabulary and the Abstract Reasoning tests. In other words, males did better on tests measuring aspects of visual-spatial reasoning abilities while females did better on verbal reasoning.

Handedness effects: Right handers were faster on the hand rotation task, and had a smaller difference in RT between the two hand orientations compared to left handers. Left handers attained higher scores onthe EFT and on Abstract Reasoning, while right handers did better on Street Closure. Right handers had higher right hand scores on the Purdue Pegboard and left handers had higher and equivalent left hand scores.

Family history: FH+ subjects had a smaller difference in RT between the two hand orientations on the hand rotation task compared to FH- subjects. FH+ subjects had smaller absolute difference scores on the Purdue Pegboard. There were no other simple effects of a family history of left handedness.

Sex by Family History: Whenever this interaction occurred, as it did for hand rotation (number of errors), EFT, Block Design, and Mental Rotation, it manifested itself in the same way. In all cases, presence of a family history of left handedness decreased test scores in males (and increased number of errors on hand rotation), and increased test scores in females (decreased errors on hand rotation). This effect was especially seen in the left handed females (scores of left handed females on these tasks were always increased by presence of a left handed family history), but the three way interaction of sex, handedness, and family history was not significant on any of these tasks. It could be noted that the tasks for which this effect of family history was noted were tasks that required some visual-spatial, as opposed to verbal, reasoning abilities.

Sex by handedness: For hand rotation (total RT), male right handers were fastest while male left handers were slowest. For the difference in RT between normal and reversed hand orientations, male right handers had the lowest difference in RT while male left handers had the highest difference. On the mental rotation test, male left handers had lower scores compared to male right handers, but female left handers had higher scores compared to female right handers. For abstract reasoning, male right handers had the lowest mean score while female left handers had the highest mean score.

Handedness by family history: Presence of a family history of left handedness differentially affected the handedness groups on two tasks, hand rotation and the EFT. On hand rotation (number of errors), it significantly affected left handers' scores (increased errors in males and decreased errors in females) but had no effect on the scores of right handers. For the difference score (reversed-normal hand orientation), a positive family history affected scores of right handers much more than it affected scores of left handers (it lowered the difference score for both handedness groups, 125 ms for right handers and 32 ms for left handers). On the EFT, presence of a family history decreased scores in right handers and increased scores in left handers.

A summary table of how each subgroup of subjects performed on each of the cognitive measures is presented in Table 13. A positive sign (+) indicates better than average performance compared to all subjects combined, a negative sign (-) indicates below average performance, and an equal sign (=) indicates that performance was right at the mean for all subjects. It should be noted that a + sign for the Hand Rotation task (total RT, number of errors, and difference in RT between normal and reversed orientation) indicates lower scores on these measures, while a + sign for all other measures means that scores were higher.

Since the cognitive measures tended to correlate highly (see Table 11), it was felt that a factor analysis

of all the scores would help reduce the data and pull out significant clusters or variables.

C. Factor Analysis

Scores on all cognitive and motor measures were factor analyzed by means of a principal component solution with varimax rotations. Commonalities of one were used and the number of eigenvalues greater than one determined the number of factors retained for rotation. A six factor solution accounting for 70% of the variance emerged of which three of the factors were interpretable. These were a verbal factor, a spatial factor, and a motor factor. Those tasks that loaded heavily on the verbal factor were Similarities, Vocabulary, and Abstract Reasoning. Those tasks that loaded heavily on the spatial factor were the Hand Rotation task (total RT and number of errors), Closure, EFT, Block Design, and mental rotation. Tasks that loaded heavily on the motor factor were the Purdue Pegboard (bilateral score and right-left score) and the Hand Rotation task (reversed-normal difference score). The verbal factor and the spatial factor together accounted for 60% of the variance; therefore these two factors were retained for further analyses. Factor scores, one for Verbal and one for Spatial, were obtained for each subject by direct solution; these scores had a mean of zero and a standard deviation of one. These scores were then used in place of the

individual cognitive test scores in subsequent analyses. Three-way ANOVA's on these two factors were performed with sex, handedness, and family history as the independent variables. For the Verbal score, there was a main effect for sex ($F = 9.38$, df 1,56, $p < .003$); female had higher verbal scores (.372) compared to males (-.372); there was no overlap. For the Spatial factor, there was also a main effect for sex ($F = 9.84$, df 1,56, $p < .003$) this time in the opposite direction; males had higher spatial scores (.320) compared to females (-.320). There was also a sex by family history interaction ($F = 22.3$, df 1,56, $p < .0001$) for the Spatial factor. Presence of a positive family history decreased spatial scores in males and increased spatial scores in females. Scores on the Verbal factor and the Spatial factor for each of the eight subgroups of subgroups of subjects can be found in Table 14.

D. Relationships of Verbal and Spatial with other variables

Spatial: As can be seen from Table 11, the Spatial factor was highly correlated with all the visual-spatial tasks, and with some other measures as well. For example, it was highly associated with major in school (1-Science and Engineer majors, 2-Social science and humanities majors), such that Science and Engineer majors tended to have higher Spatial scores ($r = -0.50$). The spatial score was also significantly associated with two RT measures, it was

positively associated with the Total Difference Score (r = 0.22): and negatively associated with RT errors (r = -.38). The spatial factor was not found to be generally influenced by number of left handed relatives, but when "relatives" was covaried out in the FH+ subjects only, there emerged a significant sex by handedness interaction which was not seen in the overall analysis. This interaction in the FH+ subjects ($F = 7.9$, df 1,3, $p < .01$) was such that left handed males showed the poorest performance on the spatial factor while left handed females showed the best performance; performances of right handed males and females were intermediate.

Verbal: The verbal factor was also associated with major in school, but in the opposite direction (r = .31); Social Science and Humanities majors tended to have higher Verbal scores. The Verbal factor was not significantly associated with any of the RT measures, nor with "relatives".

E. Regressions

In order to ascertain whether any of the variability in the RT measures could be additionally explained by the cognitive factors, a number of forward stepwise regression analyses (SPSS) were performed. The three criterion measures were Total RT, Total Difference Score, and Overall Change Score. Results were as follows.

1) Total RT: Neither of the cognitive factors entered significantly into the regression equation, nor did they add to family history in predicting Total RT (it will be recalled from a previous section that family history was the only subject variable to be predictive of total RT).

2) Total Difference Score: When the Verbal and Spatial factors were regressed on to the Total Difference Score, the Spatial factor emerged as a significant predictor, accounting for 14.5% of the variance (as Spatial factor score went up, the difference score went down). When the subject variables were entered into the analysis along with the two cognitive factors, the Spatial factor still emerged as the best predictor of the Total Difference Score. Family history added to the prediction, accounting for an additional 7.3% of the variance. When "relatives" were substituted for family history in the analysis, the Spatial factor still entered first, and "relatives" accounted for an additional 10.9% of the variance in the Total Difference Score. A summary of these analyses can be found in Table 15. Note that "relatives" again added more to the prediction of the difference score than did family history. The Spatial factor along with "relatives" accounted for 25.4% of the variance (see Table 15 under "Multile R^2). It was interesting that sex did not enter as a significant predictor in this analysis, as it did in a previous analyis looking at the

effects of the subject variables only on the Total Difference Score. When the Spatial factor was included in the analysis, sex dropped out of the equation. This was most probably due to the fact that some (if not most) of the variance in Total Difference Score accounted for by sex was shared by the Spatial factor (sex and Spatial factor scores were significantly correlated Pearson r = 0.32). The Spatial factor turned out to be the more important variable. Since the variable "Major in school" was also highly correlated with the Spatial factor, it, too, was entered into the regression analysis, but did not alter the equation. Finally, all tasks that were highly correlated with the Spatial factor were entered into the regression analysis of Total Difference Score, but no one task predicted difference scores better than the Spatial factor score.

3) Overall Change Scores: None of the cognitive variables significantly predicted overall change scores.

Regression analyses were also performed in reverse, i.e., RT measures were regressed on to the two cognitive factors, in order to ascertain whether laterality measures would be predictive of cognitive performance. None of the RT measures were predictive of verbal performance. The only variable that significantly predicted scores on the Verbal factor was sex; which accounted for 13.7% of the variance (females scored higher, males scored lower). For

the Spatial factor, the Total Difference Score was most predictive, accounting for 14.5% of the variance (as difference score went up, Spatial factor score went up). Sex entered second, and accounted for an additional 6.4% of the variance. Note that family history, "relatives", and handedness did not add anything to this prediction.

F. Interrelationships of the Spatial score, the Total Difference Score, and family history broken down by sex

It was observed that there was a high correlation between the spatial score and the field difference score in the overall sample. Separate correlations were also performed for each group (right handers only, left handers only, etc.), and this relationship held for all groups except the females. The correlation of the spatial score with the total difference score was only .16 in females, a non-significant correlation, whereas for males, it was highly significant ($r = .47$). Other relationships were then broken down by sex to see whether the same phenomenon occurred. Table 16 shows these breakdowns. It is obvious that the difference between the sexes in the relationship between the spatial score and the difference score was not the only major difference. The relationship of the Total Difference Score with family history and with "relatives" is much higher in the males. The most amazing difference between the sexes occurs with the correlations of the Spatial score with family history and with "relatives". The spatial

score is negatively correlated with family history in females. This same trend holds for the relationship of the spatial score with "relatives". This explains why there were no significant effects of family history or "relatives" on the spatial score in the overall sample; because males and females show opposite and significant relationships between these factors. These results show that presence of a positive family history lowers spatial scores in males but raises spatial scores in females. Additionally, the strength of the associations of the Total Difference Score with the spatial score and with family history are much greater in males compared to females.

Discussion

The findings will be discussed in the following order: the general experimental findings, findings related to individual differences, and findings that bear on the relationship between laterality and cognition. Within each section, the findings will first be discussed with relation to the hypotheses advanced in the introduction; other related findings will then be brought in and evaluated.

I. General experimental findings

A. Match effect

Hypothesis 1: There will be faster reaction times to PI as compared to NI matches. This hypothesis was supported across all experimental conditions in all subjects. Additionally, the NI-PI difference (difference in RT between the two types of matches) remained fairly constant across conditions, though not between subjects. The NI-PI difference, according to Posner and others (Posner and Mitchell, 1967, Posner et al., 1969) resulted from the fact that the NI match required a translation from a visual to a verbal representation, while the PI match required no such translation in order to be executed. Presumably, the NI-PI difference was equivalent to the amount of additional

processing time needed to make this verbal translation. The fact that this amount of time varied among individuals is interesting, for it suggests that some subjects may require more time utilizing verbal codes. However, certain facts mitigate against the interpretation that the observed individual differences in the magnitude of the NI-PI difference is due to differential efficiency in the use of verbal codes per se. Firstly, smaller NI-PI differences were associated with slower RT and an increase in RT errors; therefore, smaller NI-Pi differences tended to be associated with less efficient performance on the RT task. Secondly, the NI-PI difference did not change significantly with practice; a change over time might be expected if one was indeed measuring efficiency of utilization of verbal codes. Thirdly, the NI-PI difference did not correlate at all with verbal ability; this is difficult to interpret if one accepts Posner's hypothesis that a verbal code need be utilized to make the NI match. If a verbal translation was not being performed on the NI matches, however, then how does one explain the presence in this experiment of a strong right visual field advantage for the NI matches (see next section for a discussion of field effects). A RVF advantage for the NI matches was hypothesized because it was assumed that a verbal translation was necessary for the NI match, a translation that would be more efficiently performed by the left hemisphere. Of course, it is quite

possible that the transformation involves something in addition to a verbal code, or that it involves something other than the use of a verbal code, with the proviso that whatever is involved is more efficiently handled in the left hemisphere. For the present, the former interpretation is more parsimonious with the data, and it helps to explain between-subject differences. Subjects may have relied on other strategies in addition to verbal ones, and this reliance on one or another strategy could change over the course of the experiment. The fact that the visual field advantage for the NI matches decreased over the last four blocks of trials (see next section) provides some evidence for the notion that the strategies for making the NI match as quickly as possible changed somewhat over the course of the experiment; this change was associated with less reliance on the left hemisphere and inferentially with less reliance on the use of verbal strategies. Finally, the fact that many of the RT measures were more associated with spatial, rather than verbal abilities, provides some support to the notion that visual spatial strategies may have also been employed to make the NI match; a fact that helps explain the decrease in the RVF advantage for NI matches over time.

B. Field effects

Hypothesis 2: There will be faster reaction times to NI matches presented to the RVF as compared to the LVF. In general, this hypothesis was supported over all blocks of trials except for the final block of 32 trials. This advantage was not uniform across blocks and certainly not across subjects. The RVF advantage for NI matches was very small in the first block of trials. This advantage increased up to Block 3 and then slowly decreased afterward. During the final block, there emerged a very small and non-significant LVF advantage. Why is the RVF advantage for nominal matches lacking at the beginning and end of the RT experiment? Probably for two different reasons. Hellige (1976), Perl and Haggard (1975), and Holtzman (1979) all found an initial LVF advantage for letter processing. Holtzman and Perl and Haggard emphasized the important of initial orientation and adaptation to the experimental situation as possible contributors to this initial LVF advantage, while Hellige noted that the initial stages of letter processing, especially in the tachistoscope, may be more visual-spatial in nature, and thus produce a bias toward the right hemisphere.

As for the decreasing RVF advantage over the course of the experiment, Ward and Ross (1977) offered another explanation, that the subjects developed specific strategies for processing the presented information more efficiently.

Presumably, these strategies involve the left hemisphere to a lesser degree as the experiment progresses. However, more reliance on the left hemisphere for the processing of the NI matches (and therefore a larger field difference score) in the present experiment was associated with lower overall RT and with higher spatial abilities. It therefore may have been more advantageous to use a strategy that involved the left hemisphere to a greater degree. The fact that more reliance on the left hemisphere for this task was associated with better spatial ability is interesting in its own right and will be discussed in a later section.

It might be expected that the effect of practice on the observed visual field differences should be fairly constant across subjects, yet this was not the case. The trend toward a smaller RVF advantage for NI matches at the beginning and end of the experiment was not followed by all subjects. In fact, significant differences arose between the various subgroups of subjects with regards to the development of visual field asymmetries over the course of the experiment. For example, females had more of a tendency to exhibit a LVF RT advantage at the beginning and end of the experiment, while males tended toward a RVF advantage in RT over all blocks. Other interesting differences arose between family history negative and family history positive subjects. A complete discussion of individual differences in degree and pattern of visual field

asymmetries will be presented in later sections dealing with individual differences. These examples are mentioned here to illustrate a point; and that is, that although the visual field asymmetries obtained in this experiment may have been influenced by practice and strategy effects, it would be difficult to explain how these effects could account for the individual differences in the degree and the pattern of the asymmetries. The fact that individual differences emerged in other RT measures as well as in degree of the RVF advantage lends more support to the notion that the visual field differences reported here are related to some aspect or aspects of cerebral organization and lateralization.

With relation to visual field differences, it should be mentioned here that no overall visual field advantage obtained for the physical matches. This was in keeping with other reported findings that the hemispheres are equally efficient at processing easily extractable, low-level sensory features (Moscovitch et al., 1976) and with other reports that physical matches can be done using a variety of strategies, some of which may favor the left hemisphere and some of which might favor the right hemisphere (Segalowitz and Stewart, 1979). Moscovitch (1979) noted that most experiments that have required observers to indicate whether two letters are physically identical have found no visual field differences. He also noted

that only two studies found a significant LVF advantage for physical matching, and both these experiments used the shortest exposure durations, thus making the matching task much more difficult. Since in the present experiment the exposure duration was relatively long (100 ms), the result of no visual field advantage for the PI matches was not surprising. However, females did have a tendency to exhibit a LVF advantage for the PI matches, while males showed no differences or a small bias in favor of the RVF. These differences suggest that the sexes may have used different strategies when matching the letters. These differences will be discussed in the section on sex differences.

C. Block effect

Hypothesis 3: Reaction times to left and right visual field stimulation for both NI and PI matches will decrease over blocks of trials; in other words, there will be progressive improvement in speed of RT as the experiment progresses, although the amount of improvement may differ depending on the field. This hypothesis was supported for both visual fields and for both types of matches. The amount of improvement in RT over the eight blocks of trials differed. Over the first four blocks, there was an average decrease in RT of 79 ms, while over the last four blocks there was only an RT decrease of 13 ms. Actually, there was no significant decrease in RT after Block 4. If the

block effect is viewed as being synonymous with a practice effect (or effect of experience), then the effects of experience in this task were most pronounced initially but dissipated rapidly thereafter.

The pattern of performance over time, with the sharp decrease at the beginning, and the levelling off (asymptote) thereafter, also suggests a learning curve. Did this amount of learning differ between the two visual fields or between the two types of matches? It would seem, at least from the analysis of the overall data, that amount of learning was not differentially affected by field or type of match. In fact, the amount of improvement in RT over the first four blocks of trials for the RVF and the LVF was almost identical. However, an analysis of individual subjects shows that individuals differed not only in the overall amount and pattern of improvement in RT over time, but also in the amount of differential improvement in RT in each visual field. So, for example, family history positive subjects showed less overall improvement in RT over all eight blocks compared to family history negative subjects, and left handers and females showed less improvement in RT initially (over the first four blocks). It was also interesting that FH- subjects and right handers showed significantly more learning in the RVF, at least over the first four blocks. Positive subjects and left handers had a non-significant trend in the opposite direction. We see then

that the amount of learning over time in this RT task was affected most by individual subject differences. Thus, by studying the pattern of responses over time in addition to overall mean performance, important differences between subgroups of individuals emerged. This finding argues for the inclusion and the utilization of other performance measures besides degree of visual field asymmetry in laterality research in order to better elucidate the functional significance of differing patterns of brain organization on perceptual-motor and cognitive performance.

II. Individual Differences

Before the effects of individual differences in this experiment are discussed, a few points are worthy of mention. Individual differences in degree of visual field asymmetries have traditionally been interpreted as differences in cerebral organization or lateralization (Bryden, 1965, Hines and Satz, 1971, Levy and Reid, 1978, McKeever et al., 1973 to name just a few). This interpretation may not be fully justified unless the laterality tasks used are specifically designed to minimize or manipulate the contribution of other factors such as stimulus qualities and task demands that may contribute to the visual field effects obtained. Unfortunately, few studies of individual differences in cerebral asymmetries have discussed the validity of the experimental tasks employed or discuss

explicitly any steps taken to maximize validity (see Levy and Reid, 1978 for an exception). In the present experiment, every effort was made (and is explicitly stated) to either minimize, control, or experimentally manipulate factors such as stimulus qualities, task demands, effects of practice, and other factors that may have influenced individuals. However, it is possible that other factors which were not controlled may be operative. For example, different subject populations (e.g., men versus women) may be differentially predisposed toward different processing strategies or toward different patterns of attentional activity (see Kinsbourne (1970, 1973) during a laterality experiment. While such predispositions might be caused by underlying differences in cerebral organization, other explanations are possible. These other explanations will be discussed in the sections on individual differences, when they are relevant. It is important to keep in mind that different visual field patterns might emerge in different subject populations for reasons other than fundamental individual differences in cerebral organization. With these important points in mind, we will now turn to a discussion of individual differences.

A. Sex differences

On the average, males were somewhat faster than females on the RT task. This difference was not significant but

fairly consistent. McKeever (McKeever and Van Deventer, 1977; McKeever and Jackson, 1979) has found this to be the case in most RT experiments and has offered an explanation based on differences in "competitiveness" between the sexes in RT experiments. Males seem somewhat more motivated to attain very fast reaction times compared to females, and often request feedback on how fast they are performing. Another explanation could be that males are simply faster; but this explanation is not supported by the finding that males and females did equally well on the Purdue Pegboard, a test of fine motor coordination. This difference between the sexes in speed and competitiveness may have influenced the amount of decrement in RT over time. It will be recalled that females had a significantly lower RT change scores over the first four blocks compared to males, but smewhat higher change scores thereafter. RT of males seemed to decrease at a faster rate but reach an earlier asymptote compared to the females; the reaching of an earlier asymptote in males most probably was related to "floor" effects. These findings are interesting for they suggest that males and females may approach these kinds of tasks in a different way.

The most obvious difference between males and females were in the realm of field differences. Males had a significant overall RVF advantage in RT, and a highly significant RVF advantage for the nominal matches (31 ms). Males

even had a nonsignificant RVF advantage for the physical matches. In other words, males seemed to have an overall RVF bias; they were more dependent on the left hemisphere in this experiment. Females on the other hand, showed no RT advantage in either field and a nonsignificant RVF advantage for nominal matches (8 ms). Interestingly, females had a very small LVF advantage for the physical matches (3 ms), and three out of four females subgroups showed this effect. Another difference between males and females with regards to field effects was that males seemed more consistent and less variable within subgroups, whereas females were quite variable within and across subgroups. Its almost as if the performance of the males was more constrained by, or more dependent on, other variables such as family history and spatial abilities, while the females' performance was more unpredictable and less dependent upon other subject or cognitive variables. Findings that may be related to this have been reported. Andrews (1977) found that correlations between personal hand preference and family history of handedness; and between family history of handedness and lateralization of syllables and consonants; held more strongly for males than for females. This suggest that laterality patterns may be more heritable in males compared to females. Other explanations not directly based on genetic and or differential heritability of the sexes are also possible. The presence in many females of a LVF bias for

the physical matches coupled with a small RVF bias for nominal matches, suggests another explanation for the lack of and variability of overall field differences in females. It appeared that the females may have differentiated between the two types of stimuli (PI and NI) more than did the males. It could be said that the females were more dependent on the type of stimulus presented (more stimulus-bound). Whatever the case may be, it appears that the males stuck to one strategy more often, and therefore maximized the difference between visual fields, while the females used different strategies at different times. This task may have induced different processing strategies because there may not have been a clean separation between the verbal and the visuospatial aspects of the two types of matches. Examination of the overall visual field means showed that there was an overall RVF advantage in RT, but this effect was contributed to a great deal more by the males. The physical matches could conceivably be done in such a way as to produce no visual field asymmetry, because both verbal and nonverbal strategies could be employed. Perhaps males tended to emphasize the verbal aspects of the task while females tended to emphasize the visuospatial aspects, thus producing the LVF bias. The inference here is that females were using their right hemisphere for visuospatial processing in this experiment, and seemed more dependent on this hemisphere for visual processing.

One explanation for inconsistent field differences in females can be postulated. Kinsbourne (1970, 1973, 1975) hypothesized that the visual field differences at any given time depended not only on which hemisphere received the stimulus first, but also on the balance of hemispheric activation and attention at that time. According to Kinsbourne, a RVF advantage occurs for verbal or analytic tasks because the ongoing processing activates the left more than the right hemisphere, thereby biasing attention toward the LVF. Likewise, a LVF advantage is found for visual-spatial tasks because the ongoing processing activates the right more than the left hemisphere, thereby biasing attention toward the LVF. Its been suggested that this attention gradient may be an important factor in laterality experiments. Could it be that the reason for inconsistent visual field effects in females stems from the fact that the females' attention is biased toward the RVF when faced with the nominal match (because this particular task activates the left more than the right hemisphere), but biased toward the LVF when faced with a physical match (because this information activates their right more than their left hemisphere). But since the two types of stimuli, physical and nominal, were randomly intermixed in the experiment, the bias kept switching from one field to another, in other words, females looked like they were more "field-dependent".

The second major effect of sex in this experiment was on cognitive test scores; in general, females did better on verbal tests and males did better on spatial tests. The largest sex differences were observed on a test vocabulary (females better) and on mental rotation (males better). These results are consistent with other investigations (for review, see Buffrey and Gray, 1972 and Maccoby and Jacklin, 1974). In fact, the better performance of males on spatial tasks is one of the most persistent findings in the cognitive abilities literature (Anastasi, 1958; Buffrey and Gray, 1972), but it seems as if this superiority does not reliably appear until puberty (Harris, 1978). The sex differences observed in spatial abilities have stimulated the construction of an X - linked model of inheritance of spatial abilities (Stafford, 1961, Yen, 1975) which states that a sex-linked recessive gene contributes to high spatial ability; thereby explaining the findings that many more males than females exhibit higher spatial abilities. It would be predicted that the correlations of spatial abilities in families should be ordered such that mother-son correlations are higher than mother-daughter, but recent studies have not borne this out (DeFries et al, 1976; Park et al, 1978). Because the sex differences in spatial abilities do not reliably appear until puberty, its been suggested that other factors such as maturation and hormonal influences play an important role.

The data on sex differences in this experiment can probably be interpreted in at least three ways:

1) Females are more "bilateralized" (dependent on both sides of the brain for language processing) for language functions, which explains the smaller and inconsistent field differences very well.

2) Females are more "lateralized" (or at least more differentiated) in terms of their cognitive abilities. That is why their left and right hemisphere are activated by verbal and spatial information respectively.

3) The females data is not directly related to degree of laterality at all, but to other cognitive, strategic, attentional, hormonal, maturational, or other measure not manipulated in this experiment.

These alternatives are not meant to be mutually exclusive.

Evidence for (1) has accumulated, females have been shown to be less well lateralized on verbal tasks (Levy and Reid, 1978, Hannay and Malone, 1976a, Bradshaw et al, 1977) and on spatial tasks (Kimura, 1969, McGlone and Davidson, 1973). Additionally, "bilateralization" of language functions in females has been invoked as one explanation for females' superiority on verbal tasks (and as a consequence, poorer performance on spatial tasks) (Levy and Reid, 1978). According to this notion, those abilities that become bilaterally organized will be more

highly developed; but "bilateralization" of language functions leaves less room for spatial functions to develop to a high degree (see Levy, 1974). This notion has also been invoked to explain left handers' relatively better performance on verbal as opposed to spatial tasks. The notion of "bilateralization" of certain cognitive abilities in females can explain many diverse findings, but the major difficulty of this notion is how to explain the fact that during development, females seem more, and not less, lateralized for motoric and language functions (Buffrey and Gray, 1972) and they seem so at an earlier age. How do females proceed from more lateralization in childhood to less lateralization in adulthood, unless it is postulated that the progression of lateralization is discontinuous or decreases with age, especially in females, and this confers an advantage on language and verbal reasoning abilities. A word of caution is necessary here; lateralization and bilateralization are two notions that are probably not well understood, and it is certainly quite possible that many functions becomes more lateralized with age and many become less, and it may be more or less advantageous to have some functions go one way and some go the other way. In this context, it is interesting to note that Bradshaw and Gates (1978) found that for females, a LVF or no visual field advantage was often seen when they were engaged in making lexical decisions (words versus non-words). When overt naming was required

females showed the same RVF effect as males. Perhaps motoric functions are well lateralized in females, but other more integrative language activities (such as reading) are more bilateralized.

Evidence for (2) has also accumulated, especially with regards to development. Females seem more lateralized for motor and speech earlier in development; and even as adults seem more strongly right handed (Sherman, 1978; Annett, 1970). In this study, the females had higher absolute right-left difference scores on the Purdue Pegboard. Its possible that social influences affect females more, and that is why they are more right handed, but this doesn't explain earlier and stronger lateralization of motor and speech functions in girls. Witelson and Pallie (1973) in a small sample of infant brains, found more anatomical asymmetries in the female brains. One way of explaining the developmental data is to say that girls look like they are more lateralized earlier only because they mature earlier. The differential maturation rate allows girls to be more precocious in verbal development and to develop consistent hand preference earlier. Differential maturation may be the casual factor underlying the sex differences observed, and not different lateralization.

Evidence for (3) is only beginning to emerge in the sex differences and cognitive literature. Some discussion

of maturational and attentional factors has already been presented. As far as cognitive and strategic factors are concerned, not enough research into the issue of how different individuals approach problems and what strategies they use to solve them has been done. One theory relevant to sex differences is that of Sherman (1967, 1971) and is sometimes referred to as the "bent-twig" hypothesis. This hypothesis states that females develop a preference for left hemisphere and/or verbal approaches to problem solving because more frequent verbal precocity in females bends the twig, so to speak, in favor of these kinds of approaches. This bend in females is seen as being culturally reinforced by differention training of the sexes, so that females less often than males develop good spatial skills and hence may neglect more right hemisphere approaches to problem solving. This theory is speculative but it helps explain some of the cognitive differences between the sexes. It doesn't explain why in this experiment, the females looked as if they were particularly emphasizing the visual spatial aspects of the Posner task; if anything the males seemed to be relying more on left hemisphere verbal strategies.

There is probably no one explanation for the sex differences found in the present experiment, or in many of the laterality experiments that have reported sex differences. Problems in interpretation of laterality findings

rest not only on the presence of discrepant findings, but also on the misuse of terms such as lateralization and bi-lateralization, which are often used to explain such findings. These terms are often used as causal explanations of the relationships that are seen, but they may very well be only correlates; and other genetic and hormonal factors may indeed determine these complex relationships. The notion that difference in rate of maturation is responsible for sex differences in cognition has already received some support. Waber (1976, 1977) looked at early and late maturers of both sexes to see whether the effect of rate of maturation was greater than the effect of sex. Results supported the notion that rate of maturation was more important, in that within each sex, late maturers scored better than early maturers on all spatial tests, no differences were found for verbal tests. Overall sex differences were very small. Cerebral lateralization was also assessed in this study through the use of dichotic listening. In the older age group (8-10 grade), the late maturers consistently showed a strong REA, while early maturers showed a very small REA and sometimes a LEA. No differences were found in a younger age group (5-8 grade). Thus in both sexes, the rate of physical maturation was systematically related to spatial ability as well as to lateralization of linguistic perception. These relationships don't seem to

emerge clearly until after puberty. Harris (1978) presents evidence to support a biphasic mechanism of hormonal action in behavior; there is a high secretion of sex hormones in the first year of life and then again at puberty. These hormones may very well influence brain organization early in life; but some effects may not be clearly observed until puberty. The results above suggest that precocious development may be related to less functional asymmetry of the brain and less spatial proficiency. This might explain apparent discrepancies in the literature surrounding the lateralization issue in females, who seem to show greater lateralization earlier, but less lateralization compared to males when adults. This may not be a discrepancy at all, if lateralization is viewed as a discontinuous process contingent upon maturational gradients. These gradients interact with development of cognitive asymmetries in the 2 sexes. Late maturers (more boys on the average) may have a protracted opportunity to establish language in the left hemisphere; then the right hemisphere can become the sole domain of nonverbal spatial functions. It seems as if the male brain is more rigidly organized and less flexible in the event of environmental trauma; but more balanced in terms of verbal and spatial proficiencies. More bilateral representation of verbal skills as seen in some females may be a factor in reducing risks of language and reading disorders

seem more often in boys (Benton, 1975), as well as in heightening verbal abilities. The more exaggerated hemispheric dominance seem in some males, with its accompanying risk of language disorders may have evolved not to heighten language abilities at all, but to protect highly specialized spatial skills which normally develop later in ontogeny (see Nottebohn, 1979).

B. Handedness differences

Hypothesis: If the phenomenon of left handedness alters cerebral lateralization mechanisms, then all left handed groups should show evidence of decreased lateralization compared to right handed groups. More specifically, if left handers as a whole are more "bilateralized" for language abilities, then all left handed groups will show a smaller visual field advantage for NI matches, or put another way, right handers will show a greater RVF advantage for NI matches.

The above hypothesis is based on a current controversy in the field of cerebral asymmetry, language lateralization, and handedness. This controversy concerns the possible existence, extent, and pattern of cerebral "bilateralization" in left handed individuals (i.e. to what extent may language be bilaterally represented in some or all left handers?). Data for and against "bilaterally" in left handers has been presented over and over again in the literature (Hecean and

Sauget, 1971; McKeever and Gill, 1972; McKeever et al, 1973; 1973; Hines and Satz, 1974 to name a few). Another controversy concerns the possibility of cognitive deficit in left handed individuals and in particular, a deficit in visuospatial abilities, due to "bilateralization" or to incomplete lateralization of language in left handers. Again, data for (Orton, 1937; Levy, 1969; Miller, 1971; Nebes, 1971) and against Sparrow and Satz, 1970; Hardych et al, 1976; Kutus et al, 1975; Hardyck, 1977) this possibility has accumulated. These two controversies can now be addressed, given the present experimental data. Certain issues felt to be related to these questions will be dealt with in the following order: 1) right hemisphere language contribution 2) "bilateralization" or weak lateralization 3) variability and consistency 4) pattern and distribution of visual field asymmetries 5) handedness and cognitive deficit. It should be emphasized here that no significant differences between right and left handers were obtained in the overall analysis for any visual field measure; nor was handedness a significant predictor of field difference scores or cognitive factor scores. Handedness effects did show up in other ways, however. 1) right hemisphere language contribution - There was some evidence of a greater right hemisphere contribution in the left handers as compared to the right handers. Whether this contribution was related

more to language reception or more to motor output cannot be definitely evaluated. Left handers were more efficient than right handers at detection of letters in the LVF; and this effect was most pronounced for the NI matches. Left handers also made fewer errors in the LVF compared to right handers. RVF detection latencies and errors did not differ in the handedness groups. Could the above effect be due to the fact that left handers used their left hand to respond, which is presumably controlled by the right hemisphere (see Herron, 1980 for further discussion). If so, it doesn't explain why in both this experiment and in Cohen's (1972) experiment employing a similar task, the left handers overall speed advantage was most pronounced for detection of NI matches in the LVF. This argues for the view that dependence on the right hemisphere for visual language processing may be greater in left handers as compared to right handers, which is in accord with both clinical and experimental work (Hecaen and Sauget, 1971; McKeever and Van Deventer, 1977). If efficiency of motor output from the right hemisphere could partially account for the observed visual field latencies in left handers, it would not necessarily negate a language hypothesis; it would simply lend further support to the notion that left handers may rely more on the right hemisphere (compared to right handers) for many kinds of activities, both motoric and linguistic in nature.

One point to keep in mind is that many right handers showed evidence of right hemisphere participation for letter detection, especially at the beginning and end of the experimental session. The amount of right hemisphere participation seemed to vary more with sex and family history. Handedness in and of itself was not found to be the crucial factor. 2) "bilateralization" or weak lateralization - These terms are usually taken to mean that certain individuals may show a lesser degree of lateralization, either motorically or linguistically. Field differences for left handed subjects were smaller compared to the right handers. This effect was largely due to the unusually high difference score generated in one of the right handed groups, the male right handers with a negative family history. On a motor task (Purdue Pegboard), there was no evidence of weak laterality in left handers; the difference scores of right and left handers on this motor task were virtually identical (but in opposite directions). Evidence of lowered difference scores on both the tachistoscopic task and on the motor task was seen more often in subjects with a positive family history, whether they were right or left handed. 3) Variability and consistency - Both right handers and left handers exhibited a wide range of field difference scores, this range was not noticeably larger in left handers. Within subgroups, the variability of the Total Difference Score was higher in all four subgroups of left handers. As far as

consistency was concerned, within subgroups, left handed were shown to be as consistent with the group mean as far as field effects were concerned as the right handers.

4) Pattern and distribution of visual field asymmetries - The distribution of visual field advantages was similar for the two handedness groups (see Table 5), and differed mainly between the sexes. A more compleling comparison between the handedness groups is the one of pattern of visual field asymmetric over the eight blocks of trials for NI matches (see Figures 8-15). When subgroups are compared with respect to handedness only (sex and FH held constant), the pattern of asymmetry over time is remarkably similar for the two groups. For example, female right handers with negative family history (FRH-) and female left handers with negative family history (FLH-) both had an initial LVF RT advantage for NI matches on Day 1 and on Day 2, and a small and consistent RVF advantage thereafter. Male right handers with FH+ and male left handers with FH+ manifested a RVF advantage for the first four blocks and no consistent advantage thereafter. The point of these comparisons is that even if the overall numbers differed (overall mean difference) slightly; the fact that the patterns are so similar when FH and sex are held constant argues against the notion that the pattern of language lateralization differs markedly in left and right handers. More differences emerged between FH- and FH+ subjects, whether they were right or left handed. The various

effects of family history will be discussed in the next section. 5) Handedness and cognitive deficit-Levy's hypothesis (Levy, 1969) of a generalized deficit in spatial ability in left handers went generally unsupported, and her finding of poorer performance on the Block Design subtest of the WAIS (Levy, 1969) in left handed subjects was not replicated. Some left handers most notably males, showed deficiencies on some spatial tasks and not others. It was previously discussed that differences on the spatial tasks were attributable mainly to sex in this experiment. The most notable handedness differences occurred on the "hand rotation" task; left handers were slower, made more errors, and took longer to respond to a reversed hand relative to a hand pictured in a normal orientation; and on the Street Closure Test. These findings suggest that the purported left handers' deficit at spatial tasks can not be considered to be a general one, but may exist when information about "left" and "right" has to be encoded and then verbally expressed. Findings for the closure task are in agreement with other findings that handedness was a significant factor in speed and flexibility of Closure (James et al, 1967; Yen, 1975), but again these effects were seen more often in the male left handers.

It should be noted that Levy's hypothesis of a spatial deficit in left handers rests on the assumption that since left handers are more often "bilateralized" for language

functions, the language functions take up space, so to speak, in the right hemisphere normally reserved for spatial functions. The hypothesis really states then, that "bilateralization" of language leads to lowered spatial proficiency. There was evidence in this experiment that field differences were related to overall spatial ability in that smaller field difference scores were associated with poorer spatial scores, especially in males. This finding will be discussed in a later section, the point here is that Levy's hypothesis is really misstated, and rests on the assumption that most left handers are "bilateralized" for language functions, which may not be the case at all.

Summary: The present data do not support the notion of equipotentiality, weak dominance, or inconsistency with regards to language lateralization among the generality of left handers, as has often been proposed (Zurif and Bryden, 1969; McKeever et al, 1973; Briggs and Nebes, 1976). Such statements might be more applicable to familial left handers and to right handers with left handed relatives. The most striking finding related to handedness in this study was the notorious lack of significant findings. Why was this the case? Three possible reasons are subject selection, control of relevant variables, and methods of analysis. The left handers used were strongly left handed, and were matched as closely as possible to the right handers. The family history variable was carefully controlled so that there was a clear

separation between FH- and FH+ subjects. Finally, the method of analysis used in a laterality experiment is important. If just one overall mean difference score is obtained for a left handed group and a right handed group, then it is conceivable that a statistically significant difference will be found between the two means, especially with a large sample size. This tells you nothing about the strength of the effect, and the consistency within groups. It was observed here that other indices, such as the distribution of field effects, the pattern of field effects over time, and variability within subgroups may provide more useful information.

There was some support that left handers may rely more on the right hemisphere for language reception and/or motor output, compared to right handers but how much is related to reception of visual language stimuli and how much to output remains as open question. Females too were seen as being more reliant on the right hemisphere and right hemisphere mechansims for visual language detection compared to males, but whether this involves input mechanisms, output mechanisms, or some process in-between the two is also an open question. These questions can better be addressed in an experimental situation where information about stage of cognitive processing can better be obtained.

It is suggested that handedness is an effect, not a cause, of cerebral laterality mechanisms coupled with

environmental influences. Handedness in and of itself cannot be used to predict laterality patterns. It is suggested that the relationship between handedness and laterality is largely incidental, and is based on some other possibly genetic factor that inclines humans to be left speech lateralized and right handed. The simplest explanation for left handedness is that it occurs either when this genetic predisposition is absent (see Annett, 1972) or when some unknown environmental contingency is present; in any case, it is determined at random. It should be emphasized that family history of left handedness is not the same as being left handed; these variables are not synonymous. Having a left handed family history is a "marker" so to speak, for the possible existance of a certain type of brain organization, which can be present in both left and right handers. Maybe this "marker" is related to possible absence of a genetic tendency toward left hemisphere speech lateralization. Evidence for and against this view, along with other possible effects of a left handed family history, will be presented next.

C. Family history of left handedness

Hypotheses: If genetic history of handedness is an important determinant of extent of hemispheric laterality, than differences in pattern or degree of response asymmetries should arise between those subjects with a positive family

history and those subjects without such history. More specifically, if presence of a left handed family history results in more equipotentiality between the two hemispheres of the brain, then individuals without left handed relatives should have greater asymmetries in response times to left and right visual field stimulation compared to individuals with left handed relatives.

If a genetic theory of brain laterality is indeed plausible, then the presence of a family history of left handedness should reduce field asymmetries in all the subgroups tested; although not necessarily in an equivalent way.

The major question to be addressed in this section is the role of family handedness factors (presence or absence of a family history of left handedness) in the cerebral lateralization patterns of all subjects tested, and more specifically, whether subjects with FH+ are either more, or less, dependent on the right hemisphere for language processing compared to those subjects with FH-.

It is necessary to consider why family handedness background should affect degree of lateralization of function at all. Numerous studies both clinical and experimental, have related family history of left handedness to aspects of laterality. Findings like these are often reported but rarely if ever explained. In point of fact, a genetic model of laterality such as that proposed by Annett (1972, 1975)

can be usefully applied to provide a plausible explanation of these effects. In this experiment, family history of left handedness (presence or absence) had remarkably strong and stable effects on all groups of subjects. Most interesting was the fact that family history affected not only degree of asymmetry, but was also found to have quite unique effects on other aspects of performance. Effects will be discussed in the following order: 1) speed of RT 2) change over time 3) field differences 4) effects of "relatives" 5) cognitive data.

1) Speed of RT: FH+ subjects were slower in both fields over all blocks of trials compared to FH- subjects. It is difficult to assign a motivational interpretation to this finding, for there is no obvious reason why FH- subjects would be more motivated to be faster in this experiment. Most subjects were not even aware that they were being chosen for the experiment because they had or did not have, left handed relatives. The fact that this finding was so robust and ubiquitous suggests some type of sensory-motor inefficiency which is not obvious in overt behavior in the FH subjects.

2) change over time: All subjects exhibited improvement in performance over blocks of trials; and in general, the amount of improvement decreased over time. In FH+ subjects however, this practice or learning effect was

attenuated after the fourth block of trials, so that the performance curve of FH+ subjects showed an earlier asymptote compared to FH- subjects. One way of interpreting this finding is to say that FH+ subjects do not profit as much from practice or prior learning experience. Another interpretation is that there is some interference or inhibition effects operative in the FH+ subjects over the last half of the experiment. Presumably, this interference accumulates over time, which is why the effect is not seen during the initial blocks of the experiment. What causes this interference in the FH positive subjects? Since this effect was unexpected, only post hoc explanations can be given. Perhaps these subjects fatigue more easily: Beaumont (1974) and Dijond (1980) note evidence in their research to support the notion that non-right handers (left handers and ambidexters) tend to show greater fatigue effects in some tachistoscopic experiments, and relate this finding to a greater diffusion in the brains of non-right handers. Presence or absence of FH was not studied in their experiments, but we might expect about half of these subjects to be FH+. Perhaps a diffuse brain organization was the more important factor in the studies of Beaumont and Dimond, rather than the handedness of the subjects. It was already noted that the FH+ subjects in this experiment were much slower overall; both this

finding and the practice attenuation effect cited above are suggestive of some possible neural inefficiency. These are very general explanations, but further inspection of the data revealed that the slowness and the attenuated practice effect in FH+ subjects occurred mainly for NI matches in the RVF in males. In fact, RT actually increased in these subjects over the last four blocks for NI matches in the RVF. This suggests that the effect was more evident in the left hemisphere. The significance and reliability of this result are as yet uncertain, but other findings can be brought to bear. McKeever and Hoff (1979) and Moscovitch and Smith (1979) both looked at laterality and performance differences between two groups of left handers, those who wrote in the "normal" way (like right handers) and those who wrote with an "inverted" or "hooked" writing posture. Their results are too numerous to report here, but their conclusions were as follows. McKeever and Hoff suggested that "inverted" writers may have an isolation or "disconnection" of left hemisphere visual and motor areas of the brain, which necessitated an additional transcallosal relay in order to output a response. In other words, there seemed to be an anomaly in this group of subjects with regards to visual-motor integration in the left hemisphere. Moscovitch and Smith (1979) came to the

exact same conclusions about their group of "inverted" writers. How do these findings relate to the effects of family history? It seems as if about 2/3 of "inverted" writers have a positive family history of left handedness (McKeever and Hoff, 1979). Also interesting is that over half of the "inverted" writers (Searleman et al, 1979) or even higher (McKeever and Hoff, 1979) are males. It seems as if inverted writing and positive family history may be related (sex may also be an important correlate). If this is the case, then their explanation of a "disconnection" of visual and motor areas in the left hemisphere becomes more interesting in light of the present findings, especially since the anomalous performance of the FH+ subjects was seen mainly in the RVF. Of course, since there was no effect in this experiment of hand position when writing for the left handed subjects, this explanation has to be considered very speculative.

3) Field differences: Field differences for nominal matches were affected most markedly by FH in this experiment. FH affected not only the degree of visual field asymmetries but also the pattern over blocks and the variability of field difference scores. The variability of the difference scores for NI matches in the FH+ subgroups was almost double that of the FH- subjects. As far as the degree of field differences were concerned,

presence of a positive FH was found to decrease difference scores in all positive subgroups in a fairly analogous way, by increasing RT more in the RVF compared to the LVF, thus decreasing the RVF advantage. This implies that FH+ subjects have a decreased dependence on the left hemisphere for language processing, and thus an increased dependence on the right hemisphere compared to FH- subjects. The mechanism underlying this increased dependence on the right hemisphere doesn't seem to be the same one underlying the smaller field effect observed in the left handers. Recall that the RT of left handers in the LVF was faster than that of the right handers, leading to a smaller field difference, in other words, the right hemisphere seemed more efficient in left handers. In the FH+ subjects, there is a suggestion of some inefficiency, especially of the left hemisphere. This supports the notion presented earlier that in the realm of laterality differences, having a left handed family history is not synonymous with being left handed. The fact that these effects were observed in both right and left handers supports the notion that the effects of a positive family history extend beyond the left handed condition, and suggests a genetically based brain organization that is characterized by some degree of equipotentiality between the two hemispheres of the brain. It may also be charac-

terized by some inefficiency of sensory-motor pathways, especially in the left hemisphere, but this finding remains to be replicated.

It was suggested earlier that the right hemisphere in FH+ subjects was more involved in language processing possibly as a consequence of less optimal efficiency or a greater fatiquability of the left hemisphere. Some support for this notion comes from the observation that most FH+ subjects showed a clear RVF advantage at the beginning of the experiment; but at some point later (this point differed depending on the sex of the subject) this advantage switched to the LVF. This switch came about because RT continued to decrease in the LVF but increase slightly in the RVF. FH- subjects tended to show a small LVF advantage at the beginning of the experiment with a subsequently greater RT improvement in the RVF. Clearly then, both the pattern and the degree of visual field asymmetries differed between the FH- and FH+ subjects.

The findings presented here support a genetic model of brain laterality such as that proposed by Annett (1975, 1976). This model postulates that inheritance of a dominant "right-shift" factor predisposes most individuals to be right handed and left speech dominant. This genetic tendency is accentuated by cultural in-

fluences toward dextrality. In the absence of the shift factor, the major operative factor is simply random variation; an individual with such inheritance could be right or left handed, even ambidextrous; and exhibit any type of laterality pattern. On the average, a group of such individuals would be slightly more right handed than left handed (because of cultural influences) and exhibit more variable and atypical laterality patterns compared to individuals who have inherited a shift factor. The only way to decide whether a person lacks a shift factor is not by looking at his own handedness but to look at family patterns of handedness. Families in which left handers and ambidexters abound will more likely have the postulated recessive trait in their genes, that is, the absence of the "right-shift" factor. Perhaps other indicators of possible "atypical" laterality patterns will be found besides presence of left handed family members, which will add significantly to prediction and understanding of brain organization.

What are the implications of this genetic makeup (i.e. lack of a "right-shift" factor)? Are there any structural manifestations? Studies by LeMay (1977) suggest that there are. She looked at the CAT scans of both right and left handers, noting the size of frontal and occipital lobe regions. In right handers, 61% had a

wider right frontal region, 19% had a wider left. Left handers were divided into FH- and FH+ groups. The FH- left handers were similar to the right handers (53% wider right, 18% wider left) but FH+ left handers showed a more equal distribution (35% wider right, 25% wider left). More importantly, only 60% of the FH+ subjects showed an asymmetry at all, compared to 80% of the right handers and 71% of the FH- left handers. The trends for the occipital region were very similar. LeMay points out that these neuroanatomical asymmetries could not result from hand usage, because many left handers showed a pattern similar to the right handers; but FH- and FH+ left handers differed; yet both groups are left handed. It seems as if the FH+ subjects are characterized not only by a more equal distribution of asymmetry, but they were most likely not to show any asymmetry at all.

An obvious question is whether there are any cognitive manifestations of this "atypical" brain organization. In the present experiment, family history per se did not significantly affect the overall cognitive data. It did however interact with sex to produce interesting effects on spatial scores; positive FH enhanced spatial proficiency in females and lower spatial skills in males. Its been shown that positive FH enhances memory for tonal sequence and timbre (Byrne and Sinclair, 1979) and also pitch memory (Deutsch, 1978); but it was found to

be negatively correlated with facial recognition performance (Gilbert, 1977). Traditionally, less asymmetry or laterality has been associated with reading disability (Orton, 1937) and more recently, a study of the CAT scans of 24 dyslexic patients (Hier et al, 1978) revealed numerous reversals of the usual asymmetries observed in normal subjects. Since positive FH seems to be associated with lessened or reversed asymmetries; then it might conceivably be an important risk factor in the development of certain learning or reading disorders; though not necessarily a cause of such disorders.

In this study, it was observed that FH interacted with sex and with handedness, such that not all FH+ subgroups were equally less asymmetric. This might be explained very simply by saying that not all FH+ subjects were genotypically similar; even though they all had left handed relatives. Not all subjects had the same number of left handed relatives, so the probability of inheriting the postulated recessive "marker" differed in each of the groups. Statistically, this difference was not sufficient to explain the interactions obtained, especially with the male right handers. The simplest explanation of the overall effects of "relatives" on the field difference scores is that number of left handed relatives was a more sensitive measure of FH than was the simple "presence or absence" designation.

In summary, results support a genetic theory of laterality similar to the one presented by Annett (1972). Presence of a family history of left handedness is viewed as a general "marker" for a more diffuse, less lateralized, brain organization. Although different inheritance has been proposed for the 2 sexes (Kocel, 1977; Schwartz, 1980), this has to await further research. This does not preclude the possibility that this genetic predisposition might affect males and females in a markedly different way, depending on other maturational and hormonal factors.

This "different" brain organization helps to explain certain "anomalies" associated with left handedness, to which it is also related. Perhaps the existence of a more diffuse and less lateralized system may predispose some individuals to developing cognitive or behavioral difficulties (dyslexia?), while in others it may result in more specialization of one cognitive area relative to others (excellent verbal skills, for example), or it may not manifest in overt cognition at all. Since this genetic predisposition leads to development of left handedness about 50% of the time, and over half of left handers are "familiarl" (Annett, 1975), then it follows that all those behavioral attributes associated with this genetic marker will also tend to be associated with left handedness to a lesser degree. So more lateral symmetry can lead to

cognitive difficulties, to cognitive specialists, to left handedness, or any combination of these things (left handed dyslexics or left handed cognitive specialists). If the underlying mechanisms can be elucidated, maybe we can better understand why some individuals go one way and some go another way.

D. Interactions of the subject variables

Sex by handedness: This interactin occurred mainly on cognitive tests; left handed males performed more poorly than right handed males on spatial tasks; but left handed females did not differ from right handed females. Handedness was significantly correlated with spatial abilities in males only; this agrees with other investigations that handedness effects on spatial abilities are seen in the males only (James et al, 1967; Yen, 1975). In both studies, the left handed males performed more poorly than right handed males; no handedness effects were obtained in females. Interestingly, Levy's hypothesis of a spatial deficit in left handers (Levy, 1974) was advanced after a study in which she compared spatial performance in right and left handed males; no females were used in the study. It seems as if left handedness, with its associated variability and increased dependence on the right hemisphere, is more compatible with the female brain

rather than with the male brain, possibly because cerebral organization seems to be more flexible in females and more rigid in males. It might be that any factor that upsets the "balance" of cognitive asymmetry, whether it be genetic (handedness or family history of left handedness, for example) or environmental (neurological insult), will have stronger or more deleterious effects on males compared to females. More "bilateralization" may even be advantageous in females; evidence for this will be presented below.

Handedness by family history: In general, both handedness groups were affected in the same direction on the laterality measures by the family history variable, while for the cognitive data, there did not appear to be any systematic effects of FH on the handedness groups. In many ways, right handers and left handers with negative FH were very similar; they showed similar patterns of asymmetries and a similar pattern of cognitive test scores. The right handers did have higher field difference scores; which justifies treating the two handedness groups as separate groups. Subjects with positive PH were much more variable, the right handers seemed to be more affected by a positive FH on the laterality measures, while the left handers with positive FH (familial) differed much more from the nonfamilial left handers on the cognitive tests

compared to the same comparison in right handers. The differences between FH- and FH+ groups in right handers and left handers were strong and reliable enough to consider these groups separate and distinct. Hardyck (1976) hypothesized a continuum of lateralization such that right handers with negative FH would be the most asymmetrically organized while left handers with positive FH would be most bilaterally organized. The present data support this hypothesis, and would additionally place left handers with negative FH very near to the right handers with negative FH; and place right handers with positive FH very near to left handers with positive FH at the other end. Although Hardyck did not hypothesize where females would be on this continuum, it is clear from the present data that they would most probably fall nearer to the "bilateralization" end of the continuum, with the left handed females with FH+ representing the most extreme end.

Sex by family history and 3-way interactions of sex, handedness, and family history: Probably the most interesting findings were thnse where sex interacted with family handedness background and handedness itself. In short, two subgroups seemed to stand apart from the rest, and they were the right handed males with negative FH and the left handed females with positive FH. The fact that family history of left handedness seemed to affect male

and female left and right handers differently makes the adoption of a simple genetic model of cognitive asymmetry more difficult. When a parametric design involving three originally orthogonal factors yields such strong significances owing to the anomalous performance of single groups, it is clear that more research is needed before drawing frim conclusions. It is clear that in order to tell the whole story about differential laterality patterns in relation to differential cognitive skills; at least three variables (sex, handedness, and FH) must be taken into account. Probably the major reason for the discrepant findings in the field of individual differences in lateralization is that the differential effects of handedness history on the two sexes has not been given justice. This is surprising because a careful search of the literature reveals that most studies that have carefully and systematically controlled for these two variables have obtained very interesting and consistent interactions on laterality and cognitive measures. Studies that have carefully assessed the effects of family history of left handedness without controlling for the sex composition of their samples (e.g., McKeever and VanDeventer, 1977; McKeever and Jackson, 1978) invariably obtain findings which are discrepant with other reports; and often lead to an incorrect conclusion regarding the effects of family

history on laterality patterns. So, for example, McKeever has found in many studies that the effects of a positive family history are to increase the likelihood of obtaining a RVF advantage in left handers; and decrease this likelihood in right handers. Most other studies have found a positive FH to decrease the magnitude or even reverse the direction of visual field asymmetries in both right and left handers (Zurif and Bryden, 1969; Hines and Satz, 1971), which is more in accord with clinical findings of more "equipotentiality" in the brain organization of right and left handers with left handed relatives (Luria, 1970; Hacaen and Sauget, 1971). The results of the present study provide a clue as to why there remains a controversy in the experimental literature surrounding the effects of familial left handedness. Positive FH seems to have stronger effects on performance asymmetries in right handed males and left handed females; the effect in both groups is to significantly decrease or reverse the RVF advantage for nominal letter matching. Family history of left handedness did not significantly affect the difference score in female right handers and male left handers; if anything, it increased the likelihood of obtaining a RVF advantage (see Table 5) in those groups; but decreased the magnitude of these advantages (see Figure 17). If magnitude of asymmetry is the only

performance measure studied in an experiment, then conclusions regarding family history would not depend as much on the sex and handedness composition of the sample, because FH seems to reduce magnitude of asymmetry in all subjects, but certainly not in an equivalent way. However, if number of subjects exhibiting a RVF advantage (even if the advantage is very small, as in most studies) is taken as the dependent measure, then the effects of FH would be to increase or decrease this number depending on the sex and handedness composition of the sample. Thus, McKeever and VanDeventer (1977) found familial left handers to show more RVF advantages while in right handers, positive FH reduced the advantage. It is not surprising that more males than females were represented in their sample. Had many more left handed females been included, they may have come to the opposite conclusion regarding the effects of FH in left handers. Lake and Bryden (1976) were the first to assert that FH is related to one pattern of hemispheric asymmetry in males and to another in females, depending on whether they are left or right handed; left handed females with FH+ are more likely to show a LEA in dichotic listening compared to right handed females with FH+, but left handed males with FH+. Demarest and Demarest (1979) and Piazza (1980) have also found that left handed females with FH+ often show reversed asymmetry compared to other groups, and have

concluded that this group of left handers are most likely to have right hemisphere dominance for language.

If left handed females with FH+ is the group most likely to exhibit the most bilateralization of cognitive functions or reverse lateralization of such functions (the present findings do not permit a firm acceptance of one of these alternatives), then the right handed males without FH are most likely to exhibit marked asymmetry of lateralization. In a sense then, both groups could be considered extremes in terms of their lateralization characteristics.

The fact that sex and FH (and handedness to a smaller degree) interacted for spatial proficiency as well supports the notion that lateralization, spatial ability, sex and handedness variables are all interrelated in some way. The two most exciting findings with regards to spatial ability were that spatial ability was highly correlated with field difference scores in males but not in females; and that presence of FH+ significantly lowered spatial proficiency in males and significantly increased spatial proficiency in females. This latter finding was moderated by handedness, such that the opposite effects of FH on males and females was significant in the left handers only; male left handers with FH+ had the lowest spatial scores compared to all other males, while female left handers with FH+ had the highest spatial scores compared to all other females.

It's ironic that male right handers with FH- and female left handers with FH+ scored highest in spatial abilities in their respective sex groupings, given the fact that they were the most different in terms of their lateralization characteristics. It seems as if more asymmetry is beneficial for spatial proficiency in males, which explains the high positive correlation between field difference score and spatial score in males; while the least asymmetry seemed to be beneficial for spatial abilities in one female group, the female left handers with left handed relatives. Reduced field asymmetries did not benefit the other female groups in this way; they were markedly better in verbal abilities rather than in spatial abilities. It is interesting that spatial abilities in left handed females with left handed relatives was not increased at the expense of verbal abilities; they were above average on both factors. One other study (Kocel, 1977) has obtained this sex by family history interaction for spatial abilities. Kocel factor-analyzed a set of verbal and spatial cognitive test scores, and found better spatial performance of females with FH+ and in males with FH-. It seems as if FH serves to counteract the usual sex effects seen in spatial tasks, (though not erase them).

General Discussion

The data presented here argue for a strong genetic component in the lateralization of cognitive abilities.

The important sex differences observed in this study implicate maturational and possibly hormonal influences in the expression of genetic inheritance, and the possibility that this inheritance is sex-enhanced or sex-linked. Within the testing situation itself, other factors such as practice, fatigue, motivation, attention and other variables may exert strong influences on the magnitude of visual asymmetries. There is no strong reason to argue however, that perceptual assymmetries are not related to cerebral lateralization. How a person reacts or responds to environmental stimulation must surely depend on the brain (innate or genetically programmed structures) and also on other learning, personality, and cognitive factors. Some individuals (females perhaps) may be more affected by experiential factors because their brain structure is more flexible. Other individuals' (male right handers?) behavior may be more dependent on structural factors. These differences may become very important in the event of brain trauma or brain stress; more flexibly organized individuals may not show any deleterious effects or will seem to recover much faster, while those individuals with a more rigid organization will be at a distinct disadvantage. Recognition of these differences and how they relate to cognitive organization and reorganization will surely lead to progress in the field of clinical neuropsychology.

The finding that measures of asymmetry were highly correlated with spatial abilities leads to the practical question of whether we can eventually isolate patterns of hemispheric information processing that are coupled with optimal achievement in various cognitive areas. The prospects of doing this are very exciting.

On a more theoretical level, it seems as if the time has come to update old notions regarding laterality. The notion of language in the left hemisphere and spatial abilities in the right hemisphere is fairly narrow-minded and in many cases inaccurate. Our theories have to fit the facts; not the other way around. Current theories in the field of laterality are beginning to build upon old notions of hemispheric dominance, competition, compartmentalization and functional rigidity to ones where the hemispheres are in active cooperation, and where structure-function relationships are not invariant either over time or in individuals. Enough data warrant such new approaches in this field.

Most models of brain organization are based mainly on a male right handed population, more of whom lacked left handed relatives. In a sense, these models are based on a subject population that is in many ways "atypical," for they tend to be quite asymmetrically and rigidly organized compared to the rest of the population. If this type of brain organization is taken as the norm, then most females,

most left handers, and most people with left handed relatives would be considered to have deviant or atypical lateralization patterns. But these groups consititute over half of the population; not just a few members. Clearly, what is "atypical" is relative to the standard of measurement. If flexibility and variability of brain organization are taken as the norms, then right handed males without FH might be considered atypical. If all this seems to be just a question of semantics, it is much more than that; for all our ideas of brain-behavior relationships stem from these major premises, which may be inaccurate. Rigid views of brain organization have definitely outlived their usefulness, we are no longer living in the days of Broca. A more flexible model of brain organization that takes into account individual differences in functional organization can eventually be incorporated into the main body of cognitive psychology and personality theory. This kind of model will be of more heuristic value to the practicing clinical neuropsychologists, who all along have noted exceptions to the basic rules in their patients. Why did some patients bounce back from lesions in crucial language zones and others did not; why do boys become dyslexic but girls rarely do. Injury to a particular lobe of the brain could be seen as selectively disrupting performance to the extent that the lesion corresponded to the subject's layout of cognitive

functions and with the subject's preferred mode of cognitive strategies (see Charcot, 1883 for more discussion).

The field of neuropsychology has long been dominated by the field of neurology, a field that stresses similarities rather than individual differences. It seems as if a theory of individual differences is a necessary prerequisite to the study and understanding of brain-behavior relationships; and is long over due. Cognitive abilities and asymmetries could be mapped onto the brain in many different ways without even a change in gross structure. The possibility is strong that variation of cognitive mapping arose as part of the natural order of things, and served a useful purpose in man's evolution. Different patterns of brain organization need not be associated with pathology at all, but as a part of the natural selection process. As Levy points out (1974), ". . . the evolutionary advantage that flexibility in brain organization and localization brings to an evolving species, (is that) this brain flexibility provides a range of individuals with varied cognitive talents or specialties."

The field of psychology recognizes that individuals differ with respect to personality, intelligence, etc. Certainly, functional cognitive arrangement must differ in different people. How are these differences determined genetically and environmentally, how do they develop in

the different sexes, can they be restructured (other than by lesions)? These are some of the questions that neuropsychology can begin to answer now; surely great pioneers like Broca will not feel slighted by such progress.

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Table 1

Summary table for repeated measures
ANOVA of mean RT (raw data)

	df	F	P value
Family history	1,56	5.6	.022
Block	7,392	51.0	.001
History x block	7,392	2.1	.04
Sex x hand x block	7,392	5.4	.001
Field	1,56	10.2	.003
Sex x field	1,56	5.1	.03
History x field	1,56	4.4	.04
Match	1,56	553	.001
Sex x hand x match	1,56	9.2	.004
Hand x history x match	1,56	4.2	.04
Sex x hand x history x match	1,56	5.3	.03
Block x field	7,392	3.5	.002
History x block x field	7,392	3.6	.001
Sex x history x block x field	7,392	2.1	.04
Field x match	1,56	10.5	.003
*History x field x match	1,56	3.0	.09

* - Trend only.

Table 2

History by Field by Match

	PI Match		NI Match	
	RVF	LVF	RVF	LVF
FH-	554	558	615	647
FH+	596	595	666	674

Table 3

Breakdown of sex by field by match

	PI Match		NI Match	
	RVF	LVF	RVF	LVF
Males	565	571	624	655
Females	584	581	657	665

Table 4

Left-right difference scores for PI and NI matches for all subgroups of subjects

	PI Matches		NI Matches	
	Family history		Family history	
	-	+	-	+
Males				
Right Handers	11.0	-3.8	67.5	10.8
Left Handers	1.9	11.7	26.4	18.2
Females				
Right Handers	12.1	-10.3	17.0	9.9
Left Handers	-10.3	-3.4	15.3	-9.5

Table 5

Number of subjects exhibiting
a RVF advantage, a LVF advantage,
or no visual field advantage in each group

	RVF	LVF	no advantage	# of subjects consistent with group mean (max=8)
MRH-	7	1	0	7
MRH+	2	1	5	5
MLH-	4	2	2	4
MLH+	6	1	1	6
FRH-	4	1	3	4
FRH+	3	2	3	3
FLH-	4	1	3	4
FLH+	2	3	3	3
				(max=32)
Males	19	5	8	22
Females	13	7	12	14
Right Handers	16	5	11	19
Left Handers	16	7	9	17
FH-	19	5	8	19
FH+	13	7	12	17

Table 6

"Corrected" standard deviations for two performance measures in each subgroup of subjects

	Total RT	Normalized difference score
MRH-	12.3	7.1
MRH+	3.7	14.3
MLH-	15.0	15.8
MLH+	12.2	28.2
FRH-	10.9	21.7
FRH+	14.0	46.2
FLH-	8.1	22.5
FLH+	7.3	58.2
Males	12.9	6.8
Females	10.8	48.0
RH	8.7	16.0
LH	13.2	32.0
FH-	10.4	17.4
FH+	8.1	45.8

TABLE 7

Change scores for Day 1, Day 2, and overall for each subgroup of subjects

DAY 1 (Blocks 1-4)

		FH-	FH+
MALES	Right handers	122	113
	Left handers	79	56
FEMALES	Right handers	71	71
	Left handers	84	34

DAY 2 (Blocks 5-8)

		FH-	FH+
MALES	Right handers	12	-21
	Left handers	32	8
FEMALES	Right handers	26	23
	Left handers	29	0

Overall Change Score

		FH-	FH+
MALES	Right handers	156	98
	Left handers	250	216
FEMALES	Right handers	330	174
	Left handers	95	53

Table 8

Comparison of FH- and FH+ subgroups on a number of performance measures

(a) Total RT

		FH-	FH+	Difference
Males	RH	579	644	-65
	LH	566	630	-64
Females	RH	631	614	+17
	LH	589	649	-60

(b) Normalized Difference Score

		FH-	FH+	Difference
Males	RH	11.38	1.88	9.50
	LH	4.58	2.78	1.80
Females	RH	2.43	1.34	1.10
	LH	2.22	-1.21	3.43

(c) Overall Change Score

		FH-	FH+	Difference
Males	RH	156	98	58
	LH	250	216	34
Females	RH	330	174	156
	LH	95	53	42

*(d) Verbal Score

		FH-	FH+	Difference
Males	RH	-.318	-.548	-.230
	LH	-.156	-.466	-.310
Females	RH	.351	.170	-.181
	LH	.419	.547	+.128

*(e) Spatial Score

		FH-	FH+	Differnce
Males	RH	.114	.121	.007
	LH	.549	-.526	-1.075
Females	RH	-.608	-.090	.498
	LH	-.914	.331	1.245

* A negative difference indicates poorer performance for the FH+ subjects.

Table 9

Scores on "relatives" for each family history positive subgroup

	Score on "relatives"	
	$\bar{X}$	S. D.
Male right handers	2.12	0.78
Male left handers	1.62	0.70
Female right handers	1.75	0.66
Female left handers	2.00	0.50

Table 10

Relationship of "relatives" to Total Difference Score in various subgroups of subjects

	Relatives		
	1	2	3
All positive subjects	2.88 (n=10)	2.43 (n=16)	-4.90 (n=6)
Right handers	1.05 (n=5)	3.12 (n=7)	-0.35 (n=4)
Left handers	4.71 (n=5)	1.89 (n=9)	-14.0 (n=2)
Male left handers	6.37 (n=4)	3.84 (n=3)	-14.77 (n=1)
Female left handers	-1.90 (n=1)	0.92 (n=6)	-13.0 (n=1)
Male right handers	0.86 (n=2)	1.54 (n=3)	2.90 (n=3)
Female right handers	1.20 (n=3)	4.30 (n=4)	-10.0 (n=1)

Table 11
Intercorrelation Matrix

	Hand rotation Total RT	# of errors	EFT	Closure	Block Design	Similarities	Abst. Reas.	Ment. Rot.	Vocabulary	Purdue R-L	Major	Spatial	Verbal	Eye dominance	Eye acuity	Hand pos.	Total RT	Total diff. Score	RT errors	Change score
Hand rotation	-	.51		-.21	-.38			-.34		-.23		-.55					.27	-.24		
Total RT		-	-.40	-.43	-.55			-.48			.35	-.81						-.35		
# of errors	.51		-		.56		.38	.41	.30		-.40	.59	.26						-.26	
EFT		-.40		-	.36		-.25	.35		.28	-.22	.59				.22		.30		
Closure	-.21	-.43			-			.52			-.31	.81						.31		
Block Design	-.38	-.55	.56	.36		-	.29		.54				.81		.25					-.29
Similarities			.38	-.25		.29	-		.35	-.29			.57	.26					-.27	
Abst. Reas.			.41	.35	.52			-			-.44	.74								
Ment. Rot.	-.34	-.48	.30			.54	.35		-				.86							
Vocabulary				.28			-.29			-				-.50	-.27	-.35			.24	
Purdue R-L	-.23							-.44			-	-.50	.31					.38	-.22	
Major		.35	-.40	-.22	-.31			.74			-.50	-								
Spatial	-.55	-.81	.59	.59	.81				.86		.31		-							
Verbal			.26			.81	.57							-	.47	.33				
Eye dominance							.26			-.50					-	.35				
Eye acuity						.25				-.27				.47	.35	-				
Hand pos.				.22						-.35				.33	.35	-				
Total RT	.27																	-.26	.44	
Total diff. score	-.24	-.35		.30	.31							.38					-.26			
RT errors			-.26					-.27		.24		-.22					.44			
Change score							-.29													

Only significant correlations are printed

Table 12

Regressions of the subject variables on the RT measures

Name of analysis	Predictor entered	Pearson r	Multiple R	Multiple R^2	Variance accounted for by this predictor	F	df	P value
Field effect-raw difference in RT-effects of sex, handedness and FH.	1) Sex	-.27	.27	7.3	7.3	5.1	1.62	.05
	2) FH	-.25	.37	13.4	6.2	4.3	2.61	.05
Total difference Score-normalized score for NI matches Effects of sex, handedness and FH.	1) FH	-.29	.29	8.6	8.6	6.3	1.62	.05
	2) Sex	-.28	.40	16.4	7.8	5.7	2.61	.05
Total RT-effects of sex, handedness and FH.	1) FH	.29	.29	8.6	8.6	5.6	1.62	.05
Day 1 change score Effects of sex, handedness and FH.	1) Handedness	-.28	.28	7.8	7.8	5.8	1.62	.05
	2) Sex	-.26	.38	14.6	6.7	5.0	2.61	.05
	3) FH	-.22	.44	19.5	4.9	3.7	3.60	.05
Field effect-Effect of sex, handedness and "relatives."	1) Relatives	-.30	.30	9.2	9.2	6.1	1.62	.05
	2) Sex	-.26	.40	16.2	7.0	5.0	2.61	.05
Total Difference Score-effects of sex, handedness, and "relatives."	1) Relatives	-.40	.40	15.8	15.8	5.6	1.62	.05
	2) Sex	-.25	.47	22.0	6.2	5.0	2.61	.05

Table 13

Performance of each subgroup
on the cognitive tasks

	Hand Rotation Task									
	Overall RT	# of Errors	Reversed-normal Orientation	EFT	Closure	Block Design	Mental Rotation	Similarities	Vocabulary	Abstract Reasoning
MRH-	+	+	+	+	+	+	+	-	-	-
MRH+	+	+	+	-	+	-	+	+	-	=
MLH-	-	+	-	+	+	+	+	+	-	+
MLH+	-	-	-	+	-	-	-	-	-	-
FRH-	-	-	-	-	-	-	-	+	+	=
FRH+	+	-	+	-	+	+	-	=	+	-
FLH-	-	-	-	-	-	-	-	+	+	+
FLH+	-	+	+	+	-	+	+	+	+	+

Table 14

Scores on the verbal and spatial factors for each subgroup of subjects

	Verbal	Spatial
MRH-	-0.318	1.137
MRH+	-0.548	0.121
MLH-	-0.156	0.549
MLH+	-0.466	-0.526
FRH-	0.351	-0.608
FRH+	0.170	-0.090
FLH-	0.419	-0.914
FLH+	0.547	0.331

Table 15

Regressions of RT and cognitive measures with the subject variables

Name of Analysis	Predictor Entered	Pearson r	Multiple R	Multiple R^2	Variance Accounted for by this Predictor	F	df	P value
Criterion: Total Difference Score Predictors: Spatial and Verbal Factor	1) Spatial	.38	.38	14.5	14.5	6.8	1,62	.05
Criterion: Total Difference Score Predictors: Spatial, sex, handedness, FH	1) Spatial	.38	.38	14.5	14.5	6.8	1,62	.05
	2) FH	-.29	.47	21.8	7.3	6.0	2,61	.05
Total Difference Score Predictors: Spatial, sex, handedness, "relatives"	1) Spatial	.38	.38	14.5	14.5	6.8	1,62	.05
	2) Relatives	-.33	.50	25.4	10.9	6.1	2,61	.05
Criterion: Verbal Predictors: Sex, Handedness, FH, Total RT, Total Difference Score	1) Sex	.37	.37	13.7	13.7	6.2	1,62	.05
Criterion: Spatial Predictors: Sex, handedness, relatives, total RT, total difference score	1) Total Difference Score	.38	.38	14.5	14.5	6.2	1,62	.05
	2) Sex	-.25	.46	20.9	6.4	5.2	2,61	.05

Table 16

Interrelationships of field difference score, spatial score, and family history in males and females

Variables	Pearson r	p value
MALES		
Field difference score with Spatial score	.47	.001
Field difference score with Family history	-.38	.001
Field difference score with "relatives"	-.44	.001
Spatial score with Family history	-.59	.001
Spatial score with "relatives"	-.52	.001
FEMALES		
Field difference score with Spatial score	.16	NS
Field difference score with Family history	-.20	.05
Field difference score with "relatives"	-.31	.01
Spatial score with Family history	.44	.001
Spatial score with "relatives"	.28	.05

Figure 1

Overall performance (block effect)

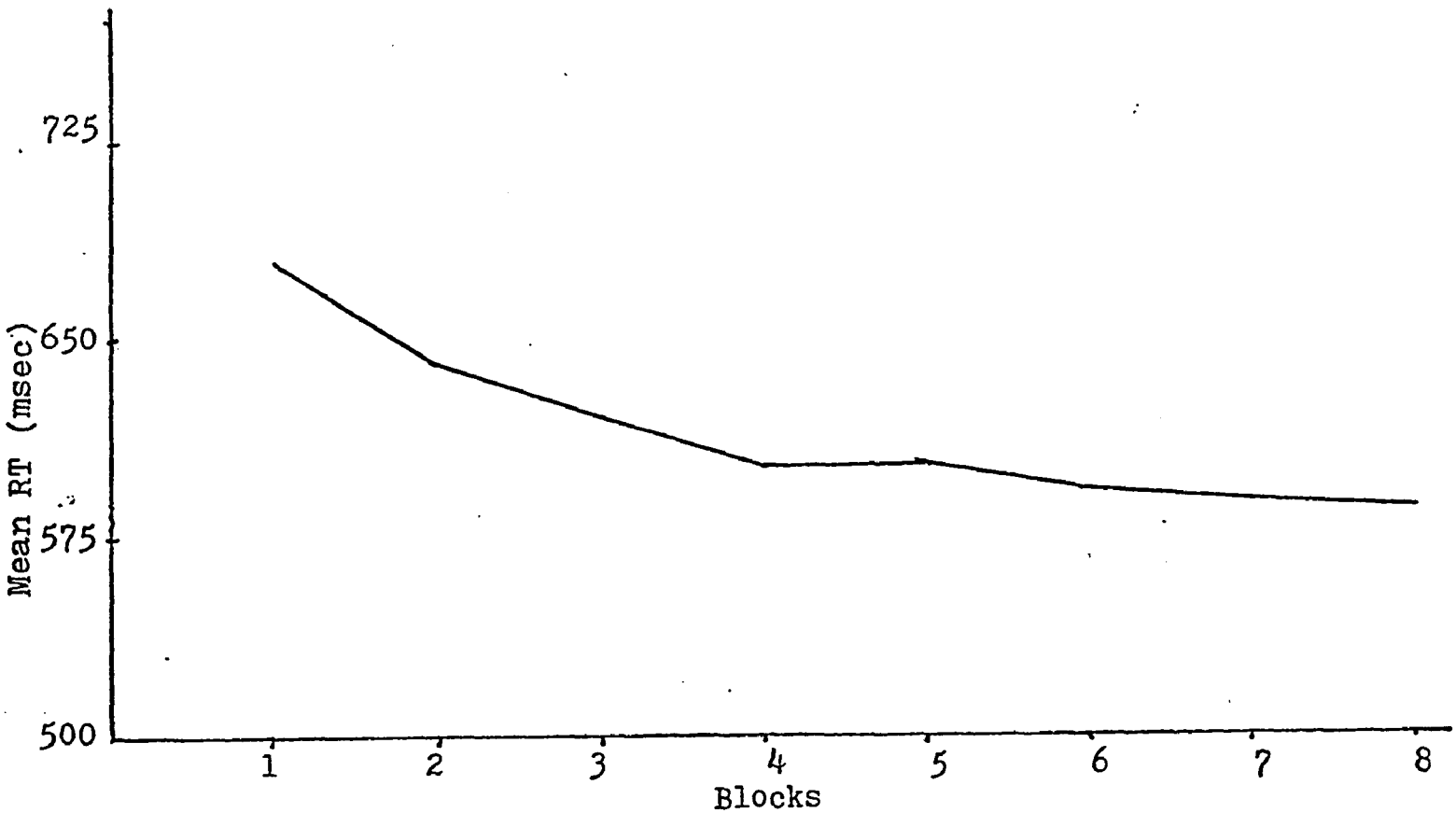


FIGURE 2

FIELD BY MATCH INTERACTION

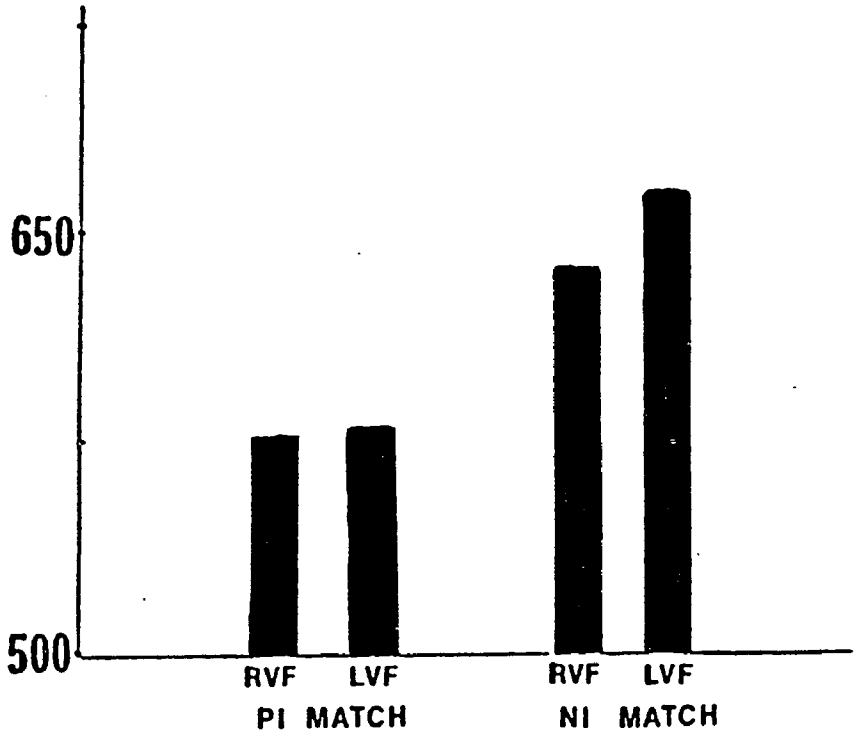


Figure 3

Effect of family history on overall performance

(History by block interaction)

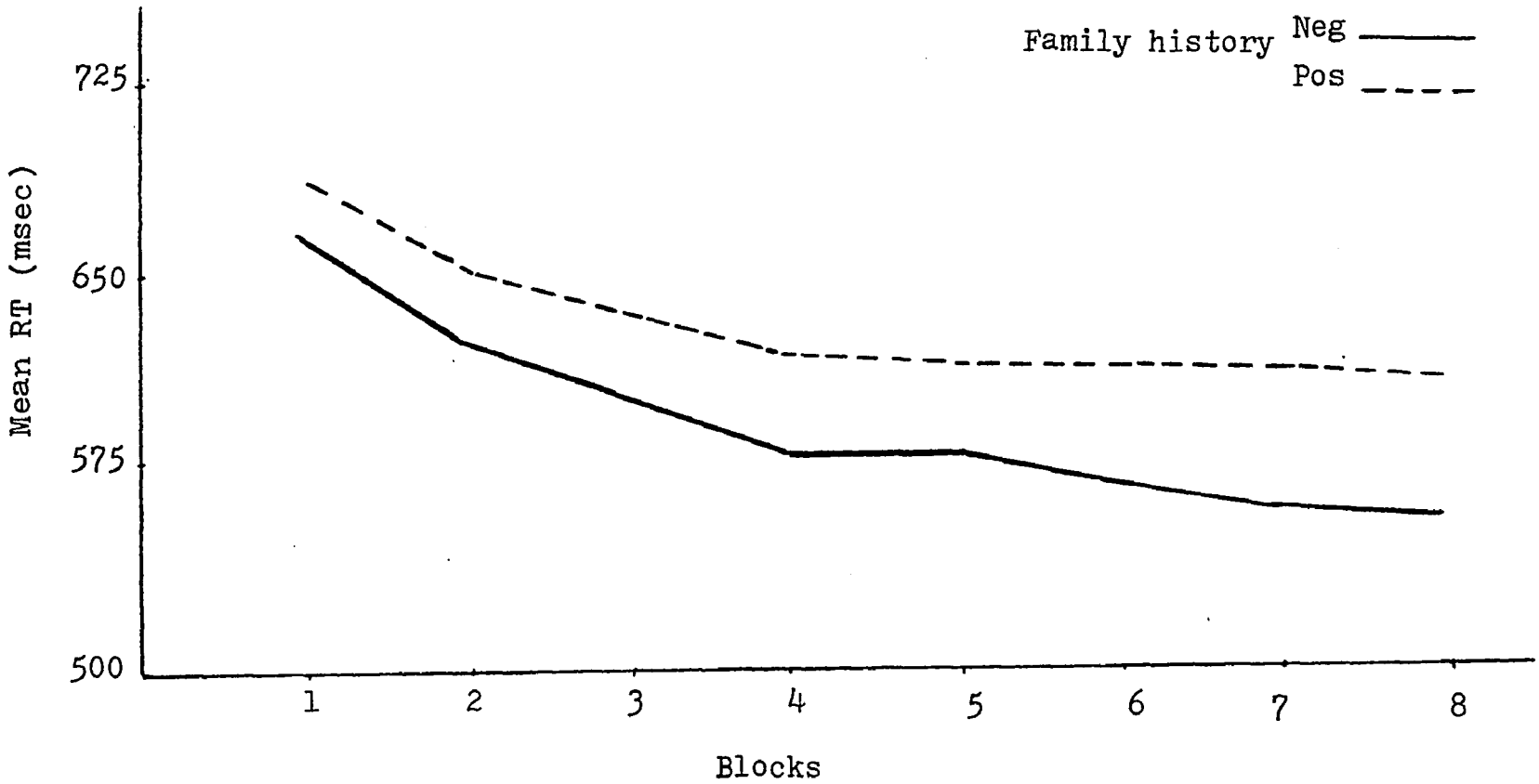


FIGURE 4

History by block by field interaction

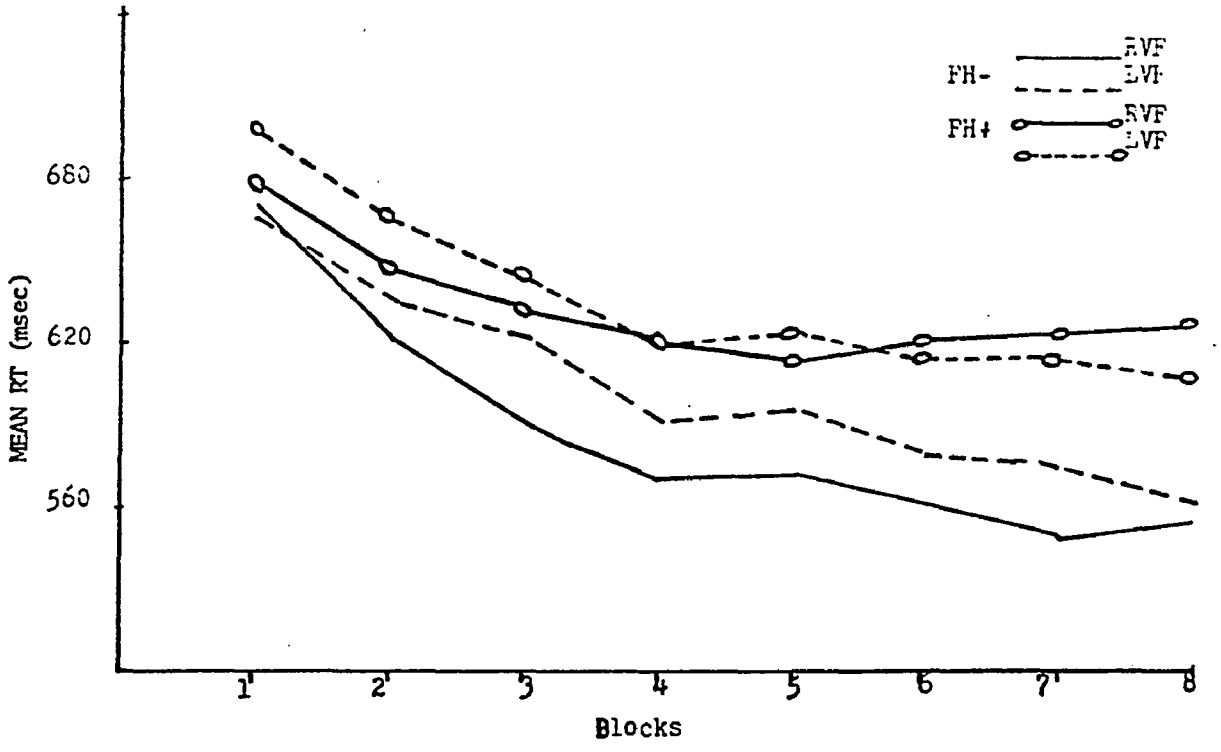


FIGURE 5

Sex by handedness by block interaction

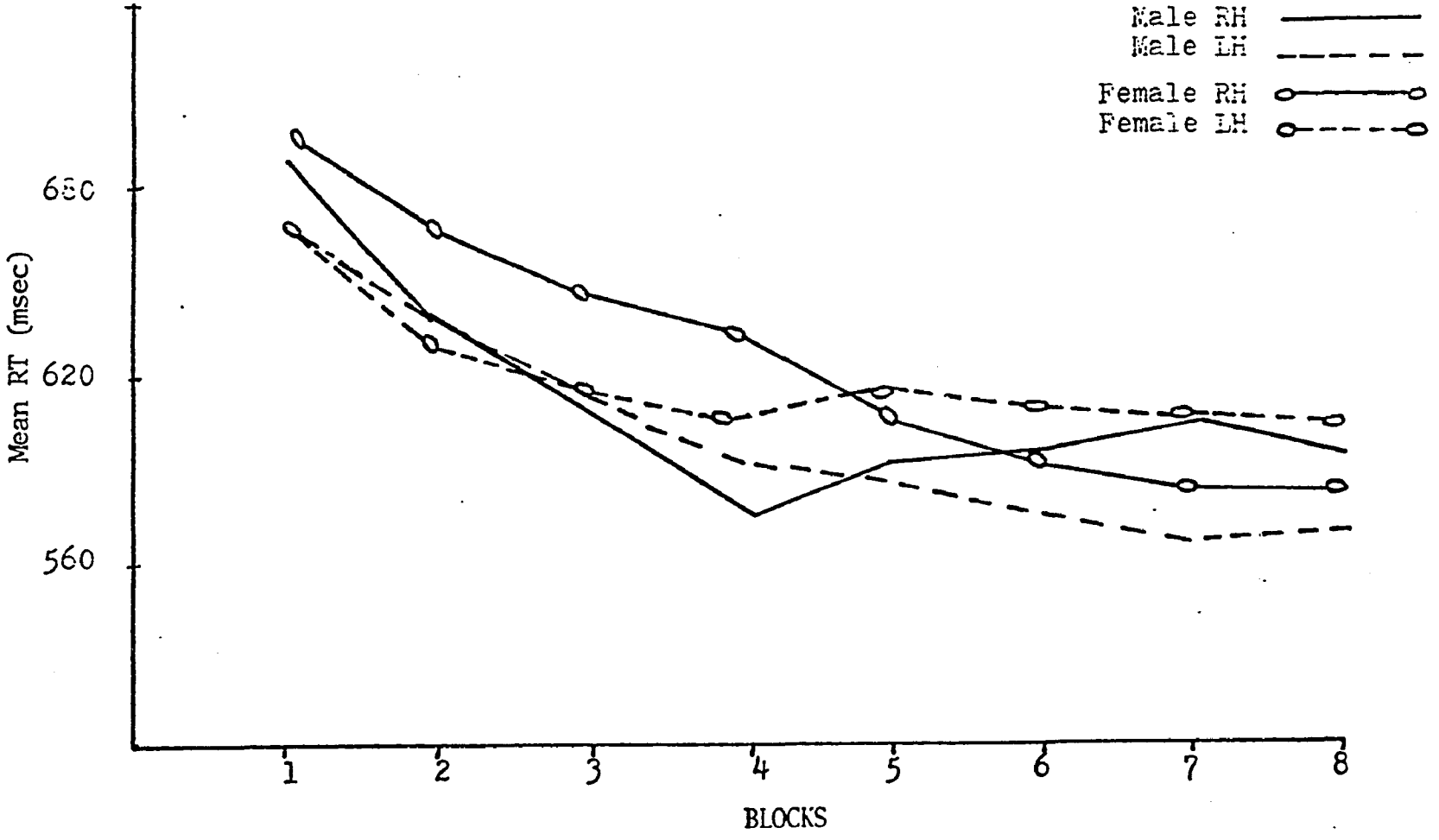


FIGURE 6

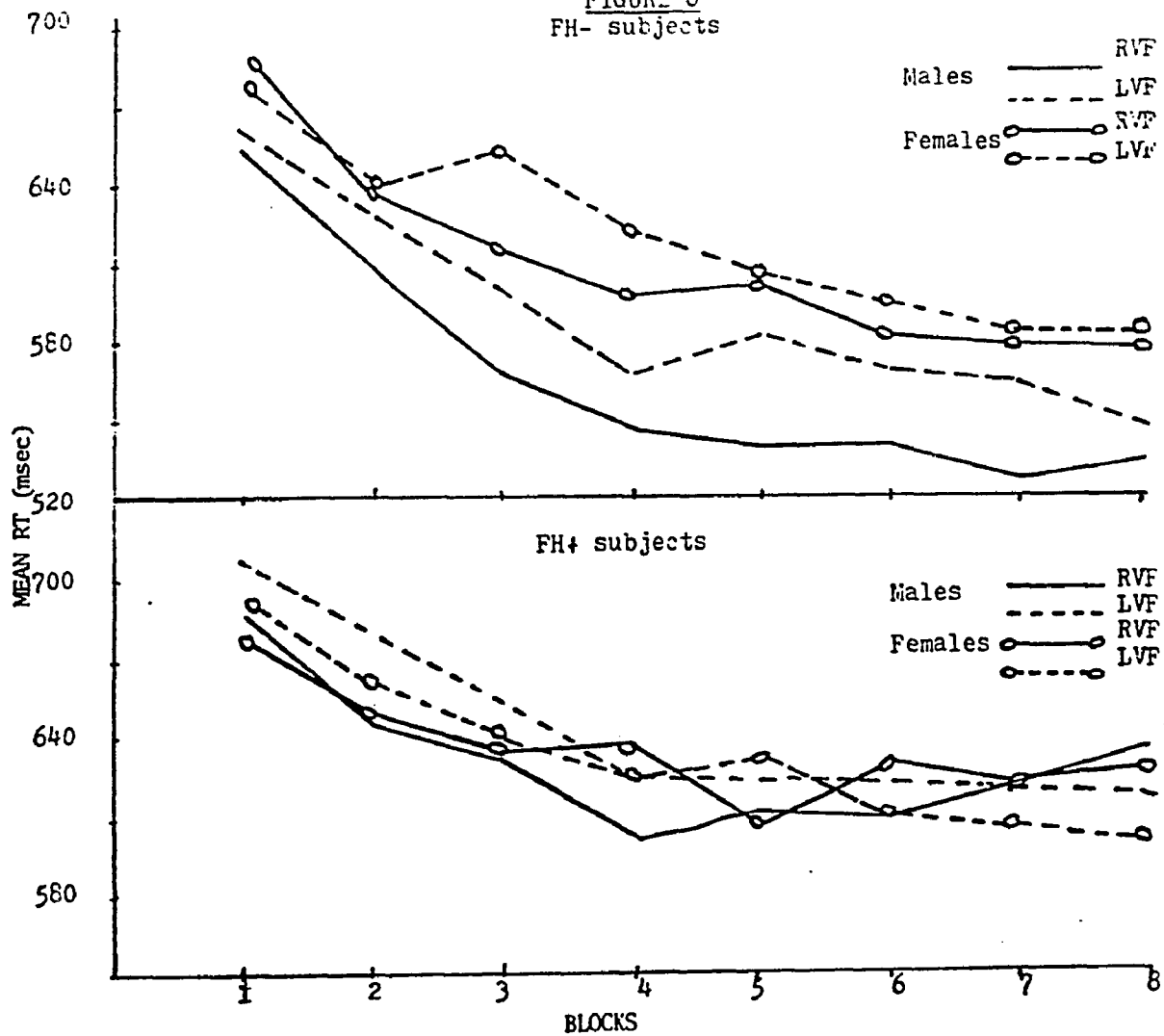

FH- subjects
Males
RVF
LVF
Females
RVF
LVF
700
640
580
520
MEAN RT (msec)
FH+ subjects
Males
RVF
LVF
Females
RVF
LVF
700
640
580
1
2
3
4
5
6
7
8
BLOCKS

Figure 7

Performance of all subjects

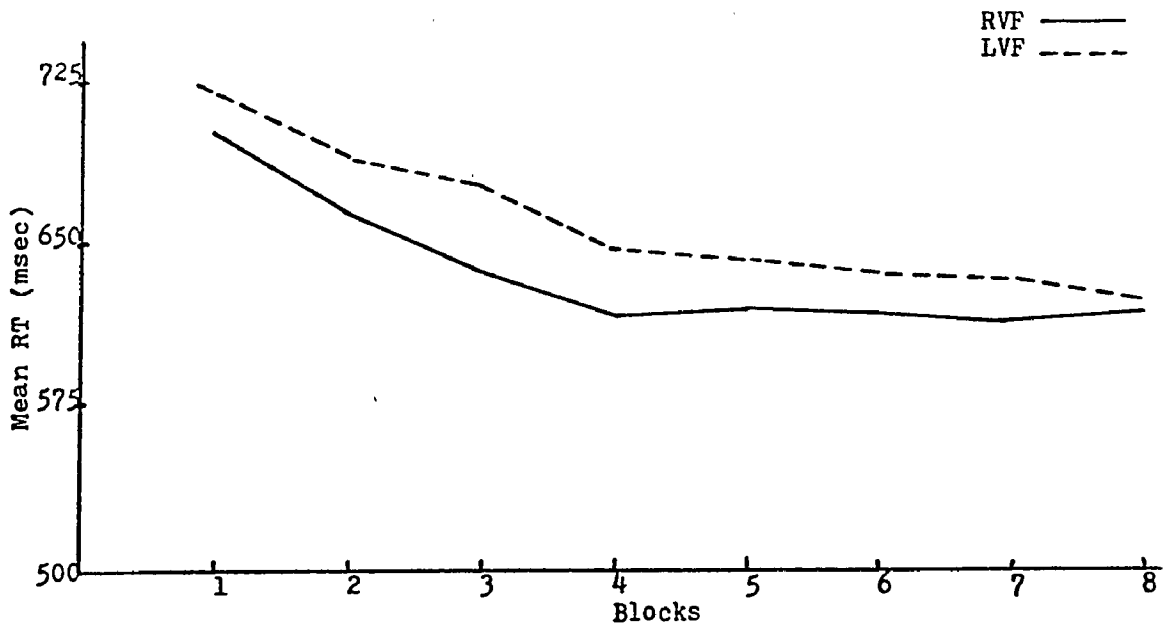


FIGURE 8
Male Right Handers Negative Family History
(MRH-)

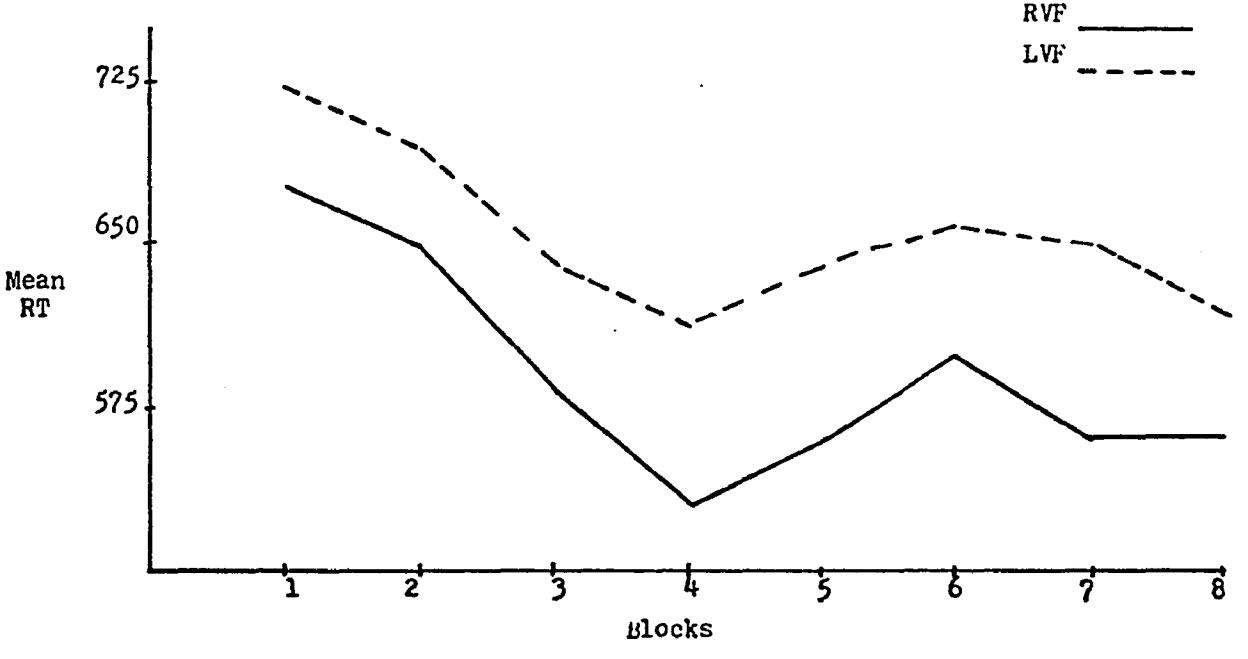


FIGURE 9

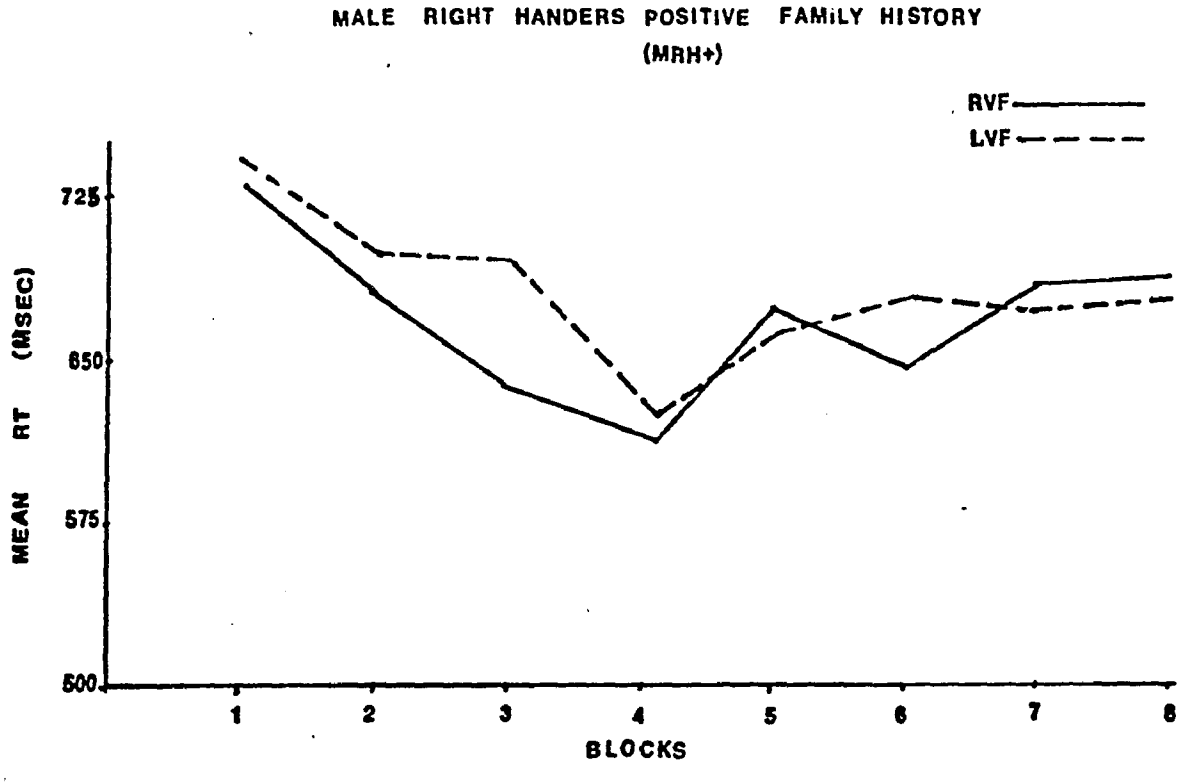

MALE RIGHT HANDERS POSITIVE FAMILY HISTORY
(MRH+)
RVF
LVF
MEAN RT (MSEC)
725
650
575
500
1
2
3
4
5
6
7
8
BLOCKS

FIGURE 10

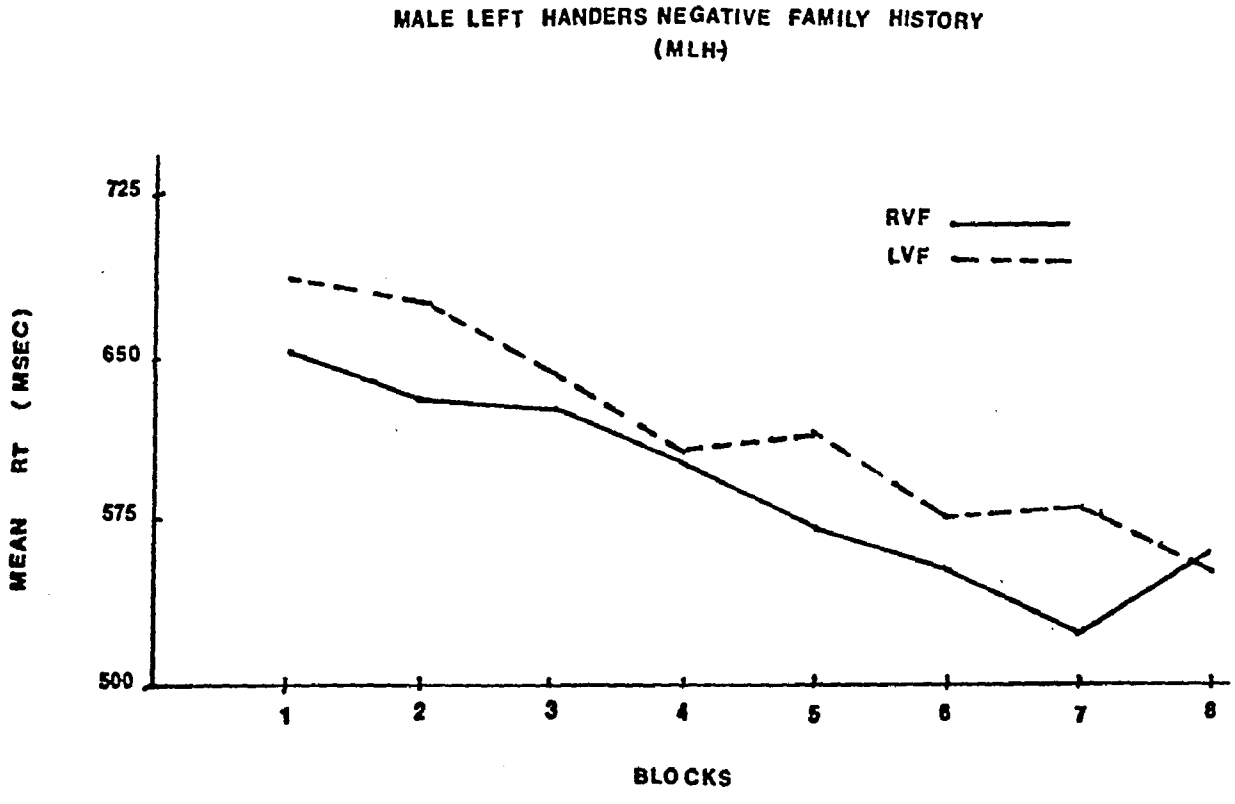

MALE LEFT HANDERS NEGATIVE FAMILY HISTORY
(MLH-)
725
650
575
500
MEAN RT (MSEC)
RVF
LVF
1
2
3
4
5
6
7
8
BLOCKS

Figure 11

Male Left Handers Positive Family History

(MLH+)

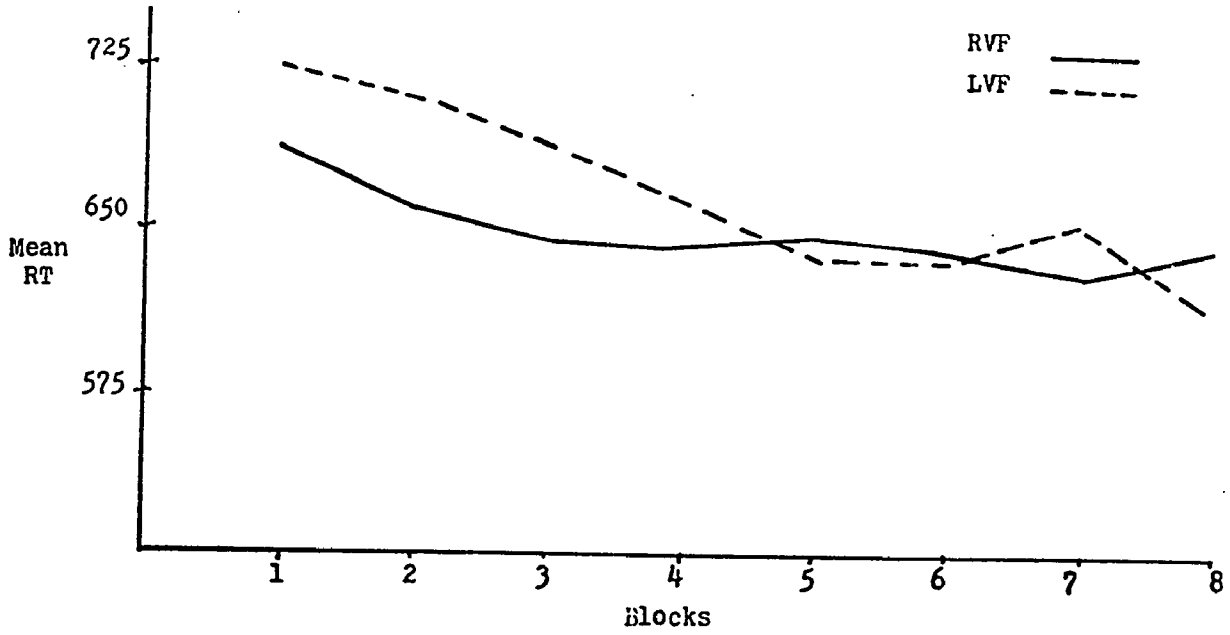


FIGURE 12

FEMALE RIGHT HANDERS NEGATIVE FAMILY HISTORY
(FRH-)

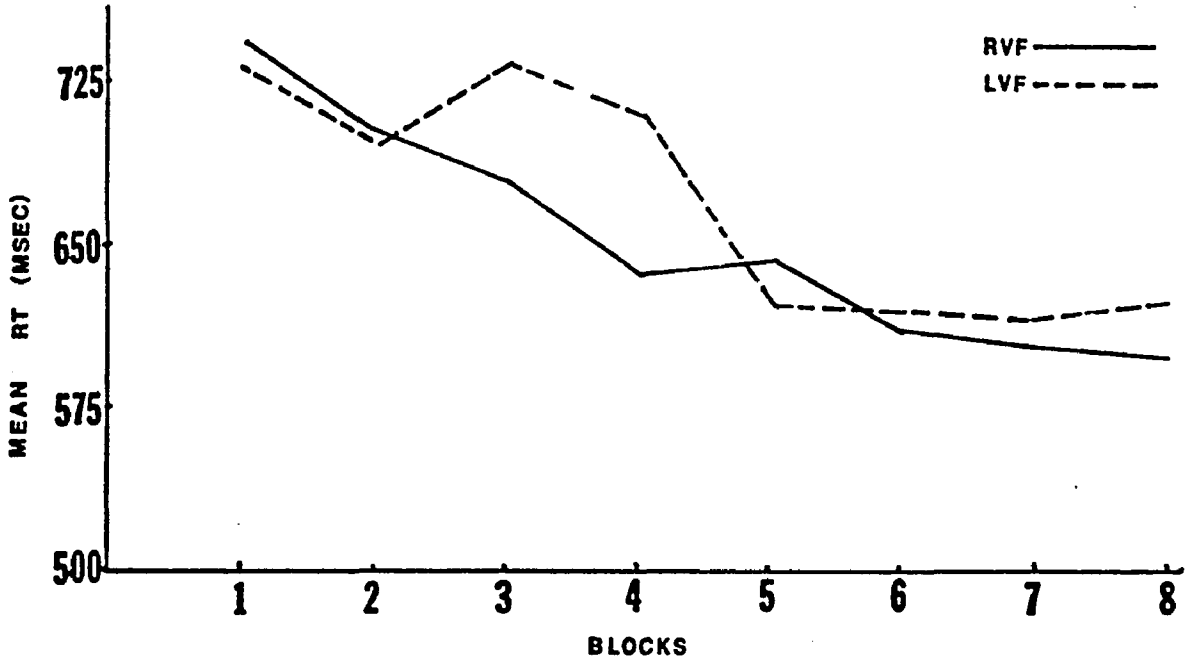


FIGURE 13
Female Right Handers Positive Family History
(FRH+)

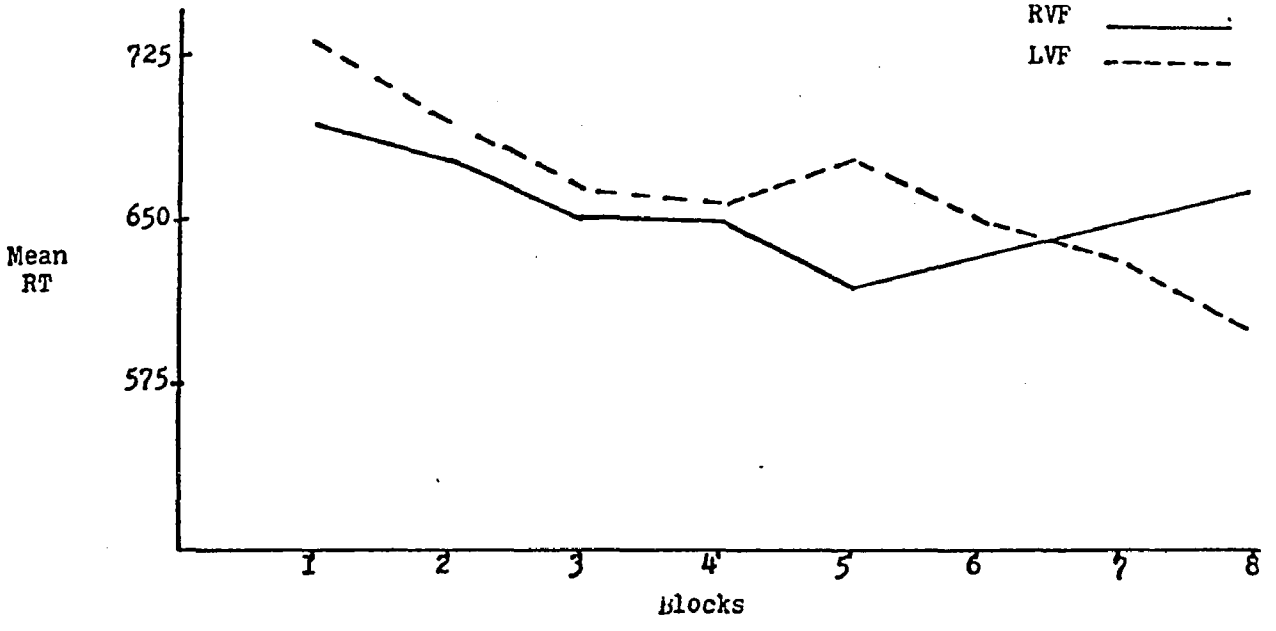


FIGURE 14

FEMALE LEFT HANDERS NEGATIVE FAMILY HISTORY
(FLH-)

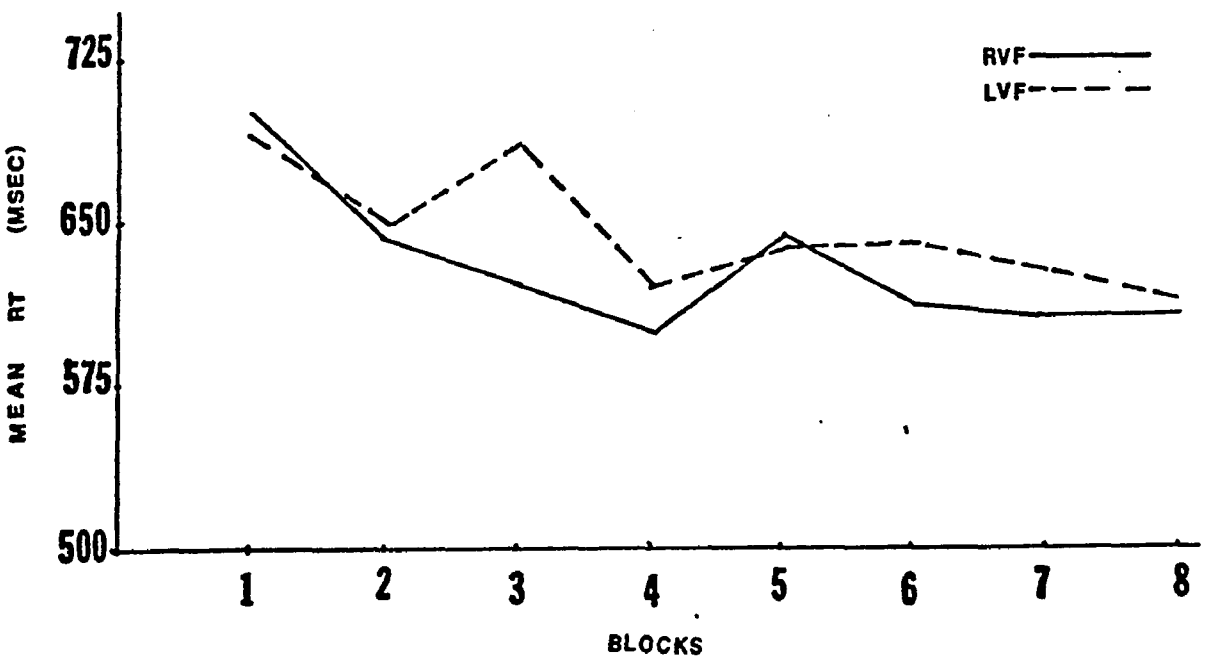


FIGURE 15

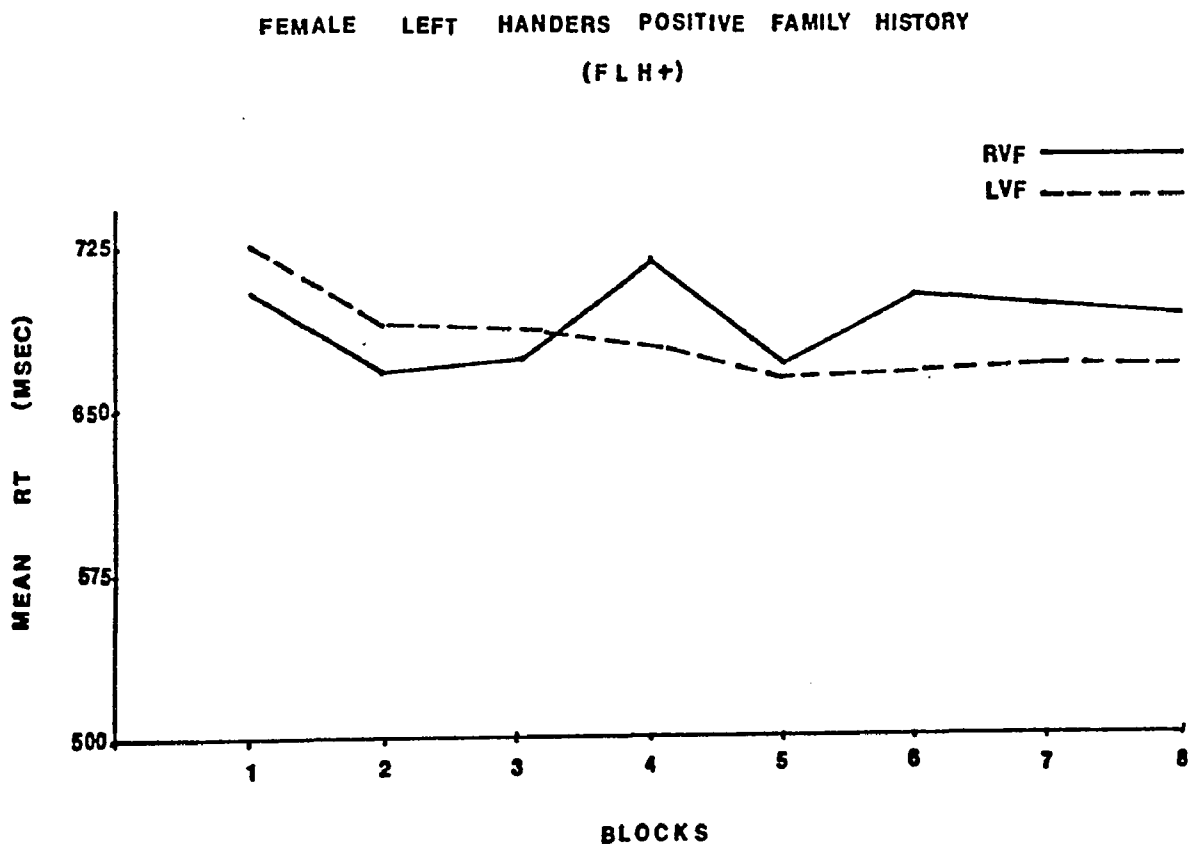

FEMALE LEFT HANDERS POSITIVE FAMILY HISTORY
(F L H+)
RVF
LVF
MEAN RT (MSEC)
725
650
575
500
1
2
3
4
5
6
7
8
BLOCKS

FIGURE 16

Block by match interaction (log transformed scores)

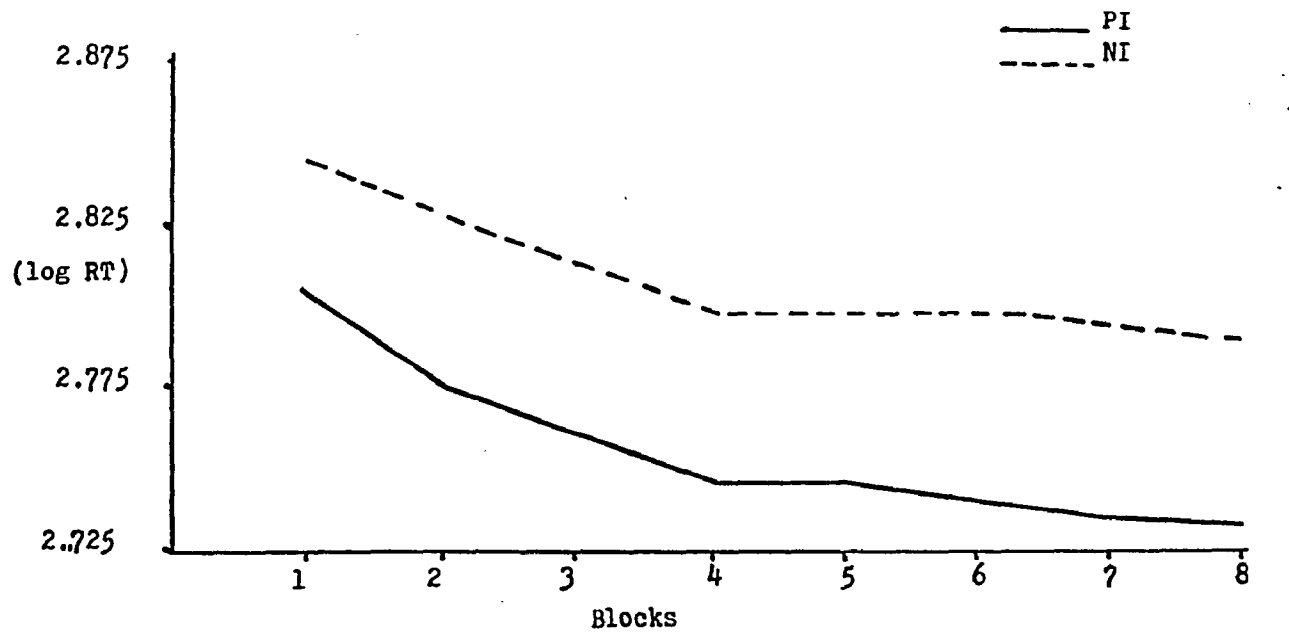
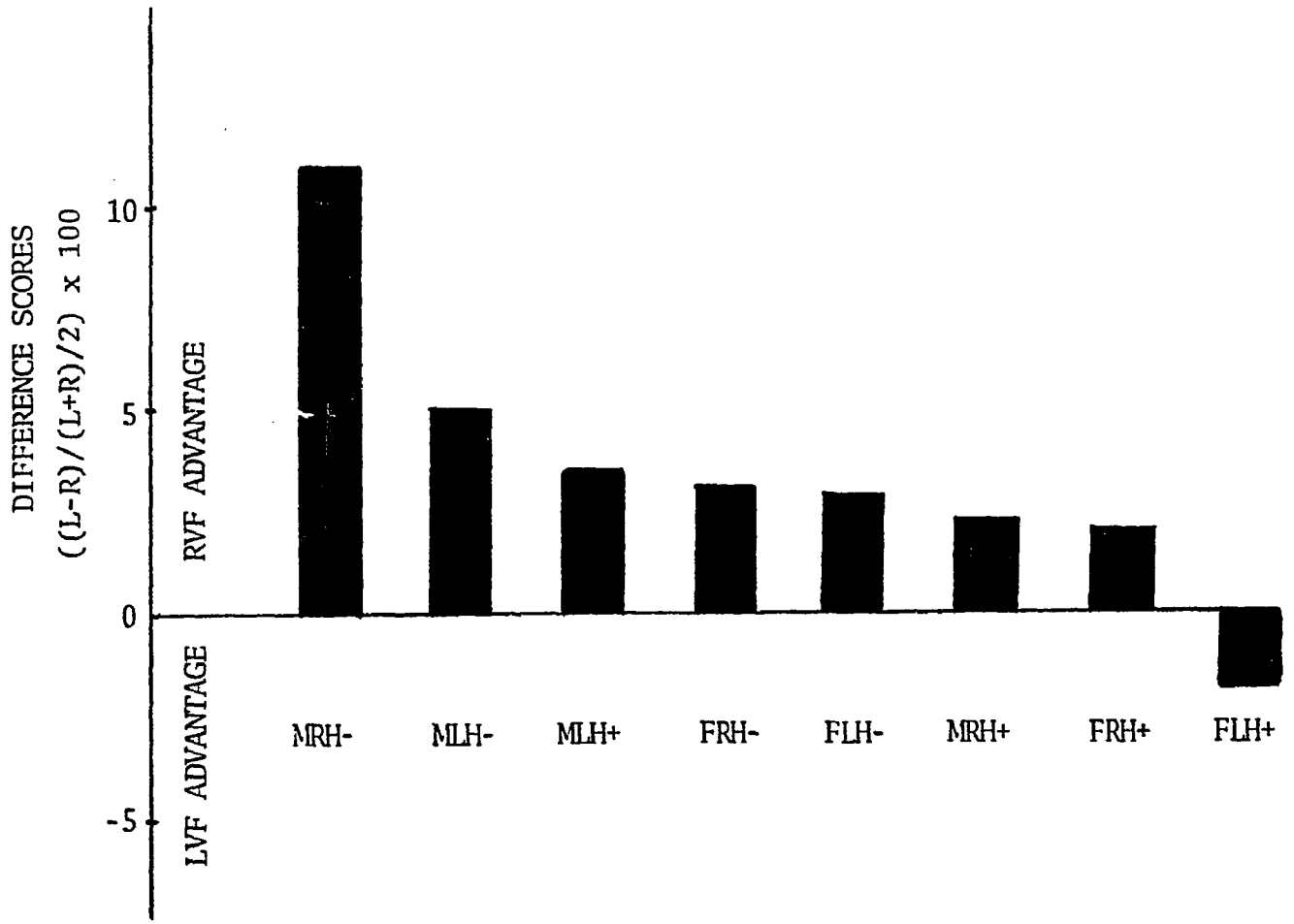


FIGURE 17

LEFT - RIGHT ASYMMETRIES FOR NOMINAL MATCHES

COMPARISON OF INDIVIDUAL SUBGROUPS



Appendix 1

INSTRUCTIONS TO SUBJECT

Session 1

This is a study that is going to examine visual perception of letters and is also concerned with issues of handedness. The first thing I would like you to do is to fill out this short questionnaire. If you have any problems or questions with it, feel free to ask.

Activity #1 - Fill out questionnaire.

Activity #2 - Bring subject into experimental room.

The rest of the experiment for today will take place in this room. I would first like to test your vision. If you wear glasses, please wear them throughout the experiment. If you wear glasses for any special reason such as for driving or reading, I would also suggest that you wear them for this experiment.

Activity #3 - visual acuity test.

Please sit in this chair, rest your arms on this board, and look into the tachistoscope. Are you comfortable?

Activity #4 - Adjust chair if necessary.

On this board in front of you are a set of telegraph keys. Yu will be working with only one of them. Place your right hand here (left hand for left handers) so that your index finger is pressing down on this key, and your right hand is in your lap. I want your right hand to remain in

this position at all times, until you have to make a response. To make a response, simply release your finger from the key like this.

Activity #5 - Demonstrate response

After you make a response, return your finger to its original position and wait until the next response has to be made.

Now I want you to look into the tachistoscope for a few minutes so that your eyes can get used to the dark. Stare straight ahead, you should begin to see light at the other end. You may begin to see an outline of a grayish rectangle. Tell me when you begin to see this. If you don't see it by the end of three minutes, we'll begin the experiment anyway.

Activity #6 - subject gets dark adapted

Now I'll explain what you will be doing in this experiment. I will be showing you a series of cards with letters on them. These are the letter cards. Before each letter card comes on, you will first see a card with just lines on it. The lines will come together and almost meet at the very center of the card. Whenever you see this card, I want you to stare at that point where all the lines would meet. That point is called the fixation point, and it's very important that you always focus your eyes on that point whenever it is presented. It will remain on for a second and a half in

order to give you time to focus your eyes at the center. Let me show you the fixation point.

Activity #7 - show subject the fixation card

Immediately after the fixation card goes off, a letter card will come on. Each letter card will have two letters on it. The two letters will be either on the left side of the card or on the right side of the card. Sometimes the two letters will be the same letter, and sometimes the two letters will be different letters. Let me show you some examples.

Activity #8 - show subject the two types of same cards (NI and PI), and one in the LVF and one in the RVF. Say, "sometimes the two letters will be the same like this, the two letters can also be the same like this. Sometimes the two letters will be different like this, or on the other side of the card like this."

If the two letters are the same letter, I want you to make a response by lifitng your finger as quickly as you can from the telegraph key. If the two letters are different letters, then I don't want you to do anything, just leave your finger where it is now. You will respond only when the letters are the same letter. You may have noticed that on each letter card there was a number at the center. There will always be a number at the center of each and every letter card. After you have responded appropriately to the letters,

meaning after you have either lifted your finger for a response or not lift for a different response, I then want you to tell me what number you saw at the center of the card. That is why it is always important that you focus right at the center of the fixation point and keep your eyes focused there, because if you don't, you may miss the number at the center. Remember, you will first see the fixation point, be sure to focus your eyes at the center. Then a letter card will come on. If the letters are the same, lift your finger as quickly as you can from the response key; if the letters are different, don't do anything. Remember to tell me what number you saw each and every time. Are you ready for some practice?

Practice #1 - I first want to see how fast you can make a response. YOu will see the fixation point first followed by a white card with a number on it. As soon as you see that number, I want you to lift your finger as quickly as you can. We'll do this ten times.

Activity #9 - present the first practice stimuli, say "ready" before each trial, and reinforce fast responses by saying "very good."

Practice #2 - Now I'm going to show you some letter cards, but the letters will be right at the center of the card this time. What I want you to concentrate on doing now is learning to make the appropriate response, that is, respond

only when the letters are the same, do nothing when they are different. Respond as quickly as you can. I'll say "ready" before each trial.

Activity #10 - Present 10 trials, stress speed and accuracy and verbally reinforce fast responses.

Now we are going to do the last set of practice trials. I'm going to show you the letters again, but this time they will be either on the right or on the left, and there will be a number at the center of each card. I want you to concentrate on three things. First, making the appropriate response, respond only when the letters are the same. Next, I want you to respond as quickly as you can. Finally, I want you to tell me what number you saw each tim. Ready?

Activity #11 - Present 24 lateralized practice trials, say "ready" before each trial and verbally reinforce fast responses. Tell subject when he makes an error. Last 15 practice trials should be errorless with reaction times less than 1000 msec.

Now we will start the experiment. Again, the ltters will be either on the right side or on the left side and there will be a number at the center of each card. Respond quickly and accurately and remember to tell me the number each time. I'll say "ready" before each trial. Are you ready?

Activity #12 - Run the four blocks of trials, pausing to

rest between blocks. Say "ready" each time but refrain from saying "good" from now on. Rerun errors at the end of each block.

Session 2

Same instructions as in Session 1, but only last set of practice trials are run, and four blocks of test trials. Immediately after, the subject is given the hand rotation test. The subject is again reminded that both speed and accuracy are important in the hand task. Two practice trials will be given, subject is told that hand can appear in any orientation. At the end of the session, subject is given the extended biographical questionnaire to take home.

Appendix 2

APPENDIX 2

Section A - Raw data

A1. Full summary table for overall ANOVA
A2. Results from overall ANOVA not presented in the main text
A3. Results from separate ANOVAS (males only, females only, etc.) not presented in the main text.

Section B - Transformations

B1. The normalized difference score for N1 matches for each block of trials for each subgroup

Section C - Other subject variables and misc. data

C1. Analyses of "relatives"
C2. Eye dominance, eye acuity, and hand position when writing: Breakdown table
C3. Analyses of eye dominance, eye acuity, and hand position.

Section D - Cognitive data

D1. A sample of some of the cognitive tests given
D2. Description of tests
D3. Table of overall means and S.D. for each test
D4. Results of 3-way ANOVA's on each test

A2. Sex by handedness by match:

Sex and handedness together interacted with the match effect ($F = 9.21$, df 1,56, $p < .004$) in the following way. Males, both right and left handers, had equal RT for PI matches (568 ms), but left handed males had a significantly faster RT for NI matches (629 ms) compared to the RT for NI matches in right handed males (649 ms). This led to a smaller NI-PI difference in left handed males. Females showed the reverse pattern. Both left and right handed females are equal on NI matches (662 ms and 660 ms respectively), but left handed females are faster on PI matches (575 ms) compared to PI matches in right handed females (591 ms), and this difference was significant (Scheffe, $p < .05$). This led to a larger NI-PI difference in left handed females compared to right handed females.

Handedness by family history interactions

Handedness and family history together interacted with the match effect ($F = 4.24$, df 1,56, $p < .045$). In FH- subjects, left handers are faster on NI matches (620 ms) compared to right handers (642 ms), and left handers are also faster on PI matches (538 ms) compared to right handers (642), both differences are significant at $p < .001$. For FH+ subjects, the situation was different. The right handers were faster on both types of matches, this difference was not significant for NI matches (668 ms versus 672 ms) but was significant for PI matches (586 ms for right handers and 605 ms for left handers).

Sex by handedness by family history

The only significant three way interaction of the three subject variables occurred with respect to the match effect. ($F = 5.29$, df 1,56 $p < .03$) This interaction can be described most simply by comparing the difference in RT for the two types of matches (the NI-PI difference) for all the subgroups of subjects. The NI-PI difference in general is larger in the FH- subjects. The only exception was for right handed females, where this finding was reversed. A positive family history of left handedness seemed to affect right handed females in an opposite manner compared to the other groups.

A3. Analyses on individual groups

FH- subjects versus FH+ subjects: Both groups had a significant block effect ($F = 30.6$, df 7,196, $p < .004$ for FH- subjects and $F = 20.9$. df 7,196, $p < .016$ for FH+ subjects). Post hoc Scheffe analyses revealed that for FH- subjects, there was a significant decrease in RT from Blocks 1 thru 4, and from Block 5 to Block 6 (no difference between Blocks 4 and 5). For FH+ subjects, there was a significant decrease in RT up to Block 4 with no change in RT thereafter.

A block by match interaction in FH+ subjects ($F = 3.94$, df 7,196, $p < .001$) showed that the lack of a decrease in RT after Block 4 in FH+ subjects was contributed to by the lack of adecrease in RT for the NI matches after Block 4. The PI matches continued to decrease after Block 4. A block by field interaction in the FH+ subjects($F = 5.49$, df 7,196,

p<.001) showed that while RT in the LVF continued to decrease throughout the eight blocks of trials, RT in the RVF actually increased slightly over the last four blocks.

A sex by handedness by block interaction occurred in both FH- and FH+ subjects, and it manifested itself in a similar way in both groups. For FH- subjects (F= 3.12, df 7,196, p<.004); male left handers and female right handers showed a progressive decline in RT until Block7, while male right handers and female left handers exhibited no decrease in RT after Block 4. In FH+ subjects, this interaction (F=2.54, df 7,196, p<.02) was very similar.

Males versus females

Separate ANOVA's on males and females produced the following major differences. Both sexes had significant block effects (F=23.9, df 7,196, p<.001 for males and F=27.9, df 7,196, p<.001) and match effects (F=399.5, df 1,28, p<.0001 for males and F=220.2, df 1,28, p<.0001 for females).

There was a hand by block interaction in both males and females. This interaction in males (F=2.33, df 7,196, p<.03) was as follows. Left handers started out faster (661 ms) compared to right handers (687 ms) and this difference was significant (Scheffe, p<.05), but the left

handers also showed a smaller decline in RT over the first four blocks (68 ms) compared to right handers (118 ms). Left handers continue to show a small decline in RT over the last four blocks (26 ms) while right handed males increase slightly (23 ms increase).

In females, the hand by block interaction ($F=4.89$, df 7, 196, $p<.001$) was similar to that seen in males in that the left handers start out faster (664 ms) compared to right handers (701) and this difference was significant (Scheffe, $p<.001$). Left handers showed less decline in RT over the first four blocks compared to right handers. Right handed females then continue to show a decrease in RT over the last four blocks while left handed females asymptote.

Right handers versus left handers

Separate analyses on right and left handers produced the following major differences. Both groups had significant block effects ($F=34.4$, df 7,196, $p<.001$ for right handers and $F=18.0$, df 7,196, $p<.001$ for left handers) and a significant match effect ($F=239.5$, df 1,28, $p<.0001$ for right handers and $F=327.3$, df 1,28, $p<.0001$ for left handers).

A sex by block interaction occurred in both handedness groups. This was not unexpected since handedness interacted with the block effect in both males and females. In right handers, this interaction ($F=3.88$, df 7,196, $p<.001$) was such that the males exhibited a substantial decrease in RT over the first four blocks,

but increased in RT thereafter. The females' RT decreased more slowly and continued to do so over all blocks. In left handers, this interaction ($F=2.53$, df 7, 196, $p<.02$) was such that both sexes were similar over the first four blocks, but the males continue to decrease in RT after Block 4 while the females asymptote.

Table B1

The normalized difference score for NI matches for each block of trials for each subgroup

	Blocks							
MRH-	7.1	7.0	10.1	15.6	14.2	9.8	16.7	10.6
MRH+	1.7	3.1	9.0	1.8	-1.7	4.7	-1.8	-1.8
MLH-	4.9	7.0	2.6	1.2	8.1	3.7	10.7	-1.7
MLH+	5.1	8.3	7.3	2.9	-1.0	1.0	3.1	-4.3
FRH-	-2.2	-1.4	7.7	10.7	-3.6	1.6	2.5	4.1
FRH+	4.4	2.3	3.4	2.5	8.3	3.2	-2.2	-11.3
FLH-	-3.1	0.2	9.1	3.7	-0.6	4.4	3.1	1.0
FLH+	2.5	2.9	1.9	-5.5	-0.3	-4.7	-3.7	-2.8

Section C

C1. Analyses of "relatives":

In order to try to determine more precisely the relationship of "relatives" alone and in interaction with the other subject variables, a number of ANOVA's and ANCOVA'S (analysis of covariance) were performed. These analyses are described below.

The two dependent measures used in all the analyses to be described were Total RT and Total Difference Score. The overall change score was not included because of its extremely low correlation with "relatives" (r=.10).

A three-way ANOVA with sex, handedness, and family history as the independent measures was first performed on Total RT and on Total Difference Score. These analyses were done for comparison purposes only; the variable "relatives"was not included in this analysis. For Total RT, there was a main effect for family history ($F=5.55$, df 1,56, $p<.02$); FH- subjects had faster total RT's compared to FH+ subjects. For Total Difference Score, there was a main effect for sex ($F=6.11$, df 1,56, $p<.016$) and for family history ($F=6.11$, df 1,56, $p<.016$). Males had higher difference scores compared to females (5.15 versus 1.20) and FH- subjects had higher difference scores compared to FH+ subjects (4.26 versus 2.09). An analysis of covariance was then performed on these two dependent measures with the same three independent variables, but "relatives" was covaried out. In other words, this

variable was equalized among all the subjects in the sample. For Total RT, there was now a main effect for the covariate "relatives", but no other effects were noted. For the Total Difference Score, again the effect of the covariate was significant, and a main effect for sex. In other words, the results of the two ANCOVA'S were very similar to those obtained when "relatives" was not equated across groups; the only difference lie in the fact that in both analyses, the significant main effect of family history was replaced by a main effect for "relatives".

C2. Table

C3. Effects of eye dominance, eye acuity, and hand position when writing

The dominant eye for sighting (right or left) was assessed in each subject. A breakdown of eye dominance by handedness and by sex can be found in Table C2. Although subjects were not selected for their eye dominance, it can be seen that males and females were equally right and left eyed, and there were as many right eyed right handers as there were left eyed left handers. Breaking eye dominance further within left handers only (see Table C2), it can be seen that almost all female left handers were left eye dominant. Eye acuity for each eye was also assessed, and the more acute eye was noted for each subject. A breakdown by handedness and by sex can be found in Table C2. More females had better acuity in the right eye; and males tended toward the reverse;

more right handers had better acuity in the right eye and vice versa for left handers. The hand position when writing was carefully assessed for left handers; those subjects who wrote with the pen below the line facing from them were said to write in the "normal" orientation, while those subjects who wrote with the pen above the line facing toward them were said to write in a "hooked" orientation. A breakdown of hand position for left handers can be found in Table C2. Notice that more males write in a "hooked" orientation and many more females write in the "normal" orientation.

A two-way ANOVA, with eye dominance and eye acuity as independent variables, was performed on Total RT and on Total Difference Score. This analysis included all subjects. There were no significant findings. An ANOVA was then performed on left handers only with sex, eye dominance, and hand position as the independent vairiables and Total RT and Total Difference Score as dpendent variables. Again, there were no significant findings.

Table C2

Breakdowns of eye dominance, eye acuity, and hand position when writing

(a) Eye Dominance

	Right eyed	Left eyed
Right Handers	25	7
Left Handers	7	25
Males	16	16
Females	16	16

(b) Eye Dominance in Left Handers

	Right	Left
Male Left Handers	5	11
Female Left Handers	2	14

(c) Eye Acuity

	Right eye	Left eye
Right Handers	21	11
Left Handers	12	20
Males	15	17
Females	18	14

(d) Hand Position in Left Handers

	Normal Position	Hooked position
Male Left Handers	6	10
Female Left Handers	12	4

Section D

D1. A sample of some of the cognitive tests given

(5)

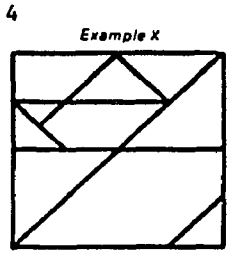
CAB-Cf

. In this test, you are to try to find a simple figure when it is hidden in a more complex design.

At the top of the test page you will see a row of *five simple figures*, labeled 1,2,3,4,5. Below them are 12 complex designs. In each of these designs *one of the five* simple figures is hidden. Only one of the five figures will be hidden in each complex design, and that one figure will be the *same size* and *in the same position* as it is at the top of the page.

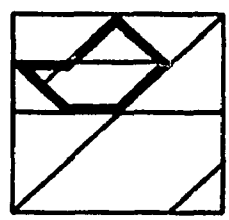
The five simple figures you are to look for are:

EXAMPLE X: Now try an example. Look for one of these simple figures in the complex design given to the right. Mark your answer by circling the correct number

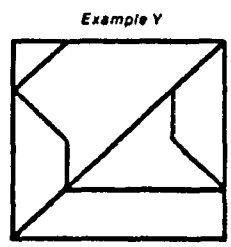


1 2 3 4 5

Figure 3 is the one that is hidden in the design, so you should have circled number 3.
You can see this more clearly in the design to the right, where Figure 3 is outlined with a heavy line.



EXAMPLE Y: Now try another example. Circle your answer below the figure.



1 2 3 4 5

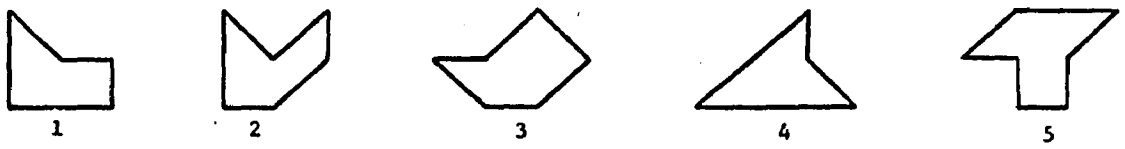
In EXAMPLE Y, Figure 4 is hidden, so you should have circled number 4.

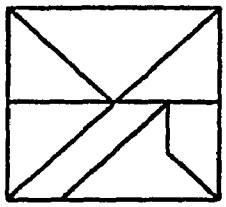
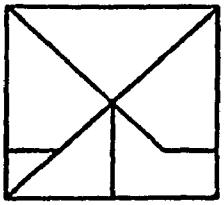
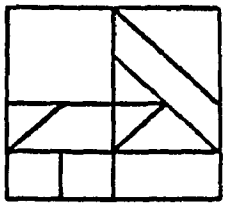
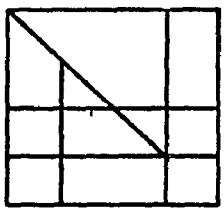
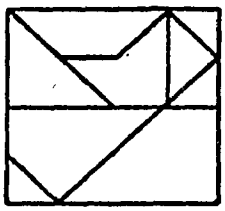
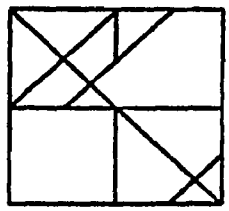
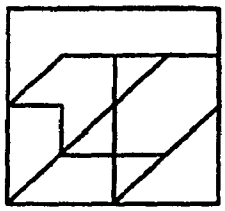
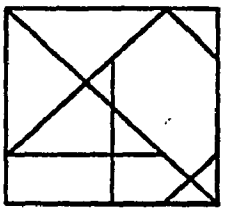
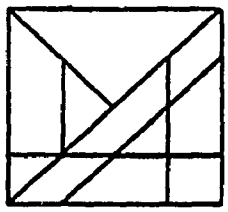
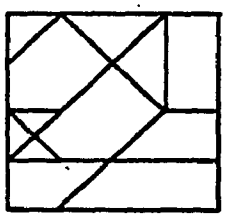
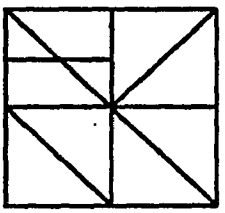
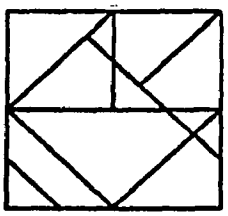
The same simple figures are on the next page. Starting with Figure A, find which one of these simple figures is hidden in each design. Circle your answer. *Work quickly* to finish as many as you can. You will have 3 *minutes* for the test. If you are not sure of the right answer for an item, mark the choice that is your best guess. If you finish before time is called, please *STOP*. Do *not* turn the page.

DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.

Cf

(6)



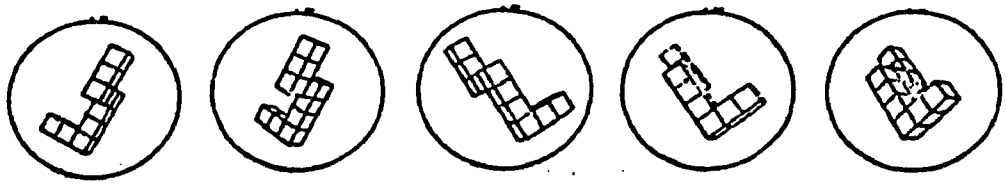
A  1 2 3 4 5	B  1 2 3 4 5	C  1 2 3 4 5
D  1 2 3 4 5	E  1 2 3 4 5	F  1 2 3 4 5
G  1 2 3 4 5	H  1 2 3 4 5	I  1 2 3 4 5
J  1 2 3 4 5	K  1 2 3 4 5	L  1 2 3 4 5

STOP. **PUT YOUR PENCIL DOWN. DO *NOT* TURN TO ANOTHER TEST.**

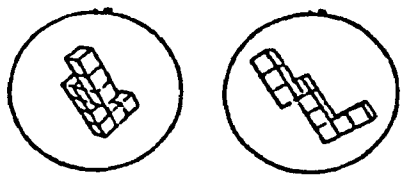
MENTAL ROTATION TEST

Instructions:

Look at these 5 drawings and notice that they show an object made up of 10 blocks which is shown from a number of different angles. Try to imagine moving the object (or yourself with respect to the object) as you look from one drawing to the next.



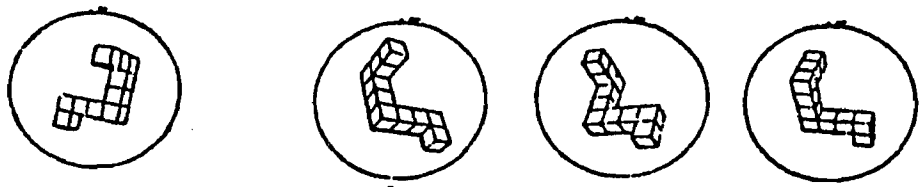
Notice that these two drawing represent different objects. That is to say that the 10 blocks which make it up are arranged a little differently than that above so that you cannot "rotate" them to be identical with the object shown in the first 5 drawings.



Now look at this object

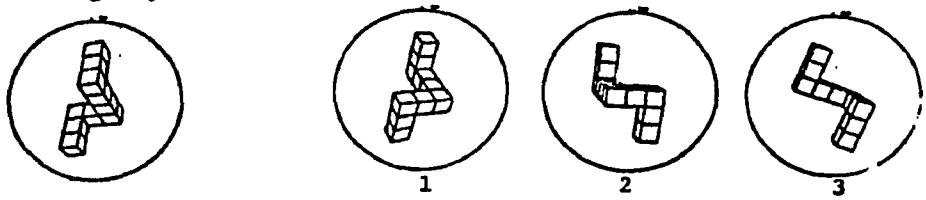
One of these three drawings shows the same object. Can you find it? Circle the number under the figure you have chosen.

(1)



If you circled number 3 you were correct. Now try the next one and Again, circle the number under your choice.

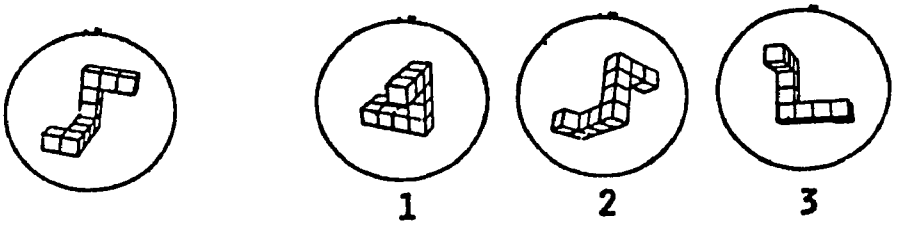
(2)

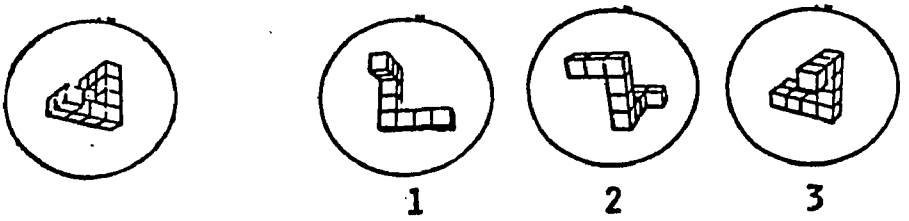


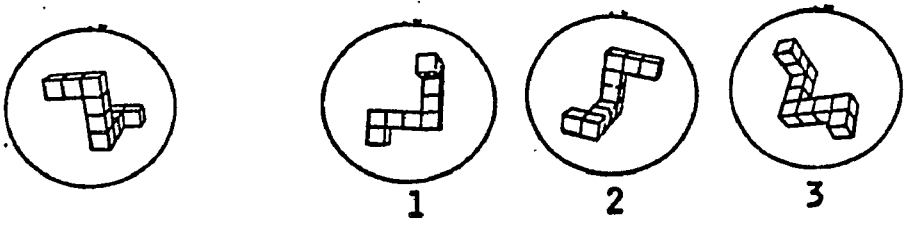
The correct answer was 2, hence you should have circled 2.

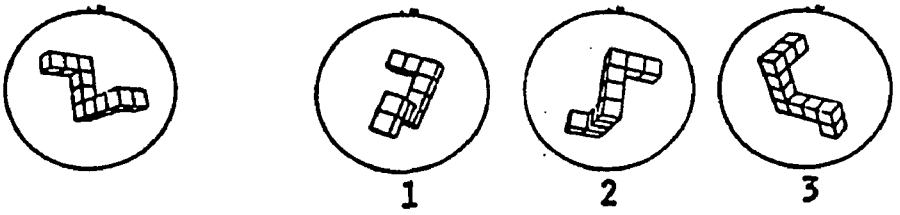
At the examiner's signal turn the page and begin with number 3. Answer each one in turn. Do not skip any and do not guess. You have 5 minutes.

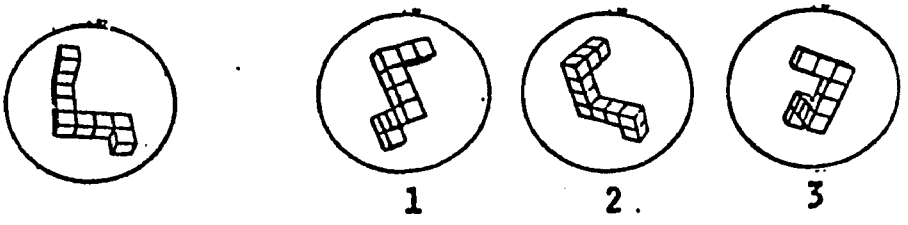
WAIT FOR THE SIGNAL BEFORE TURNING THE PAGE

(3) 

(4) 

(5) 

(6) 

(7) 

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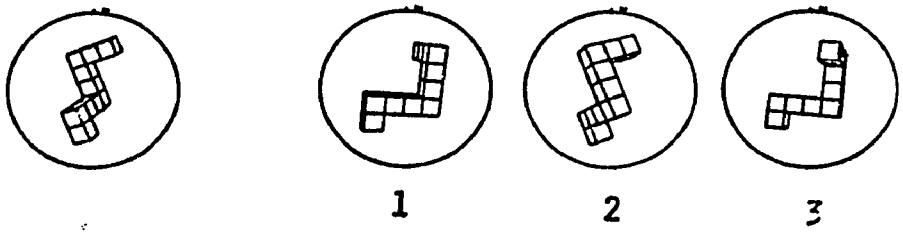
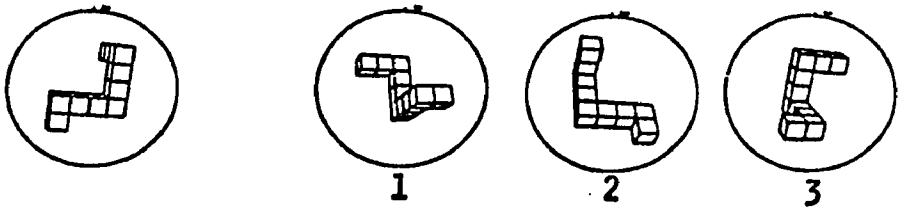
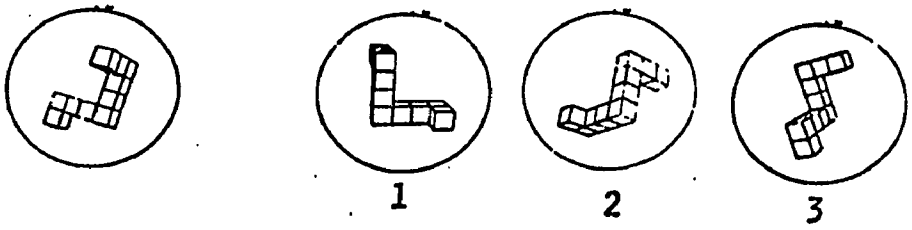
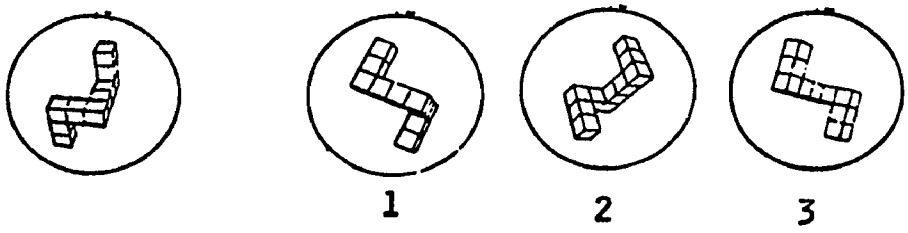
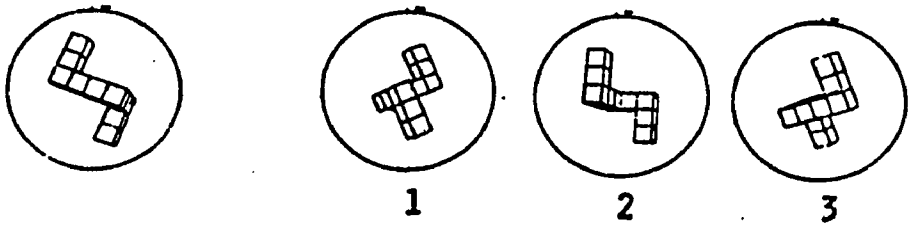
(8) 

(9) 

(10) 

(11) 

(12) 

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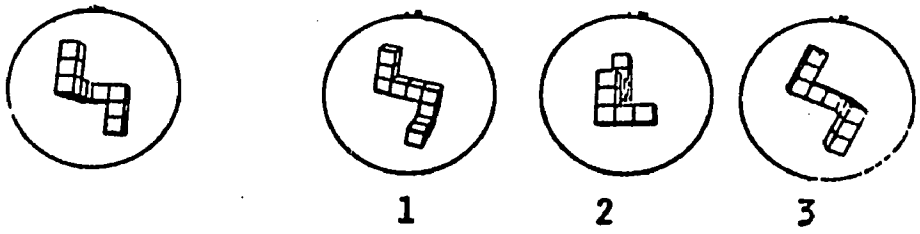
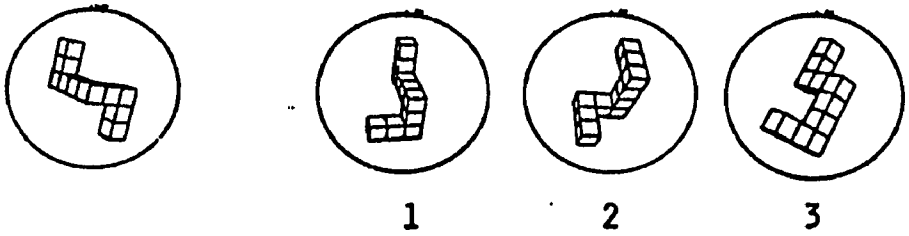
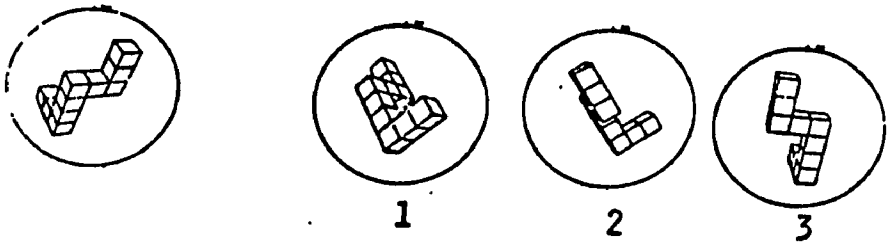
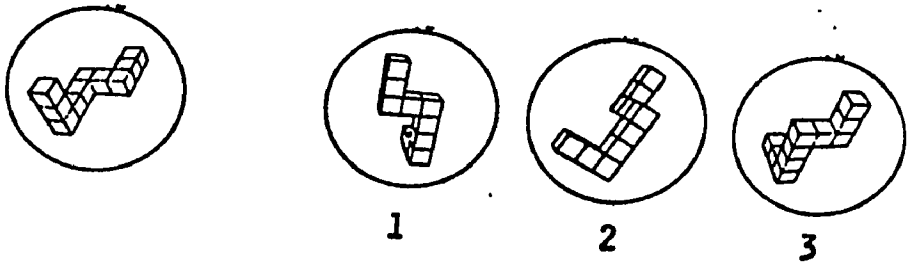
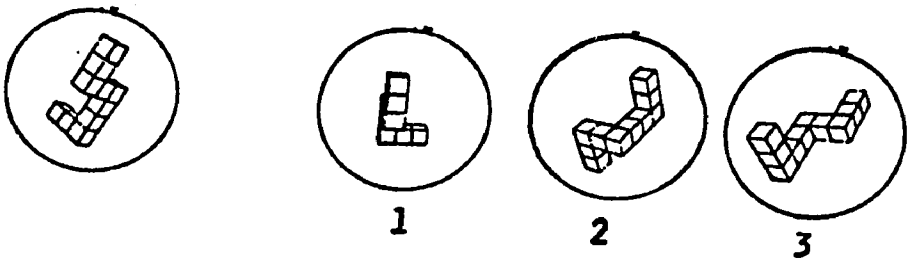
(13) 

(14) 

(15) 

(16) 

(17) 

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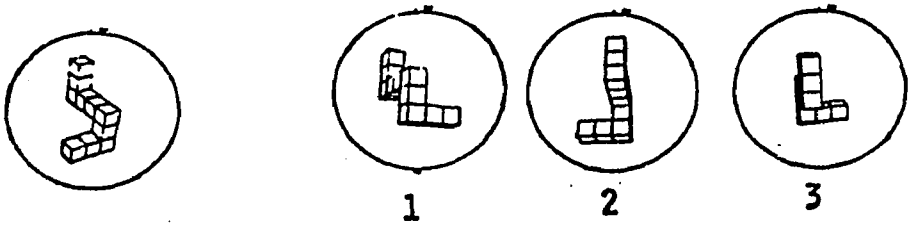
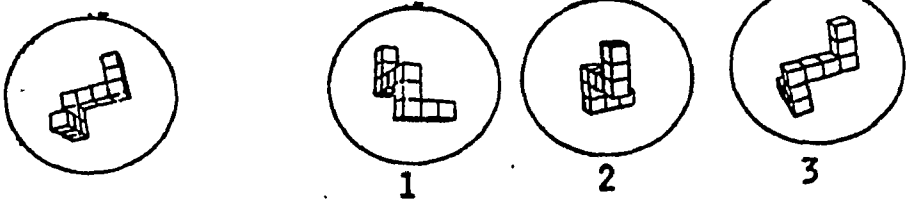
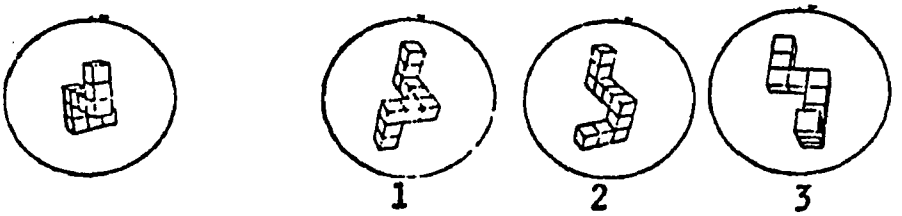
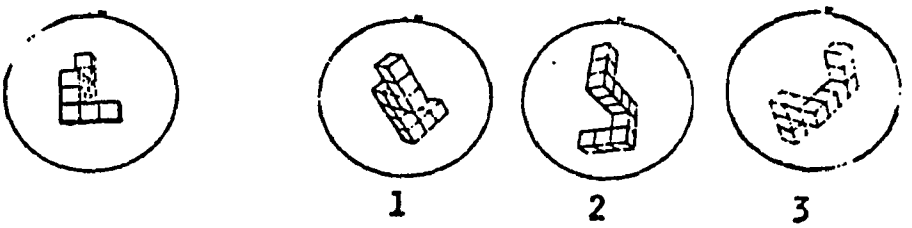
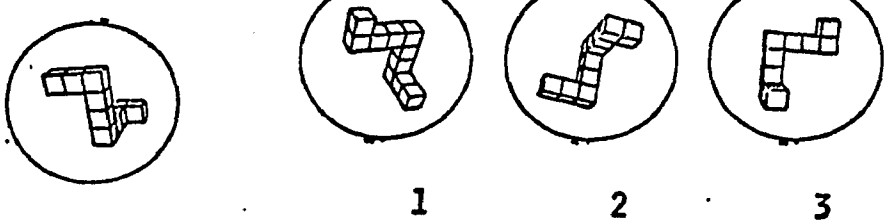
(18) 

(19) 

(20) 

(21) 

(22) 

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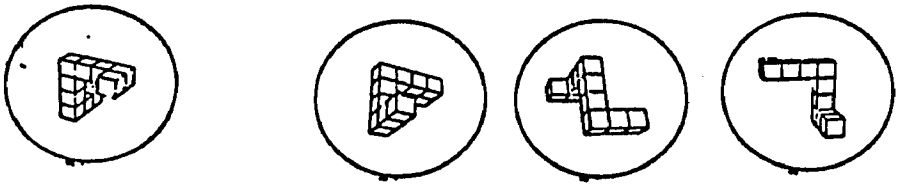
(23) 

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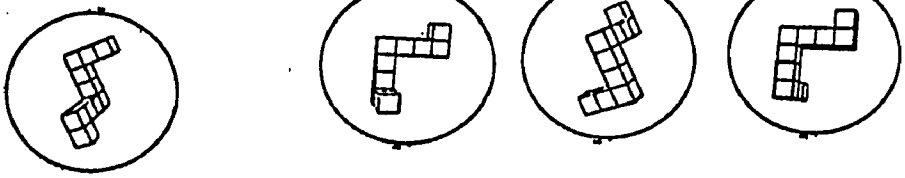
(24) 

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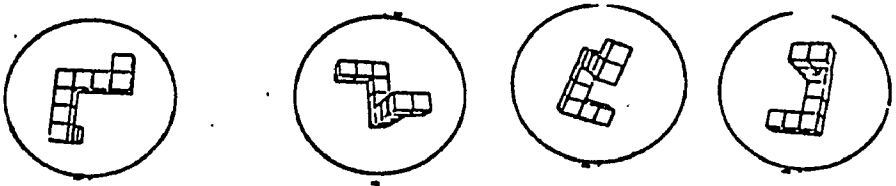
(25) 

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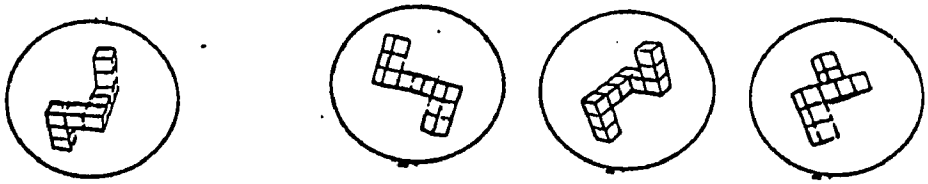
(26) 

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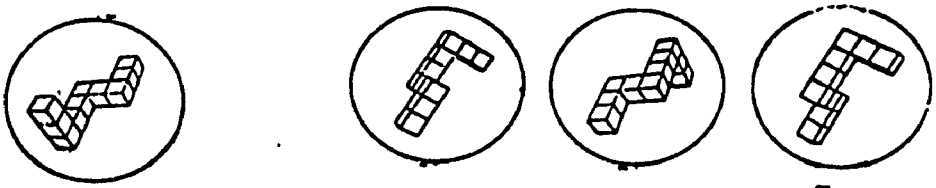
(27) 

1 2 3

PLEASE DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO. STOP.

CAB-V

For this test, look at the word in capital letters. Then, from the five words that follow, find the one that *means the same thing* as the word in capitals, and mark that answer on your Answer Sheet by circling it.

An example follows. Mark the correct answer on your Answer Sheet in the place for EXAMPLE X.

EXAMPLE X:

FAST: a. old b. rapid c. slow d. early e. late

Since FAST and RAPID mean the same thing, *b. rapid* is the correct answer. Therefore, you should have circled b on your Answer Sheet.

Work as rapidly and accurately as you can. You will have three minutes for this test

DO NOT TURN THIS PAGE UNTIL INSTRUCTED TO DO SO.

V

1. STRIVE:	a. attempt	b. hit	c. falter	d. walk	e. quarrel
2. DECEIVE:	a. blunder	b. obtain	c. conceal	d. mislead	e. disclose
3. EXCESS:	a. waste	b. departure	c. oversupply	d. tax	e. approach
4. CREDIBLE:	a. admirable	b. real	c. personable	d. unlikely	e. believable
5. MEDITATE:	a. heal	b. advance	c. ponder	d. rest	e. worry
6. AMIABLE:	a. friendly	b. humorous	c. healthy	d. convincing	e. polished
7. TURBULENT:	a. circular	b. disorderly	c. calm	d. spinning	e. air-borne
8. ILLUSORY:	a. illogical	b. unreal	c. magical	d. visible	e. clear
9. CAPRICIOUS:	a. unlike	b. musical	c. dancing	d. unpredictable	e. equatorial
10. APATHETIC:	a. ignorant	b. indifferent	c. pitiful	d. concerned	e. clever
11. ARDUOUS:	a. repulsive	b. loving	c. easy	d. interesting	e. difficult
12. PLACATE:	a. cover	b. beautify	c. arouse	d. plasticize	e. soothe
13. CLANDESTINE:	a. secret	b. safe	c. tribal	d. open	e. healthful
14. VINDICATE:	a. deny	b. state	c. persecute	d. justify	e. accuse
15. INCULCATE:	a. grow	b. inquire	c. instill	d. compute	e. acquire

STOP. DO *NOT* TURN THIS PAGE UNTIL ASKED TO DO SO.

CAB-I

. On the next page there are 12 rows of letters. In each row, you are to look at five sets of letters. *Four* of the five sets follow a certain rule. One set *does not*. On your Answer Sheet, you are to circle the one set that *does not* follow the rule. Look at the following example:

a. BBLJ b. TTRU c. FWZP d. XXBK e. MMEO

Here you see that in four of the sets, the *first two* letters are the same. In the other one, *c. FWZP*, this rule is *not* followed, so the correct answer to this example is *c.*

The rules are *not* based on *sounds, shapes,* or *types* (vowel or consonant) of the letters.

Now try another example, circle your answer on the Answer Sheet in the place for EXAMPLE X.

EXAMPLE X: a. ABCD b. GHIJ c. LMNO d. QSRT e. VWXY

In four of these sets, the letters follow one another in alphabetical order. In one set, *d. QSRT*, this rule is not followed, because the S and R are not in the right alphabetical order. Therefore, you should have circled d.

Work *quickly* to finish as many items as you can. You will have 5 *minutes*. If you are not sure of the right answer for an item, mark the choice that is your best guess.

If you finish before time is called, please *STOP*. Do *not* turn to other pages.

DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.

I

1. a. DEPD	b. RFMR	c. SJUS	d. TVWT	e. GBBK
2. a. XFGX	b. BLMB	c. KQRK	d. DTSD	e. MYZM
3. a. FGHE	b. IJKH	c. LMNP	d. RSTQ	e. VWXU
4. a. EDDG	b. IHHJ	c. NMMO	d. RQQS	e. TSSU
5. a. VWVI	b. SVWV	c. VWVR	d. QVWV	e. VWPV
6. a. CDED	b. LMOM	c. PQRQ	d. STUT	e. WXYX
7. a. RYAA	b. BBRG	c. RPCC	d. DDRD	e. RLEE
8. a. ORAR	b. PGRR	c. RBVR	d. RRUH	e. IRIX
9. a. DECG	b. JKIL	c. MNLO	d. QRPS	e. UVTW
10. a. BCFF	b. GHKK	c. KLNN	d. PQTT	e. VWZZ
11. a. CGFJ	b. EIHL	c. GKJN	d. IMNR	e. MQPT
12. a. HGFC	b. KJIG	c. NMLI	d. TSRQ	e. YXWI

STOP. PUT YOUR PENCIL DOWN. DO *NOT* TURN TO ANOTHER TEST

D2. Description of tests

1) Hand rotation task: Total mean RT for all the hand stimuli combined was calculated, and separate means for left hand only, right hand only, normal orientation only, reversed orientation only, and total errors were also calculated. These scores, along with all cognitive test scores, can be found in Table D3.

2) Street Closure test: The 13 original Street Closure items were presented for identification, and scores for this grup of subjects ranged from 4 to 13, with a mean of 8.0. This mean score is within the normal range.

3) EFT (Embedded Figures Test): On this 12 item version of the EFT, scores for this group of subjects ranged from 4 to 12, with a mean of 6.8.

4) WAIS Block Design and Similarities subtests: These two subtests from the Wechsler Adult Intelligence Scale were administered and scored in the usual format. The mean scaled scored for Block Design was 12, while the mean scaled score for Similarities was 15. Since each subtest of the WAIS in normed sothat the mean for all subtests is 10 with a standard deviation of 3, then performance for this group of subjects was within the normal range on Block Design and better than normal on Similarities.

5) Vocabulary test: Scores on this 15 item

Table D3

Overall means and standard deviations for the cognitive tests

Name of test	Mean	S.D.	%ile compared to available norms	Range
Hand Rotation Task				
Overall RT	1152	410		
# errors	1.56	2.34		
Left hand	1141	419		
Right hand	1164	429		
Normal orientation	1096	390		
Reversed orientation	1209	442		
Left-right	-23	219		
Reversed minus normal	113	150		
Street Closure Test	8.0	1.92	58%ile	4-13
EFT	6.8	2.5	40%ile	4-12
WAIS Similarities	15	1.2		13-16
WAIS Block Design	12	2.3		9-16
CAB Vocabulary Subtest				
CAB Abstract Reasoning	8.8	1.7	55%ile	7-13
CAB Mental Rotation	9.5	2.9	47%ile	4-16

vocabulary test ranged fron 8 to 15. The mean for this group of subjects (11.1) was right at the mean for college students (norms collected in Canada, see Footnote 1).

6) Abstract Reasoning Test: This 13 item test involved the discovering of a rule that governed the pattern of sets of letters, and eliminating the set of letters that did not follow the rule. Scores ranged from 7 to 13, and the mean score of 8.8 was right at the mean for college students.

7) Mental Rotation Test: This paper and pencil test is designed to measure aspects of visual-spatial perception, and more specifically the ability to rotate figures in space. Scores ranged from 4 to 16, with a mean of 9.5. This score, when compared to norms collected in Canada, was within the normal range.

8) Purdue Pegboard test: Subjects were allowed two trials for each measure (right hand, left hand, both hands), and the mean for the two trials was taken, and the mean difference score between the two hands (right minus left).

D4. Results of 3-way ANOVA's for each test

1) Hand Rotation task: Total RT to all stimuli combined was subjected to a 3-way ANOVA with sex, handedness, and family history as independent variables. There was a main effect for sex

[1] Norms collected at the University of British Columbia and the University of Victoria from 1975 to 1979.

(F=4.86, df 1,56, p-.03) and for handedness (F=7.34, df 1,56, p<.01); females were slower than males (1255 vs 1051 ms) and left handers were slower than right handers (1278 vs 1027 ms). There was also a sex by handedness interaction (F=5.53, df 1,56, p<.02) such that male right handers had the fastest RT while male left handers had the slowest RT (816 vs 1285 ms).

Number of errors made on the hand rotation task was also subjected to a 3-way ANOVA with the following results. There was a main effect for sex (F=4.99, df 1,56, p<.04); females made more errors than males (2.1 vs 1.0). There was a sex by family history interaction (F=5.57, df 1,56, p<.03); presence of a positive family history increased errors in males but decreased number of errors in females.

2) Street Closure test: There was a main effect for sex (F=6.45, df 1,56, p<.014) and for handedness (F=5.77, df 1,56, p<.02). Males had higher scores compared to females (8.56 vs 7.40) and right handers had higher scores compared to left handers (8.53 vs 7.44).

3) EFT: There was a main effect for handedness (F=3.88, df 1,56, p<.05); left handers had higher scores compared to right handers (7.40 vs 6.28). A sex by FH interaction (F=4.27, df 1,56, p<.04) revealed that presence of FH decreased scores in males but increased scores in females.

4) Block Design: There was a sex by FH interaction (F=27.0, df 1,56, p<.0001) such that presence of FH decreased scores in males but increased scores in females.

5) Similarities: There were no significant findings.

6) Vocabulary test: There was a significant sex effect ($F=8.02$, df 1,56, $p<.006$); females had higher scores compared to males (11.8 vs 10.3).

7) Abstract Reasoning test: There were main effects for sex ($F=9.0$, df 1,56, $p<.004$) and for handedness ($F=5.53$, df 1,56, $p<.02$) such that females had higher scores compard to males (9.38 vs 8.22) and left handers had higher scores compared to right handers (9.25 vs 8.34).

8) Mental Rotation test: There was a main effect for sex ($F=7.42$, df 1,56, $p<.009$) such that males had higher scores compared to females (10.35 vs 8.80). A sex by FH interaction ($F=23.0$, df 1,56, $p<.0001$) showed that the presence of a positive FH decreased scores in males (from 11.6 to 9.0) and increased scores in females (7.3 to 10.2) and these differences were significant at the .01 level (Scheffe post hoc tests).

9) Purdue Pegboard test: Right minus left difference scores were computed for each subject; a positive score indicated better performance with the right hand while a negative difference score indicated better performance with the left hand. A 3-way ANOVA on these difference scores resulted in a main effect for handedness ($F=240.7$, df 1,56, $p<.0001$); all left handed groups had negative difference scores and the converse was true for the right handed groups (1.47 for right handers and -1.53 for left handers). There was a sex by handedness interaction ($F=8.46$, df 1,56, $p<.005$) indicating that females had higher absolute difference scores

compared to males (1.78 vs 1.22). A handedness by FH interaction ($F=10.45$, df 1,56, $p<.002$) revealed that FH+ subjects had lower absolute difference scores compared to FH- subjects (1.2 vs 1.8). This was true whether the subjects were left or right handed.