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HANDEDNESS AND SEX EFFECTS ON VISUOCONSTRUCTIVE AND VISUOPERCEPTUAL ABILITIES IN COLLEGE STUDENTS

By

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ABSTRACT

HANDEDNESS AND SEX EFFECTS ON VISUOCONSTRUCTIVE AND VISUOPERCEPTUAL ABILITIES IN COLLEGE STUDENTS

By

Peter Jeffrey Snyder, M.A.

To assess the relationship of handedness and sex to spatial ability, 109 left-handed and 115 right-handed American college students were given a 9-item version of Annett's (1967) hand-use inventory, a familial sinistrality questionnaire, and three different kinds of spatial tests: the Stafford Identical Blocks Test (SIBT; a 30-item multiple-choice "mental rotation" test), the Rey-Osterrieth Complex Figure Test (ROCF), and a drawing test (3DD) that required the subjects to add whatever lines were necessary to make a series of two-dimensional figures appear to be three-dimensional.

The left-handers were further separated into subgroups based on consistency of left-hand preference across a series of unimanual tasks on the hand-use questionnaire. Based on the sample data, the results suggest that consistent (CLH) and inconsistent (ILH) individuals are about equally prevalent, for both males and females, in the general population of left-handers.

A positive history of familial sinistrality (FS+) was found to be twice as common in left-handers as in right-handers, and there were no sex differences in the incidence of FS+. Secondly, although there were no differences in the

incidence of FS+ between the CLH and ILH subgroups for females, the incidence of FS+ in the CLH subgroup was more than twice that found for the ILH subgroup among males.

The results further show that left-handers can be subdivided into CLH versus ILH subgroups not only on the basis of motor skill, but also (at least in males) on the basis of certain neuropsychological differences. Specifically, although an overall sex difference was found on the SIBT, 3DD, and ROCF (delayed condition only) tests, with the males outperforming the females on all three measures, for males the CLH subgroup performed significantly worse on the mental rotation test (SIBT) than the right-handed subgroup (with the ILH subjects performing only slightly worse than the right-handers). Therefore, where left-handers are found to report a greater incidence of FS+, or to be inferior to right-handers in mental rotation skill, it is CLH left-handers (males in particular) who are making the largest contribution to these effects.

A full understanding of the phenotypic differences between these two subgroups of left-handers may provide the basis for increased understanding of the underlying mechanism(s) and inheritance of handedness. It is suggested that the discrepant findings in previous studies of the cognitive correlates of left-handedness are caused by the mixing of two neuropsychologically distinct subgroups of left-handers, at least for males.

In memory of
Alexander Romanovich Luria,
whose writings inspired me

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INTRODUCTION

Man's ability to perceive, integrate, and organize his environment has long been a focus of scientific study. It is our higher cognitive functioning, our capacity to abstract salient features from our environment and to symbolize, conceptualize, and express our experiences, that many feel distinguish us as a species. This thesis focuses on one aspect of higher cognitive functioning - the perception and manipulation of visual-spatial information, such as the ability to mentally "rotate" a two-dimensional figure as if it were three-dimensional.

Much research over the past century has pointed to the predominant role played by the right cerebral hemisphere in mediating visuospatial functioning (cf. Luria, 1966). Over this same period, much research also reveals a great range of individual differences in visuospatial abilities within the population. The possibility arises that individual differences in the cortical organization for spatial functions might account, in part, for individual differences in spatial ability. The possibility also occurs that these individual differences are related to certain subject variables. Previous research suggests that two such variables are sex and handedness, both of which have been shown to be correlated with different patterns of lateral specialization for cognitive functions. The purpose of the current study is to better understand how these variables work, separately and in combination, to influence spatial ability, and whether they are associated with variations in lateral cerebral specialization of visuospatial functions.

LATERAL SPECIALIZATION OF COGNITIVE FUNCTIONS IN THE HUMAN BRAIN

Questions about the evolutionary bases and adaptive value of lateral specialization of the human brain have attracted interest since Broca's day in the 1860's. A paradigm that has proven to be especially useful in the study of lateral specialization is the study of patients whose neocortical commissures have been surgically transected for the control of medically refractory epilepsy. These studies have confirmed the principle that the left hemisphere plays the leading role in language functions, speech in particular.

The fact of lateralization for speech and language functions has provoked speculation about its evolutionary history. Levy-Agresti and Sperry (1968) have hypothesized that during hominid evolution the "gestalt" perception of external stimuli became lateralized to the hemisphere that is typically non-dominant for speech as a consequence of some inherent antagonism between verbal and visuospatial functioning. Levy (1969) has suggested that this development may also have come at a certain cost, so that people with "partial language competency in both hemispheres" may perform relatively poorly on tests of visuospatial ability. Levy also designated left-handers as examples of persons fitting this description.

"Mixed Speech Dominance" in Normal Left-Handers

The inclusion of left-handers in the category of individuals with partial language competency in both hemispheres, or "mixed speech dominance" (MSD), is supported by evidence from three sources: 1) studies using the Intracarotid Amobarbital Procedure (IAP) on patients with late-onset focal lesions (an invasive procedure whereby the language zones of one hemisphere are selectively anesthetized by the intracarotid administration of a barbiturate); 2) clinical studies of left- and right-handed adults who have suffered left hemisphere injuries; and 3) non-invasive studies of normal persons using such methods as dichotic listening.

In her studies with the IAP, Milner (1975) found no evidence of MSD in a group of 140 right-handed patients with late-onset epilepsy. Instead, 95-98% of these patients showed lateralization for speech to the left hemisphere (see also Rasmussen & Milner, 1977). By contrast, sinistrals with late-onset epilepsy (implying that their left-handedness is not due to an early left hemisphere injury) show a heterogenous pattern of lateralization of speech functions. In Milner's (1975) study, 15% of a sample of 122 left- or mixed-handed epilepsy patients were determined to have MSD. In other studies, estimates of MSD ranging from 0% to 50% of developmentally normal left-handers with right hemisphere lateralization for speech have been reported (e.g., H caen & Sauget, 1971; Rasmussen & Milner, 1977; Satz, 1979; Strauss, Wada, & Satz, 1988 [cited in Satz, Strauss, Wada, & Orsini, 1988]; see review by Snyder, Novelly, & Harris, 1990).

Despite the apparent lack of agreement as to the incidence of MSD within the general population, most investigators agree that where MSD is found, the individuals invariably are sinistrals (Chesher, 1936; Goodglass & Quadfasel, 1954; Humphrey & Zangwill, 1952; Kimura, 1983a; but see Loring et al., 1990). Converging evidence comes from clinical studies that reveal a higher incidence of speech disorders after right-sided lesions in sinistrals as compared to dextrals. In addition, dichotic listening studies with normal subjects show a weaker pattern of lateralization for the interpretation of verbal stimuli in sinistrals as compared to dextrals (Kimura, 1983b[1]).

Given the evidence that MSD (and right hemisphere dominance for speech) in developmentally normal individuals is largely restricted to adextrals, Levy (1969) chose left-handers to test her hypothesis relating MSD to spatial ability. She compared 10 sinistrals and 15 dextrals on the verbal (VIQ) and "performance" (PIQ) cluster scores on the Wechsler Adult Intelligence Scale (WAIS). Although the two groups did not differ on VIQ ($p<.10$), they did differ on PIQ with the sinistrals scoring well within the normal range but significantly worse than the right-handers ($p<.002$). Levy therefore concluded that the left-handers' presumably weaker lateralization for speech and language had interfered with their ability to perform the non-verbal tasks comprising the performance subtests of the WAIS-R.

"Mixed Speech Dominance" in Pathological Left-Handers

Thus far we have considered the proposition that, at a group level, MSD in neurologically normal persons is more common in left-handers than in right-handers and that this has consequences for certain cognitive abilities. In individuals who are *pathologically* left-handed (due to an early insult to the periopercular zones of the left cerebral hemisphere), there is an even higher propensity for MSD than in comparable groups of normal left-handers because the neuropathology that shifts control of handedness to the right hemisphere also tends to shift control of speech and other language functions, a phenomenon first alluded to by Broca (1865) and subsequently confirmed in many clinical studies (e.g., Gardner, 1941; Zaidel, 1983; Satz, Orsini, Saslow, & Henry, 1985; Bishop, 1988; see review by Harris & Carlson, 1988).

Will MSD that has been induced by left hemisphere neuropathology also have consequences for non-verbal functions? Some evidence suggests that it will. Lansdell (1962) tested patients who had suffered early damage to the periopercular zones of the left hemisphere with subsequent shifting of speech dominance into the right hemisphere (determined by IAP). The result was that patients with early left-hemisphere damage and subsequent right-hemisphere speech dominance scored higher on the verbal subtests of the Wechsler-Bellevue Intelligence Scale than on the nonverbal subtests, whereas patients with early left-hemisphere injuries who remained left-hemisphere dominant for speech did worse on the verbal than on the nonverbal subtests. In both groups of patients, many also were left-handed, but here both the left-handedness and the MSD stemmed from early neurological insult. In the first of Lansdell's two subject groups, listed above, the hypothesized explanation for the apparent decrease in visuospatial ability as a result of a shift in speech and language dominance to the right hemisphere has been termed the "crowding hypothesis." The hypothesized crowding of verbal and non-verbal functions in the right-hemisphere has been invoked to describe both the possible cortical re-organization of cognitive functions following early left-hemisphere injury, as well as a result of amodal organization of the brain for a subset of neurologically normal, genetic left-handers. Lansdell (1969) subsequently found that if left hemisphere brain damage occurs before 5 years of age, there is a greater likelihood that verbal development will progress at the expense of well-developed nonverbal abilities.

It is unclear how to understand the term "crowding" at the physiological level. One possibility is that verbal functions that are subsumed by the right hemisphere are "given" priority for limited space, thereby reducing the amount of cortical tissue necessary for the unimpeded development and control of visuospatial abilities. Specifically, functionally disparate neural networks might "compete" for synaptic sites during the embryological development of the cortex, thus hindering the development of neural networks subserving spatial functions if the neural architecture leading to the cortical mediation of language and speech is favored ontogenetically.

Another possibility is that in individuals with early left-sided trauma, the re-organization of speech into the right hemisphere causes cortical activity mediating verbal functions, now located in close proximity to cortical areas responsible for visuospatial functions, to interfere with the neuropsychological mediation of visuospatial functions. This latter interpretation is consistent with Levy's (1969) evolutionary model for the development of lateral specialization, that is, to separate potentially incompatible cognitive processing modalities into different hemispheres.

Although the "crowding" hypothesis has stimulated much new research, both with non-clinical and clinical populations, the term "crowding" is questionable as a valid characterization of the neural processes involved in hemispheric specialization (Nottebohm, 1979). The reason is that this metaphor contradicts modern neurobiological notions of brain organization, which posit circuit modules that can be variously combined and recombined to provide greater functional capacity and diversity (cf. Edelman, Gall, & Cowan, 1984). It also is doubtful that the linguistic categories used to describe psychological functions represent size-specific parcels of neuroanatomical space (Michel, 1989). Until more is known about the relation between different structural neuroanatomical patterns, the ontogeny of neurophysiological processes, and specific aspects of psychological functioning, there appears to be little substantive value in characterizing hemispheric specialization as territorial competition for brain space. Indeed, it is possible that the co-localization of cortical regions responsible for subserving language and spatial functions, in the same hemisphere, could serve to <u>either</u> hinder or support visuospatial functioning. For example, localization of speech and/or language zones near cortical areas responsible for spatial functions might serve to benefit visuospatial functioning if the spatial task can be accomplished, in whole or in part, by verbal strategies.

For the time being, it may be best to use the term "crowding" heuristically.

Lateral Specialization of Speech and Language Functions

There has been much progress in the study of human lateral specialization since the early reports cited above. In particular, we have a better understanding of the nature and extent of lateral specialization of both verbal and visuospatial functions.

Research over the past two decades has not supported the simple model that language functions are strictly lateralized to the left hemisphere. Although there is overwhelming evidence that speech is lateralized to the left cerebral hemisphere in nearly all dextrals (Rasmussen & Milner, 1977) and in most sinistrals (e.g., Kimura, 1983a), there is mounting evidence that the right hemisphere also plays a role in receptive language functions in neurologically normal individuals. Zaidel (1985) and others (see review by Chiarello, 1988) have argued that the right hemisphere in normal persons has limited but measurable competence for comprehending both spoken and written language but that it is generally impoverished in its ability to produce meaningful verbal expression (in dextrals), which competition from the speech-dominant left hemisphere makes difficult to observe in any case (Levy-Agresti & Sperry, 1968; Butler & Norrsell, 1968). Consistent with this view is evidence that globally aphasic patients show some recovery of language comprehension, even when a lesion amounting to a left-sided hemidecortication is present (Kertesz, 1979, p.142).

New research also has demonstrated an important right-hemisphere role in the interpretation and modulation of affect and prosody in speech, and in the comprehension of humor. Although patients with right-hemisphere damage are still able to appreciate the variety of forms of humorous stimuli, they show "particular difficulty in resolving the incongruity of humor and integrating the elements into a coherent whole" (Bihrle, Brownell, & Gardner, 1988, p.123). The authors suggest that the reason is that these patients possess "rigidity of interpretation, literalness, and inattention to relevant detail" in their approach to the comprehension and interpretation of verbal humor.

Lateral Specialization of Visuospatial Functions

The new evidence of right-hemisphere linguistic functions raises questions about the role language might play in the completion of seemingly non-verbal, visuospatial cognitive tasks by the right hemisphere. At the same time, new work has demonstrated the shared role of the cerebral hemispheres in the perception, interpretation, and manipulation of visuospatial stimuli (e.g., Geschwind and Kaplan, 1962). This raises questions about the possible role of spatial abilities for the successful completion of language tasks, meaning that just as language factors may affect spatial processing, so might spatial factors affect linguistic processing, such as language comprehension (e.g., Luria, 1966, pp. 154-158, 384-389).

One example of "bilateral" contributions to spatial functioning can be observed by performance on the block design subtest of the WAIS-R, where the subject, using red and white blocks, must duplicate a series of modal designs (both 2x2 and 3x3 design matrices). Kaplan (1988) has found that when commissurotomy patients perform this task with only the left hand (or right hemisphere in isolation), they preserve the design contour but lose the internal detail. The performance is much like that of patients with left-hemisphere lesions (Kaplan, 1988).

When the same commissurotomized patients used the right hand (or the left hemisphere in isolation), the results were fundamentally the reverse of the designs produced by the right hemisphere. Now, the matrices were rarely preserved, and the patients instead tended to pile the blocks on the right side (in the right hemiattentional field), and some of the model design's internal details were relatively preserved in their right-hand productions. These clinical data suggest that in the construction (and possibly perception) of a visual design (e.g., a drawing test), the left hemisphere contributes to the production of internal details, while the right hemisphere complements this effort by reproducing the design's outer shape.

A similar pattern of errors has been observed in patients with focal parietal lesions. Patients with right-sided lesions failed to preserve the outer shape of the design but conserved some of the internal details, whereas patients with left-sided lesions maintained the outer configuration without regard for the internal details (Kaplan, Palmer, Weinstein, & Baker, 1981). Kaplan (1988) has reported identical findings in both commissurotomy and focal-lesioned patients on the Object Assembly subtest of the WAIS-R and on the Rey-Osterrieth Complex Figure Task (ROCF).

Evidence that the two cerebral hemispheres contribute in different but complementary ways to the completion of a visuoconstructive task (e.g., Block Design, Object Assembly, ROCF) also has been found in studies of neurologically normal subjects. Kee, Bathurst, and Hellige (1984) employed a dual-task paradigm using concurrent finger-tapping and block design tasks with right-handed college students. The result was more left- than right-hand disruption of finger tapping when subjects were required to complete a block design manually, using their non-tapping hand, whereas the reverse pattern was found when the subjects had to complete the same test "mentally." These results suggest that there is more right than left hemisphere processing activity during actual performance of a visuoconstructive task, but more left hemisphere activity when the same test stimuli are manipulated mentally.

Kee et al.'s results are consistent with those of an earlier study by Ornstein, Johnstone, Herron, and Swencionis (1980). Using EEG alpha suppression as an index of hemispheric activation, these investigators concluded that a task requiring mental rotation of spatial stimuli is more likely to involve verbal strategies in part (greater left-hemisphere involvement), whereas right-hemisphere activation is greater when a visuoconstructive approach is required.

These studies lead to several general conclusions. First, the two cerebral hemispheres contribute in different but complementary ways to the interpretation and construction of a visual array. Secondly, normal individuals show a relatively greater margin of right- over left-hemisphere activation during the completion of a visuospatial task, depending on whether the task is primarily visuoconstructive or visuoperceptual. These findings indicate that as with language comprehension, the perception and manipulation of visuospatial stimuli consist of a multidimensional set of inter-related functions. The neuropsychological investigation of visuospatial functions therefore must consider the specific task demands of the non-verbal task(s). It must ask what specific patterns of performance on that task might mean with regard to cerebral distribution of non-verbal functions, as opposed to similar performance on a separate task that requires different cognitive strategies for its solution.

This progress in our understanding of the neurocognitive requirements for the successful completion of specific visuospatial tasks suggests further questions. First, do certain subgroups of individuals, but not others, show reliable overall differences in their performance on these tasks? Second, what can such differences tell us about group (and individual) differences in the neuropsychological organization of visuospatial functions? Two dimensions of individual differences, handedness and sex, for which differing patterns of performance have been observed on a variety of visuospatial tasks, will be examined below.

HANDEDNESS

In the years since Levy's (1969) report of handedness differences in PIQ, a better appreciation of the complexities involved in the analysis of handedness has developed. We now have a deeper understanding of the biological substrates and neurological correlates of handedness as well as a better understanding of the phenotypic expression of handedness itself. Both of these developments were important in the framing of the current investigation.

A Genetic Model

Of all primate species, only Homo sapiens sapiens show a population bias toward preferential use of one hand (Corballis, 1989). The population bias is of long-standing. Analysis of cave drawings suggests that it extends back at least 5,000 years (Coren and Porac, 1977), and the microscopic analysis of patterns of wear on tool specimens (shards of stone) points to a considerably longer period than that (Corballis, 1989). What this analysis shows is that tools used during the Upper Paleolithic period (35,000 - 8,000 B.C.) more often have wear patterns on the right side, indicating that if these tools were used to scrape in a downward motion, the users held the shards more often in the right hand (Semenov, 1964 [cited in Corballis, 1989]). If the population bias of H. sapiens sapiens toward right-handedness extends back for 10,000 to 35,000 years, it seems likely that this species characteristic is genetically determined.

There have been several efforts to specify the actual genetic mechanism. Perhaps the most widely accepted theory was proposed by Annett (1981). Annett proposed that both handedness and cerebral asymmetry for certain cognitive functions are influenced by a single "right shift" gene with two alleles. The dominant allele (RS+) establishes left-cerebral control for speech and right-handedness in those who carry it. In those who are homozygous for the recessive allele (RS-), there is no bias towards either right- or left-handedness, and such individuals, considered collectively, may show handedness and lateralized cerebral dominance for speech but no strong bias towards either side.

If the proportions of the two alleles are equal in the population (balanced polymorphism), the number of heterozygotes will equal about 50% of the population. If so, the proportion of the population homozygous for RS- will equal approximately 25%, and in the absence of cultural pressures against left-handedness, about half will become left-handed. This prediction, in fact, fits well with the finding that in societies without an explicit bias against left-handedness, such as would be expressed in rules or traditions actively discouraging left-hand use for writing and other public acts, the prevalence of sinistrality generally rests at about 12.5% of the population (Corballis, 1983), although even in these cultures, many covert biases remain (see review by Harris, 1990, pp. 195-196).

Neuroanatomical Correlates of Handedness

Broadly speaking, voluntary control of the upper limbs and hands relies on the synchronous operation of both cortical and subcortical mechanisms, effected through monosynaptic and multisynaptic tracts that originate in cortical grey matter and descend to synapse on spinal neurons. A review of the three descending motor systems (corticospinal, ventromedial, and lateral brain stem systems) mediating praxis of the hands and distal portions of the upper limbs, may be found in Harris and Carlson (1988). In contrast to our advanced level of understanding of the anatomical and physiological factors underlying hand control, we still know very little about the underlying neurological basis for hand preference.

One focus of attention has been on the cerebral hemispheres. Over the last twenty years there has been a spirited search for anatomical asymmetries between the hemispheres, and a no-less spirited debate on what any such asymmetries might mean. The rationale for this search lies in the assumption that asymmetries are clues to understanding lateral functional specialization. Witelson (1980) attributes this assumption to Geschwind and Levitsky's (1968) confirmation of earlier work from the 1920's showing that the opercular region of the Sylvian fissure (known to be crucial for language comprehension) is typically larger on the left side than the homologous areas on the right side. Several studies (Teszner, Tzavaras, Gruner, & Hecaen, 1972 [cited in Witelson, 1980]; Wada, Clarke, & Hamm, 1975; Witelson and Pallie, 1973, Pieniadz & Naeser, 1984) have provided corroboratory evidence that the planum temporale, the area of cortex on the superior surface of the temporal lobe posterior to the primary auditory cortex (Heschl's gyrus), is larger in the left hemisphere than in the right in approximately 70% of all brains studied (for review, see Witelson, 1977, 1980, 1988). Similarly, Albanese, Merlo, Albanese, and Gomez (1989) found asymmetries, favoring the left side, in the weight and surface area of the posterior portion of the inferior frontal gyrus ("Broca's area" -- pars opercularis and triangularis caudalis), an area important for motor coordination of speech. Other research, however, indicates that the asymmetry in surface area appears only when the entire anterior speech region, including both the visible cortex and that buried in the sulci, is considered (Falzi, Perrone, & Vignolo, 1982).

Still other neuroanatomical asymmetries that have been reported include larger motor pyramidal tracts on the right side, a longer occipital horn in the left lateral ventricle, and a variety of asymmetries in cortical vascularization. According to Witelson (1980), however, the association of these morphological asymmetries with functional asymmetry "is less obvious and more equivocal" than is the case for the temporal lobe asymmetry (p. 80).

The asymmetries listed above are found in right-handers or in unselected samples of populations where handedness was unknown but in which we can presume that right-handedness was the norm. One reason to suppose that these asymmetries have something to do with handedness, however, is that the asymmetries are less clear or consistent in adextrals. For adextrals, or left-handers, the pattern of neuroanatomical asymmetry instead is far more heterogeneous. This may imply that adextrals do not fit neatly into one homogenous group but consist instead of separate subgroups with measurable between-group differences in neuromorphology.

Why might the finding of greater heterogeneity of (cortical) anatomical asymmetries in left-handers be important? One possibility is that certain cognitive functions (e.g., speech) are more bilaterally organized in left-handers, and because we can conceive of a multitude of possible organizational patterns to foster greater interhemispheric cooperation, a more heterogeneous pattern of cortical asymmetries would be expected. One prediction derived from this hypothesis is that the commissural pathways, necessary for interhemispheric communication, are more extensive (e.g., larger) in sinistrals than in dextrals. Support for this prediction is mixed. Witelson (1985, 1989) made outline drawings of the corpus callosum, from photographs of the medial view of midsaggital hemisections, and found the posterior body segments of the corpus callosum (especially the isthmus) to be 11% larger in adextrals than in right-handers. However, Kertesz, Polk, Howell, and Black (1987), using larger sample sizes (52 right- and 52 left-handers) and MRI imaging of the corpus callosum in intact brains, found no significant handedness differences for either total collosal area or for the splenium-to-genu size distribution.

HANDEDNESS AND SPATIAL ABILITY

Since Levy's (1969) original report linking left-handedness to poorer spatial ability, there have been many further studies of the relationship of handedness to spatial ability. The results provide mixed support for Levy's hypothesis.

Handedness and Visuo-Perceptual Functions

One category of tests has been tests of visuoperceptual functions in which subjects are asked to infer what the total configuration of a geometric design from incomplete information about the stimulus. One of the first of these studies was by Nebes (1971b). Previously, Nebes had found that right-handed commissurotomized subjects were more able to "infer the total stimulus configuration from incomplete information" when the information was confined to the right hemisphere (Nebes, 1971a). Nebes (1971b) then assessed neurologically normal right- and left-handers for the same ability. He compared the performance of 26 self-described left-handers with 26 self-described right-handers on the Arc-Circle Test, which required the subject to feel an arc (part of a circle) that is hidden from view and then to point to the correct circle out of an array of circles varying in size. The left-handed group did significantly worse than the right-handers with either hand ($p<.002$). Other investigators, however, have not replicated Nebes' findings with this test (Hardyck, 1977; Kutas, McCarthy, & Donchin, 1975).

In other early studies, right-handers also have been reported to be more proficient than left-handers on copying and maze tasks (Flick, 1966) and on tasks requiring the subject to identify the sidedness of pictured body parts, to determine the localization of tactile stimulations, and to make mirror-tracings (Silverman, Adavai, & McGough, 1966).

In contrast to these reports of inferior performance by left-handers on visuoperceptual tasks, there are several reports suggesting just the reverse, namely, that left-handedness is more common in occupations -- art (Mebert and Michel, 1980) and architecture (Peterson and Lansky, 1974) -- that presumably select for excellent visuospatial ability. Peterson and Lansky (1974), for example, found that of 484 male architecture students surveyed, 16.3% reported being left-handed.[2] When assigned to construct a 2-dimensional maze according to a difficult set of design requirements, all of the left-handers designed their mazes correctly, whereas the dextrals made many errors ($p<.001$). Both the right- and non-right-handers, however, were equally able to solve mazes of comparable difficulty to the ones they were asked to design themselves.

Handedness and Visual Memory

A second major category of tests in which left- and right-handers have been compared is tests of visuospatial memory. For example, Nebes and Briggs (1974) tested 120 right-handers, left-handers, and subjects whom they called mixed-handed (the subjects were separated into the three groups on the basis of their responses to a modified version of Annett's (1967) handedness questionnaire) on tests of visual memory and verbal memory. On the verbal memory test, no group differences were found. On the visual memory test, however, the right-handers made more correct responses ($p<.025$) and fewer errors ($p<.05$) than the left- and mixed-handers, who did not differ from each other.

In a second study, Nebes (1976) examined the use of visual memory in right- and left-handed undergraduates separated on the basis of responses to his adaptation of Annett's (1967) questionnaire. He found no differences between the two groups in their performance on a verbal recall test (that is, a test that discouraged the use of visual imagery) and the Recognition of Random Shapes Test (a test that encouraged the use of visual imagery). In light of his previous findings (Nebes & Briggs, 1974), Nebes (1976) suggested that group differences now were absent because, unlike the previous study, the subjects were required only to recognize shapes upon immediate recall (rather than having to reproduce them). Nebes concluded that the left-handers show a decrement, relative to dextrals, in the manipulation of visuospatial stimuli following the verbal encoding of such stimuli for later recall. Similar results have been reported by several other investigators (e.g., Levy, 1969; Miller, 1971; Harshman, Hampson, & Berenbaum, 1983; McGlone & Davidson, 1973).

Finally, in still another study of handedness and visual memory, Weinstein (1987) used the ROCF. First published in 1941 by the Swiss neuropsychologist, Andre Rey, the ROCF is useful for evaluating an individual's ability to plan, organize, and assemble complex visual information (Goodglass & Kaplan, 1987). The ROCF also tests an individual's ability to retrieve a complex visual stimulus from short-term memory (STM) and after a 20-minute delay period. In Weinstein's study of female college students, left-handers with a math/science major (presumably being those students who have chosen fields of study requiring well-developed spatial abilities) produced the best copies and drawings from memory, whereas the poorest drawings were made by right-handed non-math/science majors. These results therefore do not agree with previous findings. They also suggest that intellectual interests (as determined by the subjects' choice of academic major) might be useful in predicting ROCF performance.

Cognitive Deficits and Left-Handedness

In several of the previous investigations reporting poorer performance by left-handers than by right-handers, the authors have described their left-handed subjects as showing performance and/or perceptual "deficits" or "deficiencies" in comparison with right-handers. The term "deficit" implies a clinically significant impairment of function or ability. It is important, then, to examine more closely the issue of possible cognitive deficits, perhaps restricted to more abstract reasoning functions, associated with sinistrality.

Historically, left-handedness has been associated with a wide range of cognitive deficits, and folk wisdom has often linked left-handedness to a variety of undesirable personality traits (Harris, 1990). For example, Lombroso (1903) reported that adextrality was more common in criminals than in law-abiding citizens. Compared to the normal population, left-handedness has also been reported to be more prevalent among the mentally retarded (Gorden, 1920) and epileptics (Mayet, 1902, cited in Gordon, 1920; see reviews by Harris, 1980; Harris & Carlson, 1988). Recently, a great deal of research has focused on the relationship between handedness and posited cognitive deficits.

As mentioned previously, Lansdell (1962, 1969), in his study of left temporal lobe epileptics, found that if seizure onset occurred prior to age five, the patients showed relatively fewer deficits on verbal scores of the Wechsler-Bellevue, and greater deficits on the non-verbal scores. All of his subjects were right hemisphere speech-dominant (determined by IAP), leading Lansdell to conclude that the sparing of language function was caused by the development of language representation in the right, nonepileptogenic hemisphere at the expense of visuospatial functions typically subsumed by the right hemisphere.

As noted earlier, there also is evidence that when language shifts to the right hemisphere in response to a pathological process of early onset, a related possible consequence for genotypic right-handers is pathological left-handedness (PLH) (Teuber, 1974; see Harris & Carlson, 1988, for a review). For example, Satz, Orsini, Saslow, and Henry (1985) found that 10 of 12 patients with early left hemisphere damage had Verbal I.Q. (WAIS-R) scores at least 15 points higher than their Performance I.Q. (non-verbal subtests) scores. This led Satz et al. (1985) to suggest that a deficit in visuospatial ability is a marker for PLH.

The prediction of a specific, atypical pattern of cortical specialization in response to neural insult stands in contrast to Levy's original prediction of a specific pattern of lateral specialization in neurologically normal, genotypic left-handers. Some investigators, however, have gone so far as to propose that, in contrast to the two-type model of left-handedness (acknowledging that left-handedness may result from either normal genetic variation or early pathology, all left-handedness may arise from a pathological process (Bakan, Dibb, & Reed, 1973). By implication, these investigators believe that any sign of poor performance, across a variety of cognitive domains, by ostensibly neurologically normal left-handers arises from the same neurodevelopmental anomaly that causes sinistral hand preference (the evidence for this hypothesis is weak, and most researchers reject it in favor of the 2-type model; see Harris & Carlson, 1988). Despite their differences, both the one-type and two-type models of left-handedness "assume that cognitive ability is related to the extent of the cortical neural networks serving a given function. Below-average spatial ability in the left-hander, then, is seen as resulting from an under-representation of these neural regions" (Lewis & Harris, 1990, p.4).

Perhaps the first report that left-handed children score lower on tests of "general intelligence" was published by Wilson and Dolan (1931). More recently, Zangwill (1962, cited in Nebes & Briggs, 1974), Berman (1971), and Branch, Milner, and Rasmussen (1964) have reported finding that these "decrements" are limited to mixed-handed individuals, that is, in those individuals who do not have a strong hand preference for performing a variety of unimanual tasks. Branch, Milner, and Rasmussen (1964) argue that "in these persons, language and visuo-spatial skills are not segregated into separate hemispheres the way they are in most people" (p.209).

In a large scale study designed to examine the postulated association between sinistrality and cognitive deficits, Hardyck, Petrinovich, and Goldman (1976) collected data on handedness, social-economic-status (SES) and cognitive abilities data (e.g., Lorge-Thorndike IQ Test, a figure copying test, several subtests of the Stanford

Achievement Tests) on 7,688 children in grades 1 to 6. No significant differences were found between left- and right-handed groups across each grade level and SES strata. The authors also provided a summary of 33 studies, most of which also failed to find significant differences between right- and left-handers on various measures of intelligence.

Possible Reasons for Discrepancies

As we have seen, the literature on hand preference and visuospatial ability presents a very mixed picture. Depending on the investigation, normal left-handers either do more poorly than right-handers on spatial tasks, are no different from right-handers, or actually surpass right-handers. How might these discrepancies in the literature be resolved?

Fluid versus Crystallized Intelligence. One possibility is that the discrepancies could result from inherent differences in the spatial tasks themselves. For example, Hicks and Beveridge (1978) have criticized the findings of Hardyck et al. (1976) on the grounds that the lack of significant findings may be due to a sampling error. They predicted that significant differences between handedness groups may be obtainable if the measures selected as dependent variables are chosen with Horn's (1976) definitions of crystallized and fluid intelligence in mind. As discussed previously, particular attention must be paid to individual task demands and to the possibility that higher or lower performance on one type of task might not mean the same thing as similar performance on a separate task requiring different cognitive strategies (e.g., fluid vs. crystallized intelligence) for its solution.

Horn (1976) defined fluid intelligence (FI) as a "facility in reasoning, particularly in figural and non-word symbolic materials, as indicated in tests such as letter series, matrices, mazes, figure classifications, and word groupings..." (p.445). Hicks and Beveridge (1978) argue that Hardyck et al. (1976) restricted their analyses to scores obtained on measures of "crystallized intelligence" (CI; Cattell, 1971; Horn, 1976), which test knowledge of previously learned information or automatized skills. Using a measure of FI and CI (see description of both tests in Hicks and Beveridge, 1978), these investigators studied performance differences on the two types of tests in 37 right-handed and 30 left-handed college students. The groups did not differ on the measure of CI, but the left-handed group scored significantly lower on the test of FI ($p<.02$).

As mentioned previously, the term "deficit" has been used to characterize relatively lower performance on various cognitive tests among specific subgroups of neurologically normal subjects. Again, the term "deficit" implies a cognitive dysfunction, but, as we have seen here, even where between-groups differences have been found, the scores all fall within the normal range for the tests themselves (e.g., Briggs et al., 1976). Hence, most subgroups of left-handers do not show cognitive deficits per se, but only lower scores in comparison to other handedness groups (or larger discrepencies between their own spatial and verbal scores). Despite this caveat, Annett (1985; cited in Corballis, 1989) argues that those individuals who are homozygous for the RS- allele tend to be more susceptible to reading deficits. In contrast, those who are homozygous for the RS+ allele may be more prone to deficiencies in mathematical ability and possibly in motor-speed skills.

Subgroups of Left-Handers. In summary, discrepancies could result from inherent differences in the nature of the spatial tasks themselves (e.g., whether they rely predominantly on FI or CI intellectual processes for their correct solution). Another possibility is that the discrepancies reflect sampling error arising from the generally greater heterogeneity of left-handers in cerebral organization and in cognitive ability, so that any given sample of non-right-handers might include a different mix of different subgroups, or phenotypes, of adextrals.

Some support for this possibility has been presented by Kimura and D'Amico (1989). These investigators administered cognitive tests and a verbal dichotic listening task to both adextral and dextral students recruited from programs that (presumably) are either spatially demanding (e.g., engineering, visual arts) or that (presumably) do not require high spatial ability (e.g., English, philosophy).

The cognitive tests included a hidden figures task, paper-folding, cube comparisons, and card rotations, as well as tests of "general reasoning ability," perceptual speed, and vocabulary. A dextral was defined as anyone who reported using the right hand on at least 7 of 8 hand-use tasks. All other subjects were classified as adextrals. The result was that when the scores were collapsed across group (program of study), dextrals outperformed adextrals. The difference, however, was predominantly between the dextrals and adextrals in the non-science group ($p<.005$). In the science group, dextrals and adextrals performed at comparably high levels ($p=.11$).

Based on further evidence from a dichotic listening task, Kimura and D'Amico (1989) concluded that their sample included at least two groups of adextrals in terms of (language) lateralization patterns. Those adextrals with higher spatial scores within each of the academic major groups showed a right ear advantage (REA) for verbal stimuli on the dichotic listening task, suggesting left hemisphere dominance for language ($p<.05$). Conversely, adextrals with lesser spatial ability showed a significantly reduced right ear advantage, suggesting a greater degree of right hemisphere dominance for language. The finding that adextrals with poorer spatial ability had a weaker REA and, by implication, a greater measure of mixed-dominance for speech and language functions (see Footnote 1) corroborates Levy's (196) original model.

Kimura and D'Amico identified their subgroups on the basis of performance on the dichotic listening test. Another possible index of subgroup membership may be in the phenotypic expression of handedness itself. Previously, we have referred to the use of questionnaires for the determination of handedness. The decision rules, however, have not been standardized, and several strategies for creating handedness subgroups have been employed. In their study of college students, Kimura and D'Amico defined a right-hander as anyone who performed at least 7 of 8 hand-use tasks with the right hand. All other subjects were classified as adextrals (non-right-handers).[3] This method of grouping subjects by handedness was also used by Witelson (1985) in her study of handedness and corpus callosum size. Another approach is to divide handedness phenotypes into the three categories of pure right-handedness, pure left-handedness, and mixed-handedness. Using this tripartite division, Annett (1967) found that pure left-handedness is relatively rare and that most groups of sinistrals are predominantly mixed-handers. A third approach (e.g., Gutezeit 1982; cited in Peters & Servos, 1989) is to use the categories right-handers, consistent left-handers (CLH) and inconsistent, or weak, left-handers (ILH). Peters and Servos (1989) prefer this classification scheme because "...in a predominantly right-handed world the average left-hander might be expected to prefer the right hand for some activities. A consistent preference for the left hand, in spite of environmental pressure to the contrary, might indicate that the committed left-hander is somewhat disadvantaged with the nonpreferred hand and is, in fact, a person with some degree of pathology" (p. 342). This possibility has been supported where infants (and young children) are concerned (see Harris & Carlson, 1988, p.307). Consistent preference for left hand use in adults likewise perhaps reflects a more benign set of etiological subtrates as well.

To test the validity of the distinction between CLH and ILH subgroups, Peters and Servos (1989) administered both unimanual and bimanual motor tests that involve varying degrees of skill, speed, and strength to 53 CLH, 65 ILH, and 57 right-handed (RH) college undergraduates. Each subject was given a 9-item unimanual hand-use questionnaire. All persons who reported (on item #1) using their left hand for writing were classified as left-handed (in this age and social cohort group -- male and female students at a Canadian university), as it was expected that all or nearly all left-handers would write with their left hand. Therefore, a subject who reported using the left hand on 7 of the remaining 8 questions was considered CLH, and a subject who reported using the right hand on any 2 of the 8 remaining items was considered ILH. The subjects then were administered a series of strength and skill tests, including a rapid finger tapping test, a grip strength test (using a hand dynamometer), the Purdue Pegboard Test (a measure of finger-tip dexterity), and a square-tracing test (to evaluate dexterous control of the distal musculature of the upper limbs).

On the hand-use questionnaire, the CLH and RH groups produced similar patterns of responses, but in the opposite direction as expected. Contrariwise, the ILH subjects often showed a "dissociation between the writing hand and the hand used for activities requiring strength and skill of whole arm movement" (e.g., throwing a ball). There were no significant differences between the three groups for writing speed. On the grip strength measure, the left hand was consistently found to be the stronger hand for the CLH subjects ($p<.025$). As expected, the right hand was the stronger hand for the RH subjects ($p<.025$). There also was some evidence of a sex difference. For the ILH males the right hand was the stronger hand ($p<.006$), whereas no significant hand difference was found for the ILH females. Thus, although CLH individuals were stronger with the left hand, ILH subjects (at least in the case of males) were stronger with the right hand.

On both the rapid finger tapping test and the Purdue Pegboard Test, the preferred hand was faster for all groups ($p<.001$); the right hand for the right-handers and the left hand for the left-handers, including the ILH group. For the ILH group, then, there seems to be a dissociation between skill (finger tapping) and strength (see above).

On the single-hand condition of a square tracing task, both left-hand groups produced "higher quality" tracking performance with the non-preferred hand ($p<.001$). In the dual-task condition, however, the difference in hand performance between the two hands working simultaneously (tracing two separate squares) was larger in the CLH group than in the ILH group ($p<.014$). This same difference between hands was also larger for the RH group compared to both the CLH and ILH groups ($p<.001$).

Finally, on a Rhythm Finger Tapping Task, Peters replicated his earlier finding that the RH group is faster than the other groups when required to tap twice with the right hand for every one tap with the left (condition R2/L1) ($p<.0001$; see Peters, 1987). The ILH group out-performed the CLH group for this same combination ($p<.013$), but the CLH group showed a non-significant trend towards better performance than the ILH group with the reverse (L2/R1) tapping combination.

In summary, whereas the ILH group showed greater grip strength with the right hand, the CLH group was stronger with the left hand. This means that in a study of grip strength that failed to differentiate these two subgroups of left-handers, these opposing trends would cancel each other out, leaving the impression of no net difference between hand strength for adextrals (see Peters, 1983). Secondly, although the ILH group showed a smaller between-hand difference than the CLH group on the tapping, Purdue pegs, and square tracing tests, both groups differed reliably from the RH group in that they consistently performed better with the left hand. The CLH and ILH groups differed significantly, however, on the 2:1 Rhythm Finger Tapping Test. Finally, although the ILH subjects reported being strongly left-handed for activities such as writing, they also reported some right-hand use (as opposed to the CLH group) for other tasks that involved the use of the more proximal, larger muscle groups controlling arm movement (e.g., throwing a ball, using a racquet).

In summarizing their results, Peters and Servos (1989) warn that if distinctions between ILH and CLH groups are not made in performance studies, misleading statements about the nature of left-handedness are inevitable. Hence, any global statements about performance differences between left-handers and right-handers are "premature." Unfortunately, this warning does not bode well for most studies of handedness published during the last few decades.

Peters and Servos (1989) discuss the significance of the demarcation of an ILH subgroup on the identification of the underlying mechanisms of handedness. For example, it may be that the developing lateralization processes that are consistent in CLH's and RH's proceed in an unusual pattern in ILH's. Peters (1983) suggests that in the developing, lateralized motor system, attentional and structural systems develop separately but in concert with each other. For instance, he notes that attentional lateral biases towards the right in dextrals are evident before the pyramidal tracts that are used to guide skilled volitional movement are structurally mature. It may be, then, that in ILH's the directional biases of the structural and attentional processes are not equivalent. If so, certain motor tasks that rely to different extents on attentional versus structural systems for their completion may favor different hands in the ILH group (e.g., handwriting, which requires highly focused attention, versus throwing a ball, which relies on more basic attentional processes) (see Peters, 1987). Because these two subgroups of left-handers differ on motor tests that require attentional processes to varying extents, the possibility arises that further differences between subgroups of left-handers might be observed on measures of verbal, spatial, and/or manual praxis abilities.

Handedness and Manual Praxis

Different subgroups of adextrals may display not only different patterns for strength of hand preference (Peters, 1989) or lateralization of attention (Peters, 1987) but possibly for the control of manual praxis as well (Kimura, 1983). By praxis we mean the ability to plan and/or execute coordinated movements that may or may not be task specific (e.g., buttoning a shirt). Although the neuroanatomical control of praxis is still not well understood, disorders of praxic movement (the apraxias) are typically the result of left-sided unilateral cortical damage with occasional lesion of the corpus callosum (e.g., Liepmann, 1900; cited in Harrington, 1987, pp. 154-164). This finding implicates certain structural components of the left hemisphere as playing an "executive" role in the voluntary control of motor function for both sides of the body.

Furthermore, certain lesions in the corpus callosum, in the absence of any other cortical damage, seem to cause left-sided dyspraxia by depriving the right hemisphere's "hand-center" (part of the pre-central motor strip) of input from the left hemisphere's control of praxis (Liepmann, 1905; cited in Harrington, 1987, pp. 136-165). Liepmann detailed his classification of the separate apraxic syndromes (i.e., limb-kinetic, ideomotor, and ideational) and their neuroanatomical correlates, all of which implicated several portions of the left occipital-parietal region as being responsible for bilateral praxis. The same evidence also showed that lesions of the corpus callosum would lead to left-hand dyspraxia in the absence of left parietal insult.

New evidence also suggests that different parts of the corpus callosum mediate different forms of praxis. For example, Gersh and Damasio (1981) have described two cases that support the conclusion that frontal-to-frontal pathways located in the anterior half of the corpus callosum support interhemispheric pathways for coordinated hand-use but not for writing. Gersh and Damasio (1981) conclude that despite the early reports of a pure motor apraxia and agraphia of the left hand occurring together following lesion of the corpus callosum, these two clinical syndromes occur as a result of anterior versus posterior damage to the corpus callosum, respectively.

The repeated finding that the "center" for the control of manual praxis is located in the left hemisphere leads to several questions. For example, why are the centers for the control of speech and praxis typically located in the same hemisphere? The seemingly unilateral control for speech and praxis may indicate that speech production, inasmuch as it requires the coordination of large numbers of muscle groups in sequence, relies heavily on praxis, and that Broca's area may be a repository for memory programs necessary for producing these motor sequences (for discussion, see Kimura, 1983a). The close association between manual praxis and speech is evidenced by the fact that the primary motor area for the right hand and Broca's area are anatomically close, and that speech and right hand movements are often precisely synchronized (Kimura, 1988).

Despite the close association between manual praxis and speech, this neuroanatomical conjunction between functions is not invariable. Kimura (1983b) presents data on 520 patients with unilateral cortical damage in which the 48 patients, each either left-handed or mixed-handed, showed evidence for more bilateral organization of manual praxis. Specifically, praxis was less affected by left-hemisphere damage and showed a trend to be more affected by right-hemisphere damage in left-handers but not in the mixed-handers. It should be noted that none of Kimura's adextral patients were rendered aphasic by lesions in the right hemisphere. Because Kimura (1983b) separated her patients into only two groups on the basis of handedness questionnaire data (i.e., consistent right-handers versus all others), the question remains open as to whether there is a subgroup of adextral individuals who have more bilateral control for manual praxis. If so, the question arises whether these individuals will differ from other subgroups of left-handers on spatial tasks that have a manipulative or construction component in contrast to tasks that are more purely visuoperceptual. It may be that one of Peters and Servos' two sinistral subgroups -- the inconsistent left-handers -- will display more bilateral control for praxis and that this shared control between the hemispheres will enhance performance on visuoconstructive measures. Recall from earlier discussion (p. 12) that the two cerebral hemispheres contribute in different but complementary ways for the completion of several visuoconstructive measures, such as the ROCF or the WAIS-R Block Design test.

SEX DIFFERENCES AND VISUOSPATIAL FUNCTIONS

In summary, the evidence for handedness-related differences in spatial ability presents a mixed picture, possibly related to uncontrolled variations in the nature of the spatial task and in the composition of handedness groups. The evidence for our second variable, sex differences, is more straightforward and consistent. What it shows is that although males and females do not differ on overall tests of cognitive ability, they do differ in certain cognitive domains. Specifically, during and after adolescence, males typically excel on tests of spatial ability, whereas females do better on tests of verbal skills, in particular those tests requiring fluency or motor production (see reviews by Maccoby & Jacklin, 1974; Harris, 1978; Bryden, 1979; McGlone, 1980).

Levy (1972; cited in Johnson & Harley, 1980) has suggested that these sex differences in specific cognitive functions are due to sex differences in patterns of hemispheric asymmetry. Levy predicted that females, like left-handed males, should display poorer spatial abilities because of a weaker lateralization of language functions in these individuals. In support of this prediction, Levy cited the findings of Culver, Tanley, and Eason (1970), who showed that right- as well as left-handed females displayed a greater primary EEG amplitude of evoked responses in the right hemisphere than in the left, an effect that had been found earlier only in left-handed men (Eason, Groves, White, & Ogden, 1967). Numerous other studies have shown weaker hemispheric lateralization in females relative to males, including reports of lesion data (e.g., Lansdell, 1961;

McGlone & Kertesz, 1973; Kohn & Dennis, 1974; Novelly & Naugle, 1986), dichotic listening data (e.g., Knox & Kimura, 1970; Lake & Bryden, 1976), tactile learning (Rudel, Denckla, & Spalton, 1974), tachistiscopic data (e.g., Marcel, Katz, & Smith, 1974), and lateral eye movements (Bakan, 1971; cited in Johnson & Harley, 1980).

With regard to visuospatial abilities, Sanders, Soares, and D'Aquila (1982) found a clear sex difference for the accurate completion of two mental rotation tests. Sanders et al. (1982) administered the Card Rotations Test (requiring the identification of simple abstract forms after mental rotation within a 2-dimensional plane) and the more difficult Shepard-Metzler Mental Rotations Test (requiring identification of complex 3-dimensional figures after mental rotation of a design in 3-dimensional space) to 672 female and 359 male undergraduates. The males scored significantly higher than females on both tests ($p<.001$), with sex accounting for 2% of the variance on the Card Rotation Test, and 16% of the variance on the Shepard/Metzler Test. Thus, as the difficulty of the mental rotation task increased, so did the sex difference. Ben-Chaim, Lappan, and Houang (1986) found a similar sex difference for the mental rotation of 3-dimensional block designs in large samples of grade school students. On a similar task (Stafford Identical Blocks Test; Stafford, 1961), Marino and McKeever (1989) also found a significant sex effect in college students. It is important to note that in all such comparisons, between-sex differences typically are less than within-sex differences. There also is some evidence that at least one subgroup of women, namely right-handers with a history of familial sinistrality and who rate themselves high in spatial experiences, are among those achieving high scores on tests of spatial ability (Casey and Brabeck, 1990).

Kingsberg, LaBarba, and Bowers (1987) have provided some support for the hypothesis that there are sex differences in patterns of cortical organization for cognitive functions. Using a dual-task paradigm with block design (a visuo-constructive task) during concurrent right- or left-hand finger tapping, they found that both men and women display similar lateralization patterns for the visuo-constructive processing of the block designs across two levels of difficulty. However, when a concurrent vocalization task was used instead of finger tapping, for the more difficult block designs, only the females showed a significant interference effect ($p<.01$).

The evidence thus repeatedly shows sex differences in visuospatial ability. It also shows that the size of the difference depends partially on the nature of the task. In a meta-analytic study, Linn and Petersen (1986) found a large male advantage on tests of mental rotation (of 2- and 3-dimensional figures), a smaller male advantage on tests of spatial perception (e.g., the Rod and Frame Test), and a weak difference on tests of spatial visualization, such as the Block Design subtest of the WAIS-R. At least two different explanations of these differences are possible. One is that sex differences are smaller on tests that are solvable using both verbal and non-verbal strategies. Another is that the occurrence of sex differences on visuospatial tests depends on the extent to which the tests draw on visuoperceptual rather than visuoconstructive functions, on the view that visuoperceptual tasks (e.g., Stafford Identical Blocks Test) tend to be less open to the use of linguistic strategies than visuoconstructive tests (e.g., Block Design) for their accurate completion.

Kingsberg et al.'s results (1987) suggest that if language functions are more bilaterally distributed in females, females might be more likely to invoke verbal strategies (drawing on greater inter-hemispheric cooperation) in attempting to complete a visuo-constructive task that otherwise is associated with predominantly right-hemisphere activation. If so, one might assume that there would be increased commissural connections between the two sides in order to facilitate interhemispheric coordination of language functions. Conversely, it may be that the neuropsychological control of speech and language functions is not more bilaterally distributed in females at all but only seems to be so because of possibly greater numbers of large diameter axons coursing through commissural connections between the hemispheres, allowing for increased bilateral cortical activation for the completion of both verbal and non-verbal tasks.

Neuromorphology and Sex Differences

As we have seen, differences between right- and left-handers in strength of lateralization of function seem to fit with the anatomical data at both the cortical and subcortical levels. In the case of sex differences, however, the evidence is either negative or inconclusive. deLacoste-Utamsing and Holloway (1982) reported that the posterior commissural connections (splenium of the corpus callosum) are larger and more bulbous in females than in males. Peters (1988), however, after examining more recent studies, concluded that convincing sex differences in splenial size have not been firmly established (cf. Witelson, 1985, 1989; Kertesz et al., 1987).

Peters (1988) also noticed a finding that emerges repeatedly in the literature, namely, that whereas male brains, on average, are larger than female brains, the corpus callosum does not show an allometric relationship consistent with the increased size of the male brain. For example, Kertesz, Polk, Howell, and Black (1987) found no correlation between total callosal cross-section and brain size in 104 subjects. Peters (1988) believes that because of the much larger sample size in Kertesz et al.'s study, their finding is more "credible" than the modest correlation found in Witelson's (1985) sample of 27 right-handed subjects. This lack of a relationship between callosal size and cortical volume/weight suggests that <u>if</u> female callosa are larger posteriorly (in the region of the splenium), thereby facilitating more efficient interhemispheric communication for the control of functions that are more bilaterally distributed, then increased splenial size is not required for the efficient interhemispheric coordination of functions in the larger and, evidently, more lateralized male brains. To complicate the picture still more, it may be that overall size differences in commissural structures are not appropriate parameters for the study of sex differences in interhemispheric pathways. Recent work by Jan Juraska at the University of Illinois (cited by Banich 1989a) revealed that although there are no sex differences in overall size of the splenial portion of the corpus callosum in the rat, a microscopic inspection reveals that this area is more densely packed with larger diameter axons in female than male brains. Despite the unresolved question whether portions of the corpus callosum are generally "larger" in females than in males, it is clear that sex differences in the performance of different cognitive tasks do exist and occur reliably (see discussion above).

SEX BY HANDEDNESS EFFECTS ON VISUOSPATIAL FUNCTIONS

The fact that males generally excel in tests of spatial ability suggests still another reason why studies of handedness and spatial ability are so confusing. It is that there may be uncontrolled differences in the proportions of males and females in these studies. There is even reason to suspect that the factors of handedness and sex are not merely additive, but rather are interactive in their influence on visuospatial functioning.

In three studies with large sample sizes (between 879 and 2477 subjects), three different patterns of sex by handedness interaction effects have been found. Sanders, Wilson, and Vandenberg (1982) found that sinistrality was associated with relatively greater visuospatial abilities in males and with poorer spatial abilities in females. Yen (1975), however, found the exactly opposite pattern of results (consistent with the cognitive crowding hypothesis). Finally, Inglis and Lawson (1984) tested a large sample of subjects (N=1,880, with equal numbers of males and females) and found no interaction effects on any of the three cluster scores obtained on the WAIS-R.

In agreement with Inglis and Lawson, other investigators have been unable to demonstrate an interactive effect of sex and handedness on visuospatial ability. For example, Johnson and Harley (1980) examined undergraduate students' performance on a test of spatial perception, a vocabulary scale, and on four subtests of the WAIS (Vocabulary, Arithmetic, Block Design, and Picture Arrangement). Using Annett's (1967) handedness questionnaire, they divided their 120 subjects into 6 groups (male dextrals [N=30], female dextrals [N=30], male and female consistent left-handers (CLH) [N's=17 and 14, respectively], and male and female inconsistent left-handers (ILH) [N's=13 and 16, respectively]. Although it is not clear whether Johnson and Harley defined CLH and ILH in the same way as Peters and Servos (1989) had, the result was that the CLH subjects did significantly better than the ILH and dextral groups on the vocabulary test ($p<.05$), but did significantly worse on the Spatial Thinking Test ($p<.05$). There were no sex differences nor any other group differences on any of the WAIS subtests. These authors therefore concluded that handedness is a better predictor of cognitive abilities than is sex, and that only the CLH groups showed a relative impairment in spatial perception.

Reasoning Ability

In an attempt to explain the discrepant results in these studies, Harshman, Hampson, and Berenbaum (1983) pointed out that the subjects' "reasoning ability" had not been controlled for and proposed that this factor moderates the relationship between sex, handedness, and visuospatial abilities. In a post-hoc analysis of three separate data sets, they categorized subjects as being either high or low in reasoning ability based on three different tests of fluid intelligence (depending on the data set). The result was that among "high reasoners," dextral males outperformed sinistral males on all of 15 separate tests of spatial ability, whereas dextral females performed worse than sinistral females on 12 of the same 15 tasks. Among "low reasoners" the males' general superiority was maintained (as seen in the high reasoners), but the direction of the handedness by sex interaction was reversed for all four sex by handedness groups. This pattern for high reasoners is similar to that found in Levy's (1969) and Nebes' (1971a,b) studies in which right-handed males performed significantly better than left-handed males on WAIS Performance I.Q. (PIQ) and Nebes' Arc-Circle test. Lewis and Harris (1990) note that both Levy's and Nebes' subjects were post-baccalaureate science students whose I.Q.'s were all well above average.

Lewis and Harris (1990) tried to corroborate Harshman et al.'s (1983) findings of a sex by handedness interaction in spatial ability for individuals with "high reasoning ability," using an independent sample of subjects whose intellectual ability had been more directly measured. They also wanted to find out whether the effect would be greater for certain categories of spatial tasks than for others.

To examine both the parameters of reasoning ability and task effect, Lewis and Harris (1990) used three different types of spatial tests -- mental rotation (the Vandenberg and Kuse [1978] pencil-and-paper version of the Shepard-Metzler Mental Rotation test), spatial perception (a pencil-and-paper version of Piaget's Water Level Test [see Harris, Hanley, & Best, 1977]), and spatial visualization (Block Design Subtest of the WAIS-R, and the Embedded-Figures Test

[Witkin, 1971]). The subjects were 56 undergraduates who had scored in the 97th percentile or above on the American College Test (ACT) in their senior year of high school. The sample included 28 males and 28 females, with equal numbers of left- and right-handers in each group (4 cells with 14 subjects per cell). Handedness was assessed with Briggs and Nebes' (1975) modification of Annett's (1967) hand preference questionnaire.

The result was that males outperformed females on the mental rotation task ($p=.011$), with a trend towards higher performance on the Water Level Task ($p=.116$). Left-handers of both sexes also excelled right-handers on Block Design ($p=.030$), and showed a trend towards better performance on the Water level Task ($p=.068$). A discriminant function analysis showed the handedness by sex interaction to be significant ($p<.05$), with the Embedded-Figures test accounting for the largest percentage of the variance, followed by Mental Rotation. The Water Level and Block Design tests contributed negligibly to the discriminant function.

These results were consistent with those of Linn and Petersen (1986) in that males performed better on mental rotation and spatial perceptual tasks, but not on tests of spatial visualization (e.g., Embedded-Figures, Block Design). Finally, consistent with the findings of Harshman et al. (1983), the results showed that in this group of high academic achievers, right-handed men outperformed left-handed men on the Embedded-Figures and Mental Rotation tasks, and left-handed women performed better than right-handed women on those same tasks.

Familial History of Sinistrality (FS)

In addition to the contributions of sex and handedness to visuospatial and other cognitive functions, the presence of familial sinistrality (left-handedness in family members) may also affect neuropsychological functioning. We have already discussed the question whether there are phenotypic differences between individuals who have developed left-handedness in response to a pathological condition, and those who, on the basis of familial sinistrality (FS+), would presumably be "Natural" (genetic) left-handers. The same question can be asked of dextrals. Specifically, are there neuropsychological differences between right-handers with different genotypes for the expression of handedness (either homozygous or heterozygous for the RS+ allele)?

Several investigators have hypothesized that right-handers who are heterozygous for handedness (RS+ and RS-) may show neuropsychological differences from right-handers who are homozygous for handedness (RS+, RS+). For example, in the study cited earlier, Weinstein (1987) found that on the Rey-Osterrieth Complex Figure Test (ROCF), right-handers with FS+ performed more like left-handers than like right-handers with no history of familial sinistrality (FS-). Namely, right-handers with FS+ and left-handers with a non-

math/science academic major did worse than the other subject groups. Recall that Weinstein tested only females and that this finding has not yet been replicated in a male population.

Gilbert (1977) examined FS+ and handedness differences for non-verbal perceptual abilities. The subjects were 64 undergraduates, divided on the basis of a 14-item handedness questionnaire into 4 equal groups ("weak" versus "strong" left-handers, and weak versus strong right-handers). Data were collected on manual dexterity, familial sinistrality, Object Assembly and Block Design (WAIS), face recognition, and visual half-field reaction times to face and alphanumeric (letters) stimuli (symbolic versus form identity of the target stimulus). The result was that although all subject groups had a comparable left-visual-field bias (70% in each group) on the tachistoscopic task with face stimuli, both left- and right-handers with FS+ had significantly smaller asymmetries for verbal (letter) processing than those without familial sinistrality. There were no differences between groups on the two WAIS subtests of visuo-constructive ability (Block Design and Object Assembly).

Gilbert concluded that the decreased lateralization for verbal processing in left-handers, or in FS+ right-handers, somehow interferes with face processing. This finding is consistent with Levy's (1969) cognitive crowding hypothesis.

In a study of reasoning ability, Briggs, Nebes, and Kinsbourne (1976) examined the interaction of handedness and familial sinistrality in WAIS and Scholastic Aptitude Test (SAT) scores. The subjects were undergraduates organized into 6 handedness groups of 34 subjects each (left, right, and mixed by FS+ or FS-). The left- and mixed-handed undergraduates showed a small but significantly lower full-scale intelligence quotient (FSIQ) than the right-handers ($p<.04$). There was no difference between the two adextral groups. In addition, in all three groups, FS+ subjects had lower FSIQ scores than FS- subjects. Finally, neither handedness nor FS histories were correlated with any between-group differences on VIQ or PIQ. It should be noted that although a significant between-groups difference on FSIQ was obtained, the range for the mean scores for FSIQ in all three groups was 118.9 to 126.7, placing all groups in the high average range of general intelligence as measured by the WAIS. The lack of significant differences between handedness and familial sinistrality groups on VIQ and PIQ cluster scores was corroborated in children by Fagan-Dubin (1974) and by Eme, Stone, and Izral (1978), who used the four subtests of the WISC-R (2 from the performance cluster [Block Design and Object Assembly] and 2 from the verbal cluster [Vocabulary and Similarities]).

To add to these confusing and contradictory sets of findings, a comparison of 86 adextral subjects separated into subgroups based on strength of handedness and history of familial sinistrality disclosed an orthogonal relationship between FS and combined SAT scores for the strongly left-handed group ($p<.01$) (Searleman, Herrman, & Coventry, 1984). Specifically, there was a 176-point difference in overall performance on the SAT between the strongly left-handed with FS+ (N=11) and the strongly right-handed with FS- (N=13). The pattern was similar when the verbal and mathematical scores were analyzed separately. In other words, consistent left-handers with FS+ did worse on tests of verbal and mathematical achievement than consistent left-handers with FS-.

The studies cited above are contradictory, several finding cognitive differences between Handedness and FS groups, others finding no such differences. In a literature review, Swanson, Kinsbourne, and Horn (1980) caution that the interactive effects of handedness and familial sinistrality on cognitive abilities are extremely complex and that any differences are due in large part to: 1) how subjects are separated into various subgroups; and 2) the nature of the dependent measures themselves.

So far we have explored the relationship between FS and handedness across several cognitive domains. How do these variables affect cognitive performance? After reviewing the literature, McKeever (1987, p.270) concluded that the common assumption that females are less lateralized for language and visuospatial functions was not readily replicable. One reason, he suggested, was that in several of the studies

showing males to be more lateralized for language functions, the finding actually reflects an interaction effect between sex and FS+ (McKeever, Seitz, Hoff, Marino, & Diehl, 1983).

In a tachistoscopic object-naming latency test, McKeever and Hoff (1982; cited in McKeever, 1987) found the FS+ by sex interaction to be important for separating language lateralization differences across subject groups. FS− females and FS+ males had smaller right visual field (RVF) superiorities than FS+ females and FS− males. This finding was corroborated by McKeever et al. (1983). The spatial test used was the Stafford Identical Blocks Test (SIBT), a measure of spatial visualization ability. The result was that: 1) males consistently performed better than females ($p<.0001$); 2) FS+ males performed better than FS− males; and 3) FS− females performed better than FS+ females on the SIBT. McKeever (1987) has not yet proposed an explanation for the FS by sex interaction.

Hemispheric Arousal Style

Finally, over and beyond the contributions of sex, handedness, reasoning ability, and familial sinistrality to lateralization and cognitive functioning, the possibility arises that individual differences in performance on certain cognitive tasks also may reflect differences in what may loosely be called "hemispheric arousal style" -- the disposition to rely on one hemisphere over the other for a broad spectrum of cognitive tasks.

Kinsbourne (1980) presents an interesting argument that cerebral lateralization for cognitive functions is not due primarily to unique characteristics of each hemisphere but rather to asymmetrical activation throughout life due to asymmetrical brain stem (thalamic) activity. For example, the left hemisphere assumes control for speech not because of "specialized neuronal hardware suited to the purpose," but because it is selectively activated for the initiation of verbal responses by the ipsilateral ventrolateral thalamus (see Ojemann, 1975). Kinsbourne (1980) presents two versions of this model as it would apply to genotypic right-handers and non-right-handers. He maintains that non-right-handers, as a group, are not so highly left-hemisphere lateralized for speech because the brain stem in these individuals is "less laterally polarized," thus leading to greater variation in the extent of differential hemispheric activation for speech. There may be clinical support for this hypothesis. Subirana (1958) found that non-right-handers recover more rapidly from aphasia. In addition, Luria (1970; cited in Levy & Gur, 1980) found that FS+ right-handers (heterozygous genotype for handedness according to Annett's model) are more likely to recover from aphasia following left hemisphere lesions than those with only dextral relatives. Kinsbourne (1980) believes that these clinical findings may be due to the availability of previously established connections between the "brain stem selector system" and both halves of the overlying cortex for the adoption of a verbal response set mediated by the non-speech-dominant, residual hemisphere.

Levy, Heller, Banich, and Burton (1983) have proposed, as an index of activational style, performance on the Chimeric Faces Test. This test requires the subject to view mirror image face composites, where one-half of each face is smiling, and the other half is frowning. The subject is asked to choose which face composite looks "happier." The rationale for this test is that if a subject consistently chooses the face from each pair that has the "happy side" in one but not the other hemispace, the cortical hemisphere that lies contralateral to that side of space is considered to be more active for the perception of emotion. Even though the two composite faces in each pair are identical mirror-images of each other, subjects typically have no difficulty with this task. Banich (1989b) has found that it shows high test-retest reliability, in that subject responses are consistent across transient mood states induced by drug treatment with either stimulant or depressive pharmacological agents.

The basis for supposing that performance on the Chimeric Faces Test is an index of a more generalized "arousal" style comes from further evidence (Levy et al., 1983) that individuals who make a preponderance of LVF (right hemisphere) choices on the Chimeric Faces Test perform better on tasks that (on the basis of independent evidence) require more right hemisphere involvement (e.g., tests of face perception), whereas individuals who make a preponderance of RVF (left hemisphere) choices perform better on "left hemisphere tasks" requiring language skills. Levy and her colleagues have proposed a model that conforms to Peters' (1987) dynamic view of laterality in that attention is seen as the proximate variable driving the laterality effect. By contrast, Kimura and D'Amico's (1989) anatomical connectivity model does not view attention as an important variable underlying lateral specialization.

THE CURRENT STUDY

In summary, the literature suggests that individual differences in performance on spatial tasks are mediated by a complex interaction of variables, including sex, handedness, hemispheric arousal style, FS, and finally spatial task type. The purpose of the current study was to measure the separate and combined contributions of these variables in college students. More specifically, the purpose was to compare the performance of different phenotypic subgroups of left-handers on spatial tasks having a manipulative or constructive component, in contrast to tasks that are purely visuoperceptual, and then to determine whether any such performance differences are affected by sex, FS, and hemispheric arousal style.

Differences Between Current Study and Previous Research

Like most previous studies of handedness and cognitive differences, a more heterogenous sample was selected than that employed by Lewis and Harris (1990). Rather than restricting the sample to those individuals in the upper 3-4% of the population with documented evidence of high academic achievement, the subjects were an unselected sample of college undergraduates. This choice was made for two reasons. First, it greatly expanded the pool of eligible subjects, a crucial consideration in light of the relative scarcity of left-handers. Second, it increased the heterogeneity of the subject pool of both right- and left-handers, thereby enhancing the likelihood that different phenotypic subgroups of adextrals would be included.

The study also adopted Peters and Servos's (1989) distinction between consistent and inconsistent left-hand dominant individuals. This "levels of handedness" approach comes closer to the recognition that handedness, like the majority of other behavioral variables under psychological study, rests on a continuum from exclusive dextrality to exclusive sinistrality.

The study was also designed to address the contributions to spatial performance of FS and hand differences in motor speed (see e.g. McKeever, 1989), and the influences of subjects' choices of fields of academic study that presumably involve more or less spatial skill (Weinstein, 1987).

The study also attempted a more fine-grained analysis of each spatial task, recognizing that for any complex task, both hemispheres are involved to varying degrees at different stages of task analysis. For example, whereas Levy (1969) and Miller (1971) used the Block Design subtest of the WAIS-R to test the "crowding" model, thereby implying that the successful completion of this task largely involves right hemisphere activity, more recent evidence shows that performance on Block Design, as well as the other performance subtests of the WAIS-R, can be augmented through verbal strategies (see Kaplan, 1988), which may explain why sex differences on these tasks are weak or non-existent, in contrast to other spatial tasks. The current research therefore included a different mix of spatial tests, including the Rey-Osterreith Complex Figure Task, a visuoconstructive test that, unlike Block Design, appears to draw more heavily on purely spatial skills while preserving the manual component.

With regard to spatial tests that do not require a motor response, converging evidence from the clinical and nonclinical literature indicates that tests of mental rotation, tests like the SIBT, are effective measures of right-hemisphere involvement (Corballis and Sergent, 1989). For example, Deutsch, Bourbon, Papanicolaou, and Eisenberg (1988) found marked asymmetries in regional cerebral blood flow, with greater perfusion in the right parietal lobe than in the left hemisphere, during performance of the

Shepard-Metzler Mental Rotation Test, corroborating Ratcliff's (1979), and Masure and Benton's (1983) findings that men with right (rather than left) hemisphere lesions make more mental rotation errors. Other data, however, suggest that even mental rotation tests involve left-hemisphere verbal processing strategies (Kee, Bathurst, & Hellige; 1984). In neurologically normal individuals, for instance, there is a great degree of both left- and right-hemisphere alpha suppression on EEG for more difficult mental rotation tasks (Ornstein, Johnstone, Herron, & Swencionis; 1980). This finding implies that spatial stimuli may be verbally encoded and analyzed to a larger extent for difficult spatial tests than for more simple ones.

Finally, in light of Levy et al.'s (1983) evidence of consistent lateralized individual differences in hemispheric arousal that are separate from patterns of lateralization of specific cognitive functions, the current study used an estimate of hemispheric arousal style (performance on the free-viewing chimeric faces task) as a covariate in the analyses of variance.

In sum, the primary objective was to compare sex and handedness effects on spatial tasks that vary in the extent to which they are likely to incorporate non-verbal strategies as well as manipulospatial ("visuoconstructive") or spatial visualization ("visuoperceptual") abilities for their solution. The prediction is that, like Harshman et al. (1983) and Lewis and Harris (1990), there will be a significant sex by handedness interaction for performance on visuoperceptual tasks. A further, and perhaps different interaction might be found for performance on visuoconstructive tasks. It was difficult to predict the direction of this interaction effect, but the most likely possibility seems to be that the ILH group would perform better on the visuoconstructive measures than the CLH and right-handed subject groups. If, as discussed previously, there is a subgroup of left-handers with more bilateral cortical control for manual praxis (Kimura, 1983), then ILH subjects may be more likely to show this disjunction in left hemisphere dominance for praxis. If so, ILH subjects, in comparison to CLH subjects, should show: 1) a less dramatic between-hand difference for motor speed; and 2) increased performance on visuoconstructive tasks, relative to purely visuoperceptive tests (requiring the use of no motor systems other than those responsible for visual guidance).

Summary of Predictions

Sex Differences. Consistent with earlier evidence, it was predicted that males would outperform females on all of the spatial tasks but that the difference would be greater on the the mental rotation test (the SIBT) than on the more complex visuoconstructive measure (the ROCF). This result would be consistent with earlier findings (Sanders et al., 1982; Ben-Chiam et al., 1986; and Marino & McKeever, 1989).

Handedness Differences. The prediction for handedness is more difficult to make, given the mixed evidence reviewed earlier. If, however, there is a subgroup of left-handers with more bilateral cortical control for manual praxis (Kimura, 1983), and on the assumption that this condition is manifested as an inconsistency of left hand preference, it suggests that the ILH subgroup will do better on the visuoconstructive measures (3D-Drawing Test; ROCF) than the CLH and right-handed subject groups. In contrast, no differences would be expected between the two left-handed subgroups on the more purely visuoperceptual measure (SIBT). Due to the many and varied discrepant findings in the literature comparing left- and right-handers on spatial tests, no prediction was made how either left-handed subgroup would compare against the right-handers on any of the dependent measures.

Sex by Handedness Interaction. Finally, in line with previous findings (Harshman et al., 1983; Lewis & Harris, 1990), a significant sex by handedness interaction was predicted for performance on the spatial tests. Because the subjects in the new study, however, were unselected for reasoning ability, in contrast to Lewis and Harris' selection of "high" reasoners exclusively, no explicit prediction was made about the direction of the interaction (see Sanders et al, 1982; Yen, 1975; and Inglis and Lawson, 1982). However, to the extent that college students in general would be more likely to be drawn from the high- than from the low-reasoning end of the distribution, it was expected that the direction of any interaction effect was likely to be in the same direction as that found by Lewis and Harris (1990).

METHOD

Subjects

All subjects were recruited through the Michigan State University Psychology Department undergraduate subject pool. Followings standard procedures for informed consent (explanation of the study and conditions of participation), all subjects agreed to participate. Subjects also received credit in their introductory psychology classes for participation in this study. The experimental design required a minimum of 40 left-handed males, 40 left-handed females, 40 right-handed males, and 40 right-handed females. Subjects were recruited on the basis of self-report of hand-preference, and they were further divided on the basis of post-hoc analysis of their responses to the handedness questionnaire into three groups: right-handers, CLH, and ILH. Although it was difficult to predict the eventual size of each of the left-hand subgroups, Peters and Servos (1989) had obtained roughly equal sample sizes for their CLH and ILH groups without much difficulty. Johnson and Harley (1980) were also able to obtain roughly equal numbers of CLH and ILH subjects in their study of college undergraduates. Because the subject variables FS and hemispheric activational style (predicted by the chimeric faces test) were meant to serve as co-variates for many of the statistical analyses of the data, no pre-screening was used for these variables.

Materials

I. Handedness Tests.

Questionnaire Data: Each subject was given Annett's (1967) 11-item inventory of hand preference. A self-report questionnaire was chosen because the evidence indicates that self-ratings and actual hand performance are related (Kozlowski & Bryant, 1977; see discussion by Harris, 1978); The questionnaire packet also included a survey of familial sinistrality, a question about academic major, and several other items that were included in order to collect data for studies other than this one (e.g., a question concerning the hand position used for writing with the dominant hand; see Appendix A). The subjects' scores on the first 9 items of the hand preference questionnaire (the same items used to determine handedness subgroup membership) were summed in order to yield a laterality index (LI) for each subject, with the lowest score (9) indicating exclusive left-hand use, and the highest score (45) indicating exclusive right-hand use. For purposes of separating the left-handed subjects into CLH and ILH subgroups, the questionnaire was scored following the method used by Peters and Servos (1989).

<u>Familial Sinistrality</u>: FS was determined on the basis of the subjects' report of hand preferences for their parents and grandparents only. This decision rule was employed because determination of FS on the basis of reports of hand use by siblings and aunts/uncles risks confounding FS with family size (Bishop, 1983). A subject with either one left-handed biological parent or with two left-handed grandparents was classified as being FS+.

<u>Performance Test</u>: Each subject also was given a timed test (60 sec. for each hand) of motor speed. The test consisted of filling in open circles, arranged in a zig-zag pattern (see Appendix A). Each hand was tested twice: the hand used for writing was always tested first, and the hands were alternated between trials. The average number of circles filled in was computed for each hand, providing a measure of manual speed for each hand.

II. Chimeric Faces Test.

Individual and group differences in hemispheric arousal for the judgement of emotion were assessed with the free-viewing chimeric faces test. A comparison of results across studies and subject populations suggests that this test is an externally valid measure of hemispheric arousal for the perception of emotion in human faces (Harris & Snyder, 1990). It was included on the hypothesis that individual differences in hemispheric arousal (a dynamic condition that is constantly in flux, in response to transient changes in cognitive activity) as indexed by this task, might be a better indication of an individual's real-time analysis of a visuospatial task than his more enduring pattern of cortical lateralization for visuospatial functions.

This test consisted of 16 pairs of chimeric faces constructed from photographs of faces published by Ekman and Friesen (1975). The only photographs used were of those four models (two men, two women) for whom both "happy" and "sad" expressions were modeled. Each of the two photographs for each model was divided along the midline axis and then re-combined into a composite, or chimeric, face with the happy expression on one side and the sad expression on the other. Each chimera was paired with its mirror image, with the resulting pair of chimeric faces arranged vertically on one page (see Appendix A for example). To control for the position of the chimeric faces comprising each pair, the positions were counterbalanced so that on half the trials, the face with the target emotion to the viewer's left was the top face on half the trials and was the bottom face on the remaining trials. Two series of eight pairs (original series and replication) were bound together into a booklet, which was stapled across the top.

Subjects were asked to choose the face composite from each pair that they judged to be "happier." This test was not timed, but the subjects were encouraged to make their choices quickly. This test can be scored as a continuous variable, or, using an extreme-groups analysis, by dividing subjects into those displaying either a strong left- or a strong right-arousal style.

III. Vocabulary Test (WAIS-R).

All subjects were given the vocabulary subtest of the Wechsler Adult Intelligence Scale - Revised (WAIS-R) as a measure of ability on a "crystallized intelligence" test of vocabulary. Although this subtest is always administered individually under normal testing conditions, for the purposes of this study it was adapted for group administration. The test consists of 32 vocabulary words of increasing difficulty. The subjects were told that they had 10 minutes to complete the test and that they were to provide short, concise, and accurate definitions for each word (see Appendix A).

All responses were scored according to the instructions provided in the WAIS-R manual (Wechsler, 1981), with the exception that, under group testing conditions, none of the usual queries by the examiner were possible. All responses therefore were scored as if, when a query would normally be indicated, the subject failed to respond appropriately to the query. This method of administration and scoring led to a "modified raw score" for this WAIS-R subtest. Although these scores cannot be compared with the normative data provided for the WAIS-R, these methods were applied consistently for the entire subject sample so that any differences between subject subgroups on this measure could be investigated with confidence.

IV. Dependent Measures.

A list of the three dependent measures is provided in Table 1. Descriptions of the research materials are provided below.

Table 1. Dependent Measures

(See Appendix A for samples of each test.)

A. Visuoconstructive (manipulospatial) Tests
   1. Rey-Osterrieth Complex Figure Test
   2. Three-Dimensional Drawing Test

B. Visuoperceptual Test
   1. Stafford Identical Blocks Test

IVa. Visuoconstructive Tests.

Rey-Osterrieth Complex Figure Task: Each subject was given the Rey-Osterrieth Complex Figure Task (ROCF; Rey, 1941; see Appendix A). The figure consists of a base rectangle divided into eight equal segments by horizontal and vertical lines that are intersected by two diagonal lines. A variety of internal features are placed within this base structure and on the outer configuration of the design. The complexity of this design allows the researcher (or clinician) to examine the subject's ability to plan, organize, and assemble complex visuospatial information (Goodglass and Kaplan, 1983).

Testing procedure. The testing procedures were nearly identical to those employed by Weinstein (1987) and Waber and Holmes (1985). The ROCF, enclosed between two pieces of cardboard, was given to each subject, along with five colored pencils, on an 8 x 10 inch piece of blank white cardboard. The use of the different colored pencils allowed the examiner to follow the subject's progress as he/she reproduced the figure during the copy, immediate recall, and delayed recall conditions, as well as to determine whether a line was drawn in a continuous stroke or was divided into segments.

Each group of subjects was given oral instructions to copy the design (hidden under the cardboard cover) onto the blank piece of paper, beginning with the designated colored pencil. After a 20-second interval the subjects were instructed to shift to the next pencil. This procedure continued until all of the pencils had been used or until the subject had completed the design. The pencil-color order was black, green, blue, orange, and red. All pencils were placed beside the subject in that order so as to permit quick access to the next pencil to be used. The ROCF was presented for a total of three minutes. Upon completion of the copy drawings, the stimulus cards and the subjects' drawings were quickly removed, and each subject was provided with a new piece of 8 x 10 inch blank paper. The subjects were instructed to draw as much of the original design (that they had just finished copying) as they could remember, beginning with the black pencil. The colored pencils were alternated every twenty seconds, following the same procedures as during the copy condition. Following the immediate recall condition, the drawings were removed and the subjects were told that "in a little while" they would have to draw as much of the figure as they could remember. They were then instructed to begin answering the handedness and familial sinistrality questionnaires. Following a 20-minute delay period, with an interpolated task (completing the handedness questionnaires), the subjects were given new pieces of blank paper and instructed to reproduce as much of the ROCF as they could remember. The same procedures for alternating the use of the five colored pencils were followed as were used before.

Scoring procedures: The total subject sample included 224 individuals who produced 3 ROCF drawings each (copy, immediate, and delayed recall conditions), yielding a total of 672 ROCF drawings. When it was calculated that it would take nearly 170 hours to score all of the drawings (based on an average of 10 minutes per drawing), the decision was made to score half (336) of the drawings, chosen at random from each of the three conditions, in order to determine whether there were any trends that would warrant proceeding with the remaining drawings.

All 336 randomly-selected drawings from the copy, immediate recall, and delayed recall conditions were scored according to the system described by Waber and Holmes (1985) and also used by Weinstein (1987). The Waber-Holmes system provides for the objective and quantifiable evaluation of organization, production style, and accuracy. All drawings were scored for: 1) the number of accurately placed line segments belonging to the four major components of the structure (base rectangle, main substructure, outer configuration, and internal detail); 2) the number of appropriately placed intersections, including corners; 3) alignment of the segments of the base rectangle, main substructure, and exterior structures; 4) the direction of execution of the drawing; and 5) the "goodness of organization." Certain modifications, however, were made in order to meet the particular needs of the current study. The procedures were as follows:

a. ACCURACY: The design was broken down into the smallest line segments possible and each segment was categorized as belonging to one of the four main components of the structure: base rectangle, BR (Figure 1A); main substructure, MS (Figure 1B); outer configuration, OC (Figure 1C); and, internal detail, ID (Figure 1D). A line segment judged to be present was assigned a score of 1. If absent, it was assigned a score of 0.

b. INTERSECTIONS (Figure 1E): All possible intersections, including corners, main diagonals contacting corners, the central intersection (diagonals, horizontal and vertical), the left-side interior box (corners and diagonals), the lower left box, the upper right exterior triangle, and the far right exterior triangle, were scored as present (1) or absent (0).

c. ALIGNMENTS (Figure 1F): Alignment of segments of the base rectangle and main substructure, as well as of the base rectangle within the exterior structures, was scored as present (1) or absent (0).

d. DIRECTION OF EXECUTION: Most subjects were observed to begin each drawing (across all three conditions) by first drawing the base rectangle and then adding the outer features before the internal detail, or vice versa. This is consistent with developmental studies indicating that after age 13 the base rectangle (BR) and main substructure (MS) become increasingly salient as "primary" organizational units; these units are typically copied and recalled first, and then the outer and internal details of the design are added (Milberg, Hebben, & Kaplan, 1986; Waber & Holmes, 1985, 1986). In this adult group, it also unlikely that most persons also would organize their drawings from left-to-right because of their experience with English and its left-to-right directed alphabet. Nevertheless, the possibility occurred that some subjects might begin by drawing one side (left or right) of the figure before the other. Color order was used to determine whether the drawing had been executed from right to left or from left to right, or whether, in the case of a subject who begins a drawing by completing the BR and/or MS first, the rater was unable to determine a clear and consistent direction of execution of the drawing(s).

e. ORGANIZATION: In addition to the objective scoring of discrete component features (see above), the designs were rated for `goodness of organization.' The organization rating was based on a 5-point scale (abstracted from Waber & Homes, 1985; see Table 2) ranging from poor (1) to excellent (5).

FIGURE 1(A - F). WABER-HOLMES SCORING SYSTEM FOR THE REY-OSTERRIETH COMPLEX FIGURE TEST.

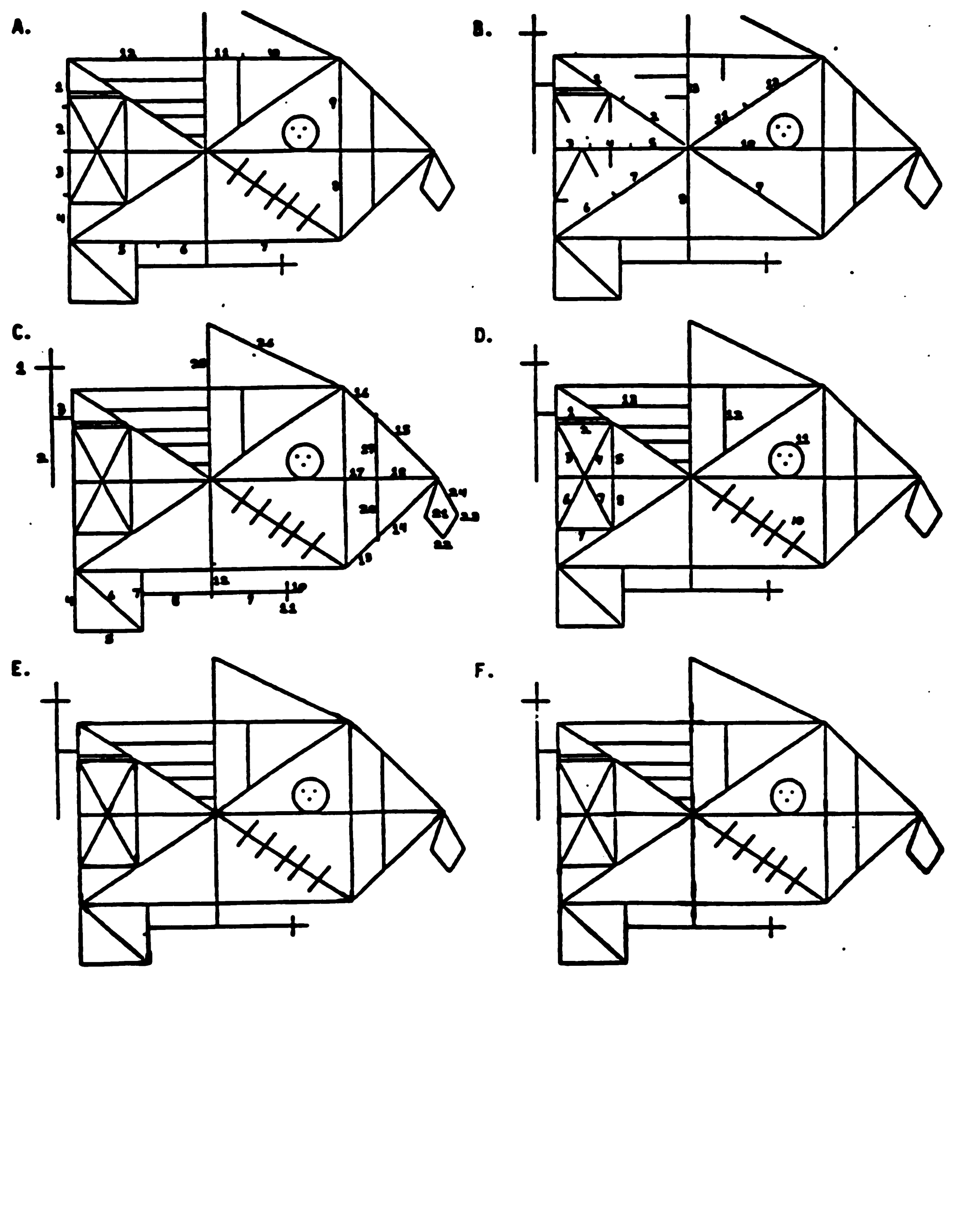


Figure 1. A. Base Rectangle (BR)(12 elements); B. Main substructure (MS)(13 elements); C. Outer configuration (OC)(27 elements); D. Internal detail (ID)(13 elements); E. Intersections; F. Alignments.

Table 2. Criteria For Five Levels of ROCF Organization

Level I: Any production not satisfying criteria for Level II.

Level II:
(1) Upper corner of base rectangle & one other corner;
(2) Left vertical of base rectangle aligned;
(3) Middle vertical of base rectangle aligned;
(4) Three of 6 of the following aligned: upper horizontal of base rectangle, middle vertical of base rectangle aligned with upper right cross; middle horizontal of base rectangle aligned with horizontal of external right triangle, right vertical of base rectangle aligned, lower horizontal aligned at middle of base rectangle.

Level III:
(1) Both corners on left side of base rectangle and 1 on right;
(2) Two of 3 sides of base rectangle (excluding left side);
(3) One of 3 outer configuration structures aligned with main horizontal and vertical;
(4) Diagonals of left interior box intersect;
(5) Upper right triangle intersects right corner appropriately.

Level IV:
(1) All 4 corners of base rectangle;
(2) All sides of base rectangle aligned;
(3) Two of 3 outer configuration structures aligned with main horizontal and vertical;
(4) Main diagonals or horizontal and vertical intersect;
(5) Two left corners and one right of left interior box touch base rectangle and main diagonals appropriately.

Level V:
(1) All 3 outer configuration structures aligned with main horizontal and vertical;
(2) Diagonals and horizontal and vertical all intersect;
(3) All 4 corners of left interior box touch appropriately.

All the drawings were scored by two raters following the Waber and Holmes protocol. Rater #1 scored 186 drawings, and rater #2 scored 150 drawings. To insure reliability, every 25th drawing was scored by the other of the original two raters and by a third independent rater (see Table 3). All three raters were completely blind with respect to knowledge of subject group membership at all times while scoring the 336 drawings. For every 25th drawing, scored by all three raters, the proportion of entries for which the three raters agreed was computed. Overall, interrater agreement was 74 percent.

Table 3. Selection of Three Independent Raters for Every 25th ROCF Drawing.

ROCF Drawing Number	Rater	1st Independent Rater	2nd Independent Rater
25	R.V.	B.L.S.	P.J.S.
50	R.V.	B.L.S.	P.J.S.
75	R.V.	B.L.S.	P.J.S.
100	R.V.	B.L.S.	P.J.S.
125	R.V.	B.L.S.	P.J.S.
150	R.V.	B.L.S.	P.J.S.
175	R.V.	B.L.S.	P.J.S.
200	B.L.S.	R.V.	P.J.S.
225	B.L.S.	R.V.	P.J.S.
250	B.L.S.	R.V.	P.J.S.
275	B.L.S.	R.V.	P.J.S.
300	B.L.S.	R.V.	P.J.S.
325	B.L.S.	R.V.	P.J.S.

R.V. = Rheiny Veii
B.L.S. = Bonnie Lynn Snyder
P.J.S. = Peter J. Snyder

IVb. Three-Dimensional Drawing Test (3DD).

The second visuoconstructive test was a group-administered, timed test of three-dimensional drawing (see Appendix A). This task, specially created for the current study, measures one's ability to add whatever lines the subject feels are necessary to make a line-drawing of simple geometric forms appear more three-dimensional. Any strategy for manipulating the line drawing so as to make it appear more three-dimensional was allowed.

In this test the subjects were first asked to copy a line drawing of a square, but to add whatever lines are necessary to make it look like a cube. Then they were told that on the following five pages there would be more line drawings of different shapes (one per page). The subjects were instructed to add whatever lines they felt were necessary (but not to re-draw the original shape) to add the illusion of three-dimensionality to each drawing. The subjects were allowed thirty seconds per page (per drawing).

To score the drawings, all five drawings for each subject were removed from the questionnaire packet, and each drawing was identified only by subject number. All of the drawings were then separated into five piles, categorized by geometric figure. Each pile was shuffled and then sorted, one at a time, into four levels of organizational quality: (0) no attempt; (1) completely failed attempt (fewer than two line segments drawn that enhance the three-dimensionality of the figure); (2) poor attempt (two or more line segments drawn that enhance the three-dimensionality of the figure); (3) reasonable/good construction; (4) excellent construction. The drawings were separated into these four groups by two independent raters, each of whom graded each drawing at separate times. Because there are several possible "styles" by which a simple line drawing may be enhanced to lend the illusion of depth (e.g., a "transparent" figure with lines drawn inside the original drawing versus a "solid" figure with lines added only to the outside of the original drawing), no method was considered to be superior to any other - the quality of the execution and the overall illusion of three-dimensionality were the only criteria used.

Once each drawing was separated into the four levels of organizational quality, these four levels were treated as a continuous scale, and a total score for each subject (based on the separate scores on each of the five drawings) was derived. Thus, each subject received two separate total scores, based on separate evaluations by the three independent raters.

VIC. Spatial Visualization (Visuoperceptual) Tests.

Stafford Identical Blocks Test. The Stafford Identical Blocks Test (SIBT, Stafford, 1961; also see McKeever, 1986) is a 30-item, 15-minute timed test that requires the subject to mentally rotate a two-dimensional drawing of a cuboidal figure to imagine how it might look from a different angle (see Appendix A). For each item, the subject must compare a "target" figure with five choices, only one of which could possibly represent how the target figure might look from a different perspective.

As mentioned previously, this task, which is similar to the pencil-and-paper version (Vandenberg & Kuse, 1978) of the Shepard-Metzler Mental Rotations Test (Shepard & Metzler, 1971), seems to be a nearly-pure measure of visuoperceptual ability in that no physical manipulative component is required. This task also was chosen because it has been shown to produce reliable sex and handedness differences in college undergraduates (McKeever, 1986).

Procedure

All subjects were tested in groups of 17 to 25 individuals, and they were guided through the test booklet (both timed and untimed tasks) together. The ROCF copy and immediate-recall drawing tasks were administered first, followed by the personal data and handedness questionnaires.[4] After 20 minutes, the subjects were required to complete the ROCF delayed-recall drawing. After the remaining questionnaires, the subjects were given the WAIS-R vocabulary subtest, followed by the SIBT, the chimeric faces test, and the three-dimensional drawing test.

Data Analyses

Both the males and females were divided into right- or left-handedness groups based on the questionnaire data. Non-right-handers were further divided into ILH and CLH subgroups according to the scoring system used by Peters (1989). Basic tests of mean differences, including crosstabulations and analyses of variance, were used to examine group differences for motor speed, hemispheric activational style, type of academic major, vocabulary skill, and familial sinistrality.

Next, analyses of variance, with performance on the chimeric faces task (a measure of hemispheric arousal) entered as a co-variable, were carried out to examine the main effects and interaction effect of sex and handedness on visuoconstructive versus visuoperceptual performance measures. Similar analyses were carried out to examine the influence of FS and verbal ability (vocabulary) on the dependent measures.

To test the hypothesis that both visuoconstructive performance and visuoperceptual performance differ between handedness and sex groups (controlling for hemispheric arousal style, vocabulary skill, and/or familial sinistrality), multivariate analyses of variance (MANOVA) were conducted. To conduct a MANOVA test with confidence, however, each dependent measure entered into the analyses must have generated a normal distribution of performance for the total sample. The consensus among statisticians is that this will often be the case for dependent measures that are continuous variables (Norusis, 1988, B-104).

Finally, following Lewis and Harris (1990), a discriminant function analysis (a linear regression with stepwise selection, using the variables entered into the analysis as discrimination variables with which to predict which subjects belong in one of several discrete groups) was run in order to assess the contributions of the three visuospatial tests to the accurate classification of all subjects into their respective sex and/or handedness groups.

RESULTS

I. Demographic Statistics

Sex and Handedness. A total of 224 subjects participated in this study (109 sinistrals, 115 dextrals). The numbers of female and male subjects, separated into handedness groups, are shown below in Table 4.

Table 4. Subject Groups: Sex X Handedness

	Female	Male
Dextrals:	63 (50.4%)	52 (52.5%)
Sinistrals:	62 (49.6%)	47 (47.5%)
Totals:	125 (55.8%)	99 (44.2%)

Age Differences Between Subject Groups. No statistically significant differences in age were found between any subject group, as shown below in Table 5.

Table 5. Subjects' Ages (in years): Sex and Handedness Groups

	Mean Age	Standard Deviation	Standard Error	Age Range
Females:	18.9	1.08	.096	18 - 23
Males:	19.7	1.70	.171	18 - 32
Dextrals:	19.2	1.57	.150	18 - 32
Sinistrals:	19.3	1.30	.122	18 - 24

Academic Major. Fifty-six subjects named as their academic major a field that could be inferred to require a relatively high degree of competence in spatial reasoning (i.e., math/science -- mathematics, economics, the natural sciences), while 146 subjects listed undergraduate majors in fields presumably lacking this requirement (i.e., liberal arts -- English, philosophy, history). For 22 subjects, either no major had been selected, or the major did not easily fit into either of the two broad categories listed above (e.g., hotel and restaurant management). These subjects were excluded from any further statistical analyses involving `academic major' as either an independent or control variable. No sex differences were found in the proportion of subjects selecting either a math/science major (females = 26.3%; males = 29.5%) or a liberal arts major (females = 73.7%; males = 70.5%) (Chi-Square = 0.13; df = 1; p = .73).

Handedness Subgroups. Based on their responses to the first nine items on Annett's (1967) handedness questionnaire, each left-handed subject was placed into either the CLH or ILH subgroup following the decision rule used by Peters and Servos (1989). In other words, whereas all CLH and ILH subjects reported left-hand use for writing, the CLH subjects responded in the "left hand direction" [score of 1 or 2 on a 5-point scale, where 1 equals exclusive left-hand use, and 5 equals exclusive right-hand use] on at least seven of eight hand-use questions, whereas the ILH subjects reported a preference for left-hand use for fewer than 6 hand-use questions. The numbers of men and women in each handedness subgroup are shown below in Table 6.

Table 6. Subject Subgroups: Sex X Handedness

	Left-Handers: Consistent Left-Hand Use (CLH)	Left-Handers: Inconsistent Left-Hand Use (ILH)	Right-Handers
Females:	34 (58.6%)	28 (54.9%)	63 (54.8%)
Males:	24 (41.4%)	23 (45.1%)	52 (45.2%)
Totals:	58 (25.9%)	51 (22.8%)	115 (51.3%)

Based on the sample data, the results suggest that CLH and ILH are about equally prevalent in the general population of left-handed college students. These results also give no indication of a sex difference, which suggests that the higher incidence of left-handedness in the general population among males (e.g., Oldfield, 1971) does not represent a surplus of ILH males relative to females. Inspection of the individual handedness protocols also proved to be revealing. All CLH subjects reported "always" using their left hand for writing and for drawing. For ILH subjects, it was the same, except that left-hand preference was marginally weaker for drawing, with 12 percent of the subjects reporting "usually" (instead of "always") using the left-hand for drawing. It was the responses to the remaining seven items that differentiated the CLH and ILH subjects, with the majority of the ILH subjects either favoring the <u>right</u> hand, or reporting no hand preference, for throwing a ball (a finding consistent with Peters and Servos' [1989] report) and with 33 to 77 percent also favoring the right hand (or reporting no hand preference) for each of the remaining items (see Table 7).

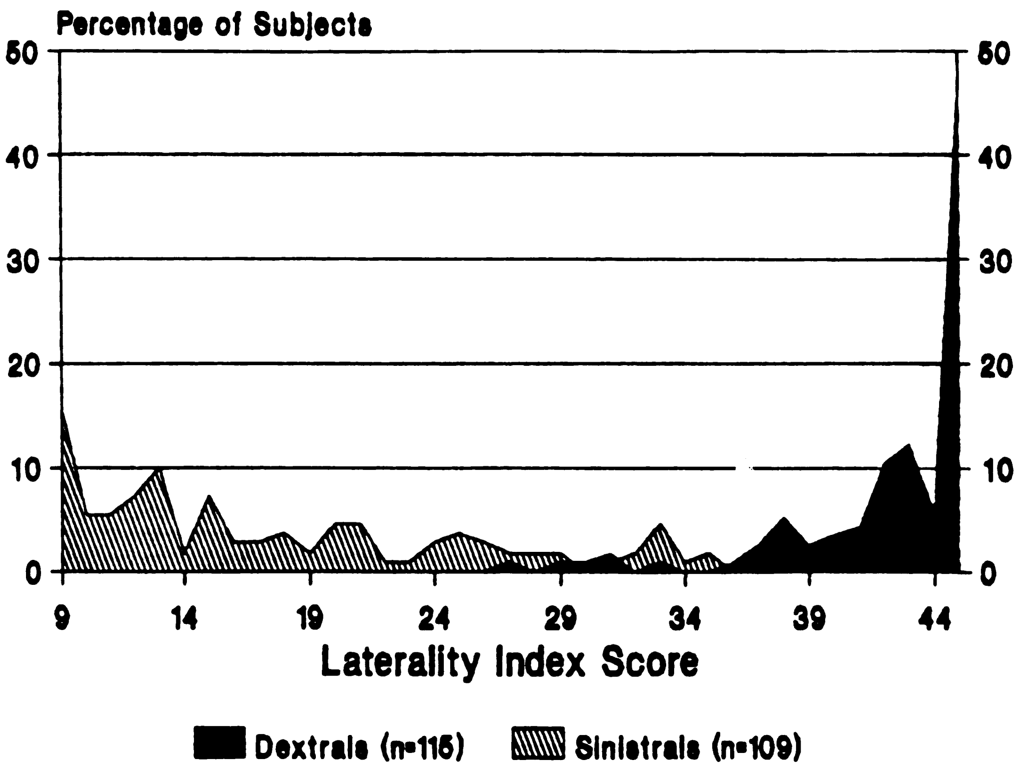
Table 7. Percentage of CLH, ILH, and RH Subjects Favoring the Right Hand (or with No Hand Preference) for Specific Unimanual Tasks.

Unimanual Task	Percentage of Subjects Favoring Right Hand Use: CLH (N = 58)	ILH (N = 51)	RH (N = 115)
Writing a Letter	0.0	0.0	100.0
Drawing a Picture	0.0	2.0	100.0
Throwing a Ball	2.0	69.0	97.0
Using a Tennis Racquet	3.5	65.0	97.0
Hammering a Nail	2.0	77.0	98.0
Brushing Teeth	2.0	33.0	98.0
Cutting with Scissors	38.0	73.0	99.0
Striking a Match	3.5	67.0	97.0
Threading a Needle	5.0	67.0	96.0

Note that, at most, only four percent of the RH subjects reported preferring their left hands for all of the nine tasks. This finding shows that it would be problematic to separate right-handers into consistent versus inconsistent hand use groups, as right-handers are clearly more homogeneous than left-handers in consistency of hand preference across a variety of unimanual tasks (Oldfield, 1971; Coren & Porac, 1977; Peters & Servos, 1989).

Strength of Handedness. Because all subjects answered each of the first nine items of Annett's questionnaire on a five-point Likert-type scale (0 = exclusive left hand use; 5 = exclusive right hand use), it was possible to sum the responses to each question to obtain a "laterality index" (L.I.) for each subject (range = 9 to 45). For all of the left-handers (n=109; both CLH and ILH subgroups), L.I. scores ranged from nine to 35 points (mean = 17.5, SD=7.7), whereas for the right-handers (n=115), L.I. scores ranged from 27 to 45 points (mean = 42.4, SD. = 3.8). The mean scores for the two handedness groups were significantly different from each other (F=950.95, df=1, p<.00001), and the frequency distributions of L.I. scores for both groups are shown in Figure 2. This result shows that whether hand preference for a series of unimanual tasks is treated as a continuous variable or as a dichotomous variable (see Table 7), the same finding emerges, that is, right-handers show far greater consistency in preference for use of the dominant hand.

Figure 2. Frequency Distributions for Both Dextrals and Sinistrals on the Laterality Index (L.I.), Where 9 = Exclusive Left-Hand Use, and 45 = Exclusive Right-Hand Use.



To determine whether there was any sex difference for the pattern of L.I. scores, one-way analyses of variance were performed for each subgroup. The results indicate that frequency distributions of L.I. scores for males and females were nearly identical in the ILH and RH handedness subgroups. In the CLH subgroup, however, although the difference fell short of significance (p = .09), there was a suggestion that males "always" preferred the left hand for each of the nine tasks (L.I. scores of 9) more consistently than females did. The results for each subgroup are shown below in Table 8.

Table 8. Sex Differences on Laterality Index (L.I.) Scores

Subgroup	Sex	Mean	SD	SE	Range	F Ratio	Signif.
CLH	Male	10.96	2.23	.46	9 - 16	2.96	.091
	Female	12.00	2.30	.39	9 - 18		
ILH	Male	23.65	5.65	1.18	15 - 35	0.40	ns
	Female	24.71	6.28	1.19	15 - 35		
RH	Male	42.71	3.77	.52	30 - 45	0.74	ns
	Female	42.71	3.80	.48	27 - 45		

<u>Performance Test of Hand Dominance</u>. All subjects completed a timed test of motor speed (see Method section and Appendix A). The subjects completed two trials of this test with each hand, and the raw scores for each hand were averaged together. The average scores for the dominant and non-dominant hands, for each subgroup, are displayed below in Table 9.

Table 9. Average Scores (Dominant and Non-Dominant Hands) on the Performance Test of Hand Dominance for Each Subgroup

	DOMINANT HAND				NON-DOMINANT HAND			
	Mean	Std. Dev.	Std. Error	Range	Mean	Std. Dev.	Std. Error	Range
FEMALES	73.8	11.0	.98	43-92	36.3	10.4	.93	15-69
MALES	76.6	11.3	1.1	40-92	37.7	10.1	1.0	16-64
CLH FEMALES	74.0	11.0	1.9	52-92	39.8	11.9	2.0	20-69
CLH MALES	73.6	11.5	2.4	54-92	34.3	8.7	1.8	17-51
ILH FEMALES	70.9	10.0	1.9	52-88	35.2	7.4	1.4	22-49
ILH MALES	73.8	11.8	2.5	40-91	38.0	10.9	2.3	26-64
RH FEMALES	74.9	11.2	1.4	43-92	35.0	10.4	1.3	15-68
RH MALES	79.2	10.4	1.5	50-92	39.0	10.1	1.4	16-61

A single "hand difference" score was computed for each subject by subtracting the average number of open circles filled-in in 60 seconds with the dominant hand from the average score with the non-dominant hand (see Table 10).

Two-way analysis of variance revealed no sex difference in the subjects' average difference score for motor speed

Table 10. "Hand Difference" Scores on the Performance Test of Hand Dominance for Each Subject Subgroup

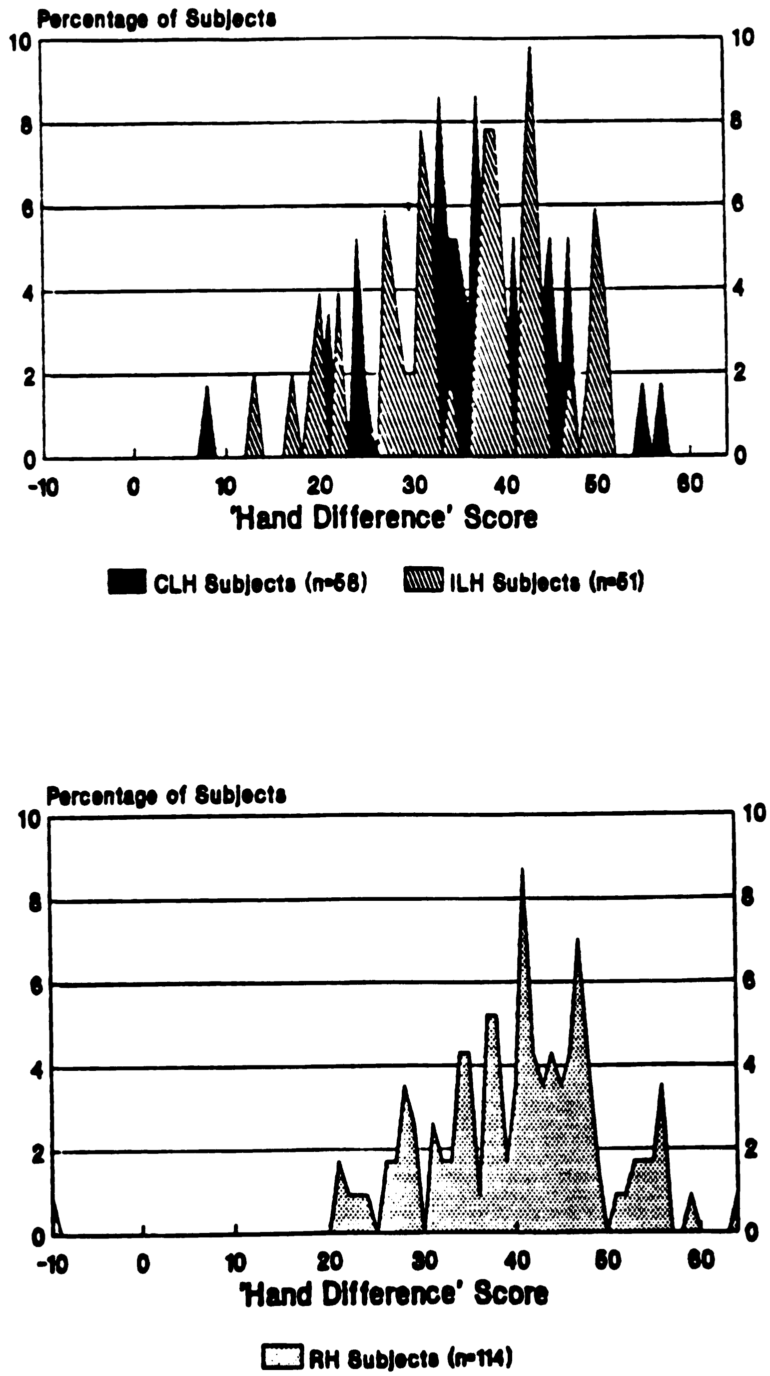
	"HAND DIFFERENCE" SCORE			
	Mean	Std. Dev.	Std. Error	Range
FEMALES	37.5	8.91	.80	8 - 56
MALES	38.9	10.9	1.1	-10 - 64
CLH FEMALES	34.2	8.60	1.5	8 - 51
CLH MALES	39.3	9.30	1.9	20 - 57
ILH FEMALES	35.7	10.9	2.3	13 - 51
ILH MALES	35.7	10.9	2.3	13 - 51
RH FEMALES	40.0	8.64	1.1	21 - 56
RH MALES	40.2	11.5	1.6	-10 - 64

between dominant and nondominant hand ($F = 1.16$, $df=1$, $p=.28$). There was, however, a significant difference in performance on this test between right- and left-handers ($F=9.615$, $df = 1$, $p<.003$). The mean hand difference score was 40.01 (Std. Dev. = 9.97, range = -10 - 64) for the 115 right-handers, whereas the mean hand difference score for the 109 left-handed subjects was 36.06 (Std. Dev. = 9.32, range = 8-57). These results indicate that the left-handers, as a group, were faster with their nondominant (right) hand on this test of motor speed than right-handers were with their nondominant (left) hand. It is interesting to note that one right-handed male (classified as right-handed because he reported that he consistently prefers to <u>write</u> with his right hand) received a hand difference score of -10, which means that he was faster on this test of motor speed with his nondominant (left) hand.

There were no differences between handedness subgroups on this hand performance test. When both sexes were examined together, the mean hand difference score was 36.35 for the CLH subgroup, and 35.73 for the ILH subgroup ($p = .730$). Likewise, no significant differences were found between handedness subgroups when males and females were examined separately. The frequency distributions for each handedness subgroup are shown in Figure 3.

To determine whether performance on this test of motor speed is related to strength of handedness (as determined by the laterality index; L.I.), a correlational analysis between scores on the two tests was conducted for each handedness subgroup. The scores were not significantly related to each other for either subgroup (CLH: Pearson-R correlation = -.024; ILH: Pearson-R correlation = -.251). That is, for both subgroups of left-handers, increased preference for use of the nondominant hand was unrelated to decreased differences in motor speed between hands. In the RH subgroup, by contrast, the two measures proved to be significantly, although very modestly, correlated (Pearson-R = .260, $p \leq .01$, two-tailed test). For right-handers, therefore, a stronger preference for exclusive right-hand use is at least weakly correlated with a greater hand difference in motor speed.

Figure 3. Distribution of 'Hand Difference Scores' on the Motor Speed Test, Where a High Score Indicates a Large Diffference in Motor Speed Between Subjects' Dominant Hand and Non-Dominant Hand.



II. Independent and Control Variables

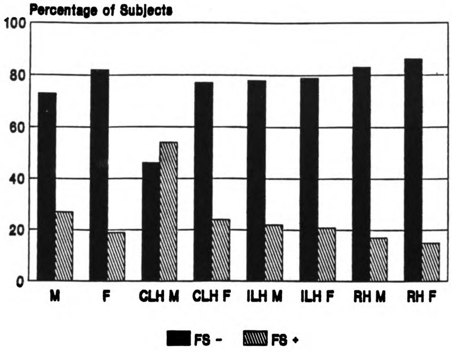
Data were collected on a number of independent variables, some of which were selected to serve as control variables for multivariate analyses of variance with the three dependent measures (SIBT, ROCF, and 3DD). These independent variables were familial sinistrality (FS), performance on the 32-item vocabulary test, academic major, and performance on the Chimeric Faces Test.

Familial Sinistrality. In all but two cases, subjects were classified as FS+ on the basis that they reported having one left-handed parent. The two exceptions were classified as FS+ on the basis of reporting two left-handed grandparents. When the incidence of FS was compared between right- and left-handers, the results disclosed a significant difference between the groups. Eighteen of the 115 right-handers (16%) reported histories of FS, versus 32 of the 109 left-handers (29%; Chi-Square = 5.143, df = 1, p = .023).

When males and females were included in the same analysis, no significant differences in FS were found between the CLH and ILH subgroups (Chi-Square = 2.143, df = 1, p = .143). Similarly, for the 125 females there were no significant differences between the three handedness subgroups in FS (Chi-Square = 1.38, df = 2, p = .50). For males (n=99), however, a significant difference was found between the CLH and ILH subgroups: 21.7% of the 23 ILH males were FS+, vs. 54.2% of the CLH males (Chi-Square = 3.944, df = 1, p = .05). In other words, more than twice as many CLH males were FS+ compared to the ILH males. The group differences (sex by handedness subgroups) are illustrated in Figure 4.

On the premise that individuals with probable genetic histories of left-handedness will show a decreased preference for exclusive right-hand preference, it was predicted that for the RH subgroup, those subjects with histories of FS would show something less than exclusive right-hand preference. For right-handers, this prediction was not supported. A one-way analysis of variance comparing right-handers with and without FS revealed negligible group differences for L.I. scores ($F = .675$, $df = 1$, $p = .413$). Both groups of right-handers produced nearly identical frequency distributions of L.I. scores. For left-handers, however, and in both the CLH and ILH subgroups, FS+ and FS- subjects did differ in strength of handedness. Among the CLH subjects, FS- subjects (n=37) had a mean L.I. score of 12.0 (Std. Dev. = 2.43, S.E. = .40), whereas for FS+ subjects (n=21), the score was 10.81 (Std. Dev. = 1.91, S.E. = .42). The between-groups difference approached significance ($F = 3.73$, $df = 1$, $p = .059$). For the CLH subjects, the FS+ individuals had a somewhat stronger preference for exclusive left-hand use. A similar statistical comparison for ILH subjects could not be made because there were too few FS+ subjects (n=11) for a reliable analysis of variance or similar test (e.g.,

Figure 4. Percentage of FS- and FS+ Subjects in Each Sex by Handedness Subgroup.



M = Male; F = Female

t-test). As mentioned above, FS was less than half as frequent in the ILH males as in CLH males.

Finally, no sex differences were found in FS. Roughly equal numbers of males (n=27) and females (n=23) reported FS histories (Chi-Square = 1.93, df = 1, p = .16).

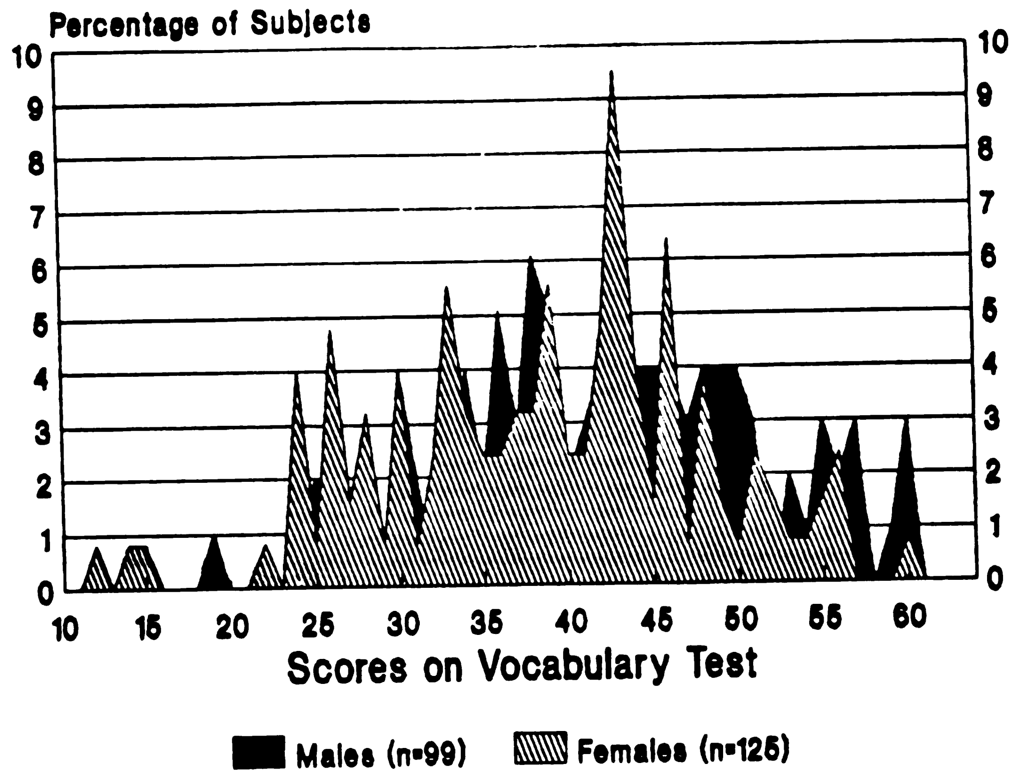
32-Item Vocabulary Test. All subjects received a pencil-and-paper version of the Vocabulary subtest of the WAIS-R. This subtest is thought to measure the ability to use and express knowledge of previously learned verbal information. The possibility of any handedness group differences on this measure of "crystallized" verbal ability was investigated as a potential control variable for the subsequent examination of group differences in visuospatial ability.

Analysis of variance revealed no differences between right-handers (mean = 40.11, S.D. = 9.47) and left-handers (mean = 40.24, S.D. = 9.60) on this test (F = .013, df = 1, p = .91). Nor were there any interactions between sex and handedness subgroup (F = 1.01, df = 1, p = .37). This means that any between-groups differences in visuospatial ability are unrelated to any differences in verbal ability (as measured solely by this vocabulary test).

Although the analyses failed to disclose any handedness differences on the vocabulary test, they did reveal a significant overall sex difference (F = 8.76, df = 1, p = .003). The mean score on this test for the 125 females was 38.5 (Std. Dev. = 9.5, S.E. = .85, range = 12-60); the mean score for the males was 42.2 (Std. Dev. = 9.20, S.E. = .93). The distributions of scores, for both sexes, are shown in Figure 5.

Inspection of the distributions of scores, however, shows that this significant difference is due in large part to a few more males than females achieving near perfect scores of 60 (maximum possible score = 64), along with three females (and only one male) scoring very poorly (less than 24 points). By and large, the scores for both sexes are distributed in a "bell-shaped" fashion over the same range of possible scores, and the mean raw scores of 40 for both sexes correspond to a WAIS-R Vocabulary scaled-score of eight (recall, however, that the administration of this test was modified to accommodate a group-testing format, meaning that the data cannot be directly compared with the WAIS-R normative sample, as the scoring systems were not identical). This (estimated) scaled score of eight falls within the low average range for students attending a four-year public university, and yet because none of the one-point responses generated by the subjects received a "query," when they normally would have received one under individual-testing conditions, it is reasonable to assume that the scores are depressed to some extent (due to the special requirements of test administration and scoring), and that these results reflect conservative estimates of the subjects' performance on this WAIS-R subtest.

Figure 5. Sex Differences for Performance on the 32-Item Vocabulary Test (maximum range = 0 - 60).



Finally, there was no statistically significant difference in performance between math/science majors (mean = 41.02, S.D. = 10.56) and liberal arts majors (mean = 39.95, S.D. = 8.90) ($F = .53$, $df = 1$, $p = .47$).

Academic Major. As just mentioned, there were no sex differences in the overall percentage of subjects in the two academic major subgroups. Similarly, no overall handedness differences were found (Chi-Square = .275, $df = 1$, $p = .600$); 70.2% of the 115 dextrals, and 74.5% of the 109 sinistrals chose academic majors in the liberal arts (non-math/science areas).

Additionally, there were no significant differences in academic major between CLH and ILH females (Chi-Square = .642, $df = 1$, $p = .423$). For males, however, 36.4% of the CLH subjects were in math/science majors, compared to 9.5% of the ILH subjects. This difference approached statistical significance (Chi-Square = 2.96, $df = 1$, $p = .085$, with Yates' correction for attenuation). For male sinistrals, then, those with a stronger preference for use of the non-dominant (right) hand showed a trend towards selecting a liberal arts major.

Chimeric faces Test. All subjects completed a free-viewing Chimeric Faces Test. As mentioned previously, the test consisted of 16 pairs of chimeric faces, and the subjects were asked to designate the "happier" face in each pair. For each subject, the test was scored as follows: The number of faces chosen as happier when the smile was on the left (left visual half-field; LVH) was subtracted from the number of faces chosen as happier when the smile was on the right (right visual half-field; RVH). This value was then divided by the total number of face pairs (RVH - LVH / 16). This transformation of the raw data resulted in a score for each subject ranging from +1.0 (indicating exclusively RVH responses) to -1.0 (exclusively LVH responses). The mean scores for each subgroup are given below in Table 11.

Table 11. Scores on the Chimeric Faces Test

	Mean	Std. Dev.	Std. Error	Range
ALL DEXTRALS	-.31	.58	.06	-1 - +1
ALL SINISTRALS	-.28	.57	.04	-1 - +1
FEMALES	-.34	.56	.05	-1 - +1
MALES	-.24	.58	.06	-1 - +1
CLH FEMALES	-.24	.60	.10	-1 - +1
CLH MALES	-.23	.64	.13	-1 - +1
ILH FEMALES	-.38	.45	.09	-1 - .38
ILH MALES	-.25	.53	.11	-1 - .50
RH FEMALES	-.37	.58	.07	-1 - +1
RH MALES	-.23	.59	.08	-1 - +1

In all cases, the results show that most subjects consistently made their choice based on the location of the emotional cue in the RVH, although a few subjects in each subgroup just as consistently favored the LVH. One-way analysis of variance, however, failed to reveal any statistical difference between the pattern of responses made by the 115 right-handers and the 109 left-handers ($F = .185$, $df = 1$, $p = .67$). The distributions of index scores on this test for the two handedness groups are shown in Figure 6.

In addition, no significant differences on Chimeric Faces Test index scores were found between handedness subgroups for either females ($F = .73$, $df = 2$, $p = .48$) or males ($F = .003$, $df = 2$, $p = .99$), nor between the two sexes ($F = 1.747$, $df = 1$, $p = .19$). The distributions of scores for the right-handed males and females and for the four subgroups of left-handers (by sex) are shown in Figures 7A and 7B, respectively.

Figure 6. Performance of Dextrals and Sinistrals on the Chimeric Faces Test, Where -1.0 = Exclusive LVH Response Style, and +1.0 = Exclusive RVH Response Style.

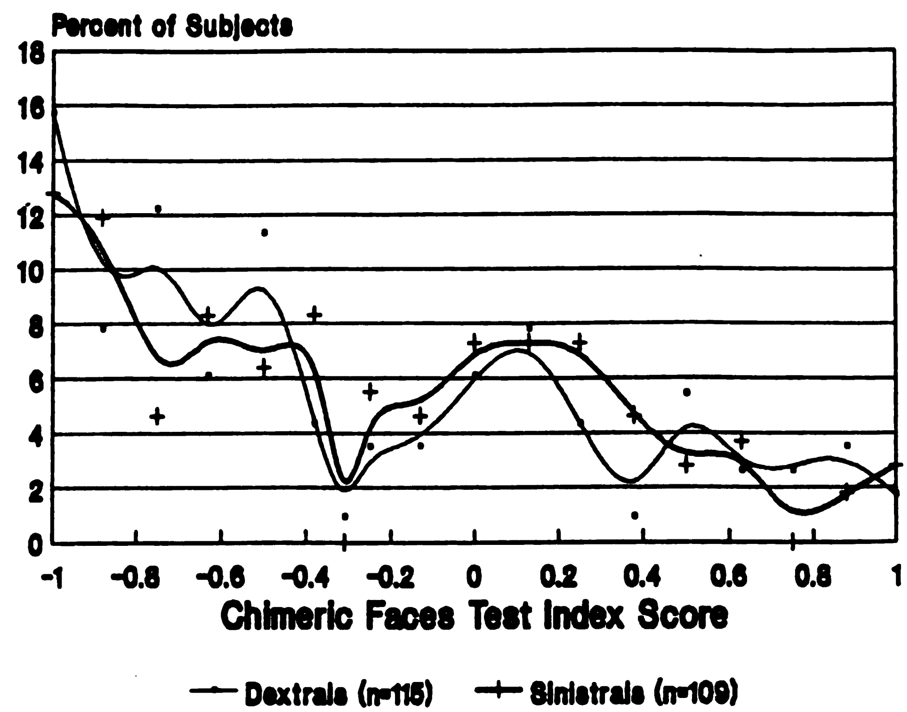


Figure 7A. Performance of Dextral Subjects on the Chimeric Faces Test.

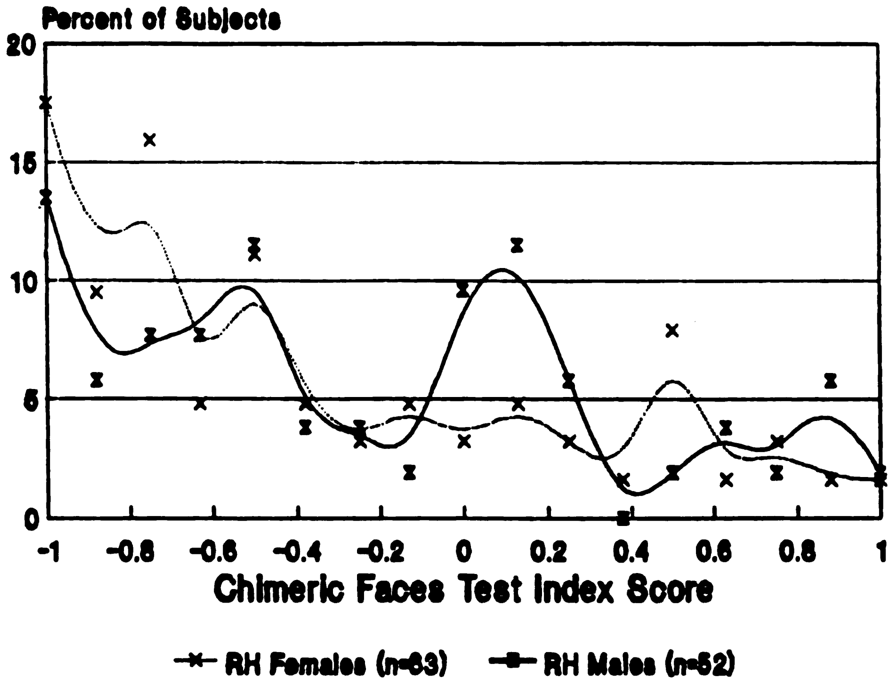
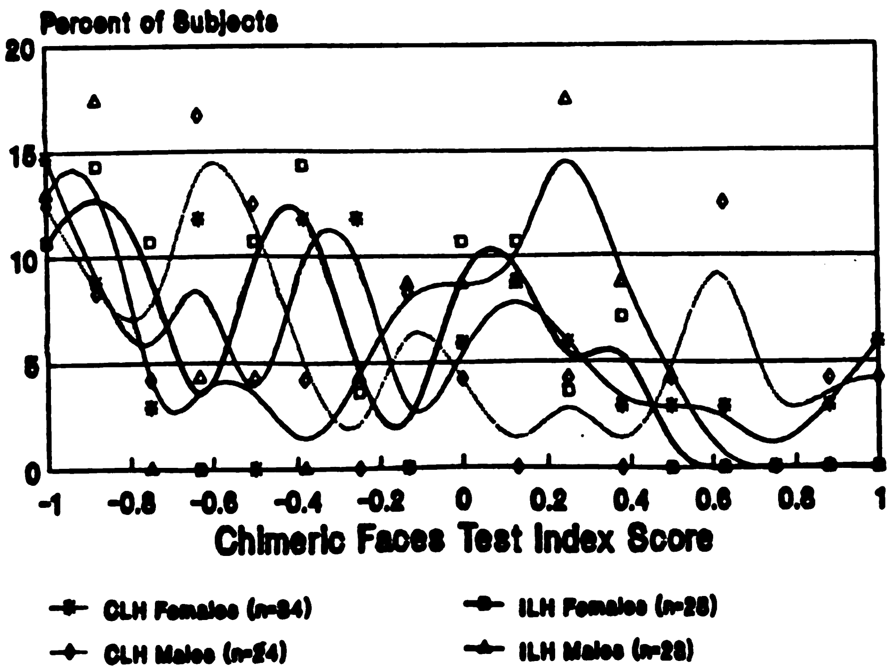


Figure 7B. Performance of CLH/ILH By Sex Subgroups on the Chimeric Faces Test.



III. Dependent Variables

A. Stafford Identical Blocks Test (SIBT)

All subjects completed the 15-minute timed SIBT (30 items), and the total number of correct answers was calculated for each subject. The mean scores on the SIBT for each subject subgroup are listed below in Table 12.

Table 12. Scores on the Stafford Identical Blocks Test

	Mean	Std. Dev.	Std. Error	Range
ALL DEXTRALS	19.9	6.76	.63	2 - 29
ALL SINISTRALS	18.6	6.42	.87	3 - 29
FEMALES	17.6	6.50	.58	2 - 29
MALES	21.4	6.21	.62	6 - 29
CLH FEMALES	18.7	6.33	1.09	3 - 29
CLH MALES	18.9	6.28	1.28	6 - 29
ILH FEMALES	16.0	6.47	1.22	3 - 29
ILH MALES	21.2	6.06	1.26	9 - 29
RH FEMALES	17.7	6.58	.83	2 - 29
RH MALES	22.6	6.01	.83	6 - 29

Multivariate analysis of variance (with univariate F tests) revealed a significant main effect of sex ($F = 14.39$, $df = 1$, $p < .001$), with males outperforming females. In addition, there was a significant sex by handedness subgroup interaction ($F = 3.03$, $df = 2$, $p = .05$). To further analyze the interaction, one-way analyses of variance with *post hoc* tests of pairwise differences (Tukey-B Multiple Range tests) were conducted.

The one-way ANOVA failed to disclose any overall differences among the three female handedness subgroups ($F = 1.32$, $df = 2$, $p = .27$), and the Tukey-B tests did not reveal any two groups to be different at the .05 level. For males, however, the one-way ANOVA revealed an overall groups difference nearly reaching statistical significance ($F = 2.98$, $df = 2$, $p = .055$), and the Tukey-B test revealed a significant difference between the CLH and RH subgroups (Tukey-B = 4.304, $p \leq .05$). The distributions of scores for all of the handedness by sex subgroups are shown below in Figures 8A and 8B.

Figure 8A. Males Performance on Stafford Identical Blocks Test.

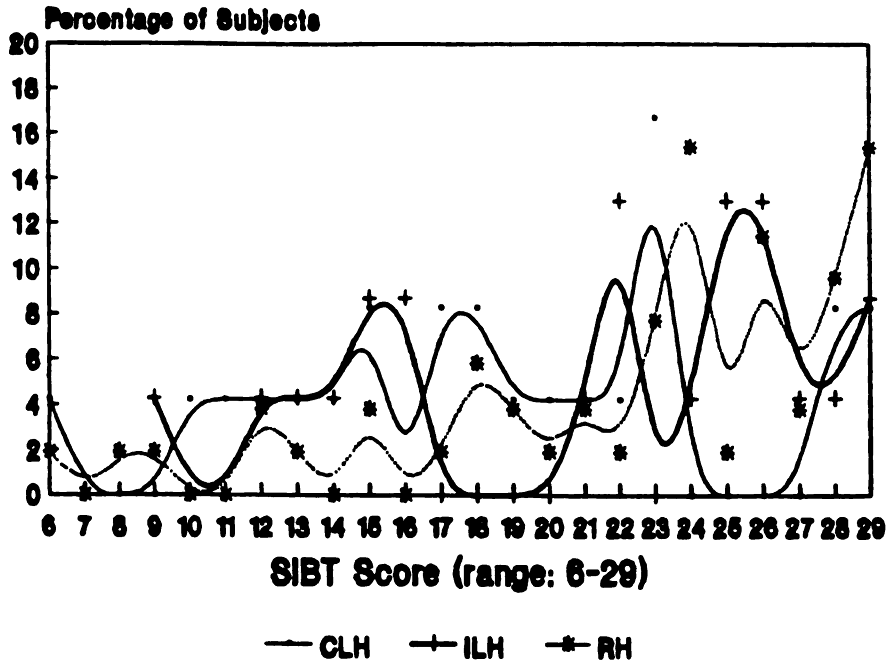
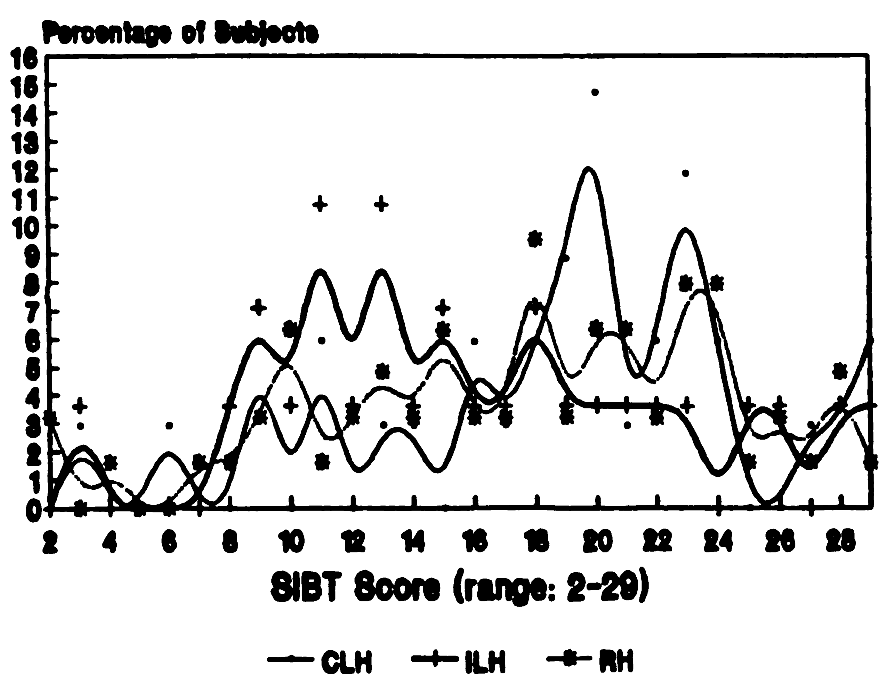


Figure 8B. Females Performance on Stafford Identical Blocks Test.



In addition to the difference between the male CLH and RH groups, a significant difference was found for familial sinistrality, with FS+ subjects doing less well (mean = 16.7) than FS- subjects (mean = 19.2; $F = 4.52$, $df = 1$, $p = .035$). Finally, there was a trend towards a significant difference between the subjects divided according to academic major, with the "math/science" majors having higher SIBT scores (mean = 20.38, S.D. = 6.39, Range = 2 - 29) than the "liberal arts" majors (mean = 18.45, S.D. = 6.69, Range = 2 - 29; $F = 3.37$, $df = 1$, $p = .07$).

Rey-Osterreith Complex Figure (ROCF). As stated in the Methods section, half (336) of the 662 ROCF drawings (three drawings per subject) were scored in order to determine whether there were any promising trends before a decision was made to score the remaining drawings. Of the 336 randomly-selected drawings scored, 113 were from the "Copy" condition, 109 from the "Immediate Recall" condition, and 114 from the "Delayed Recall" condition. The numbers of drawings scored for each subject group are shown below in Table 13.

Each drawing was scored along five indices: 1) "Accuracy" (the sum total of the scores for BR, MS, OC, and ID; see Method section); 2) number of correctly placed intersections in the drawing; 3) number of correctly placed alignments; 4) direction of execution (left to right, right to left, or undeterminable); and 5) "organizational level." To search for any relationship between these dependent measures and the sex and handedness of the subjects, multivariate analyses of variance (MANOVA) were conducted with the four dependent measures scored on continuous scales, and crosstabulations were run to yield coefficients of contingency across each drawing condition (copy, immediate, delay) for the dependent measure ("direction of execution") scored on an ordinal scale.

Table 13. Sample Sizes of Each Subject Group for the 336 Scored ROCF Drawings

Subject Group	COPY	IMMEDIATE RECALL	DELAYED RECALL
FEMALES	65	47	60
MALES	48	62	54
DEXTRALS	62	52	69
SINISTRALS	51	55	45
CLH FEMALES	19	18	18
ILH FEMALES	13	10	10
RH FEMALES	32	22	34
CLH MALES	10	15	11
ILH MALES	10	15	10
RH MALES	29	32	32

For each MANOVA described below, two major assumptions to be met for use of the MANOVA statistical technique were tested independently. The first assumption, that the dependent variables have a multivariate normal distribution with the same variance-covariance matrix in each group (this is a square arrangement of elements, with the variances of the variables on the diagonal, and the covariances of pairs of variables off the diagonal), was examined with the Box's M test. This test is based on the determinants of the variance-covariance matices in each cell as well as of the pooled variance-covariance matrix (Norusis, 1988, pp.B-116 - B-117). The Box's M test is very sensitive to departures from normality: a significant departure means that the homogeneity of variance assumption, necessary for the use of MANOVA, may not have been met.

The second assumption for the use of MANOVA is that the dependent measures are correlated. To test this assumption, Bartlett's Test of Sphericity was employed. This test is based on the determinant of the within-cells correlation matrix (Keppel, 1982, pp.97-98). A determinant close to zero indicates that one or more of the variables can almost be expressed as a linear function of the other dependent measures. A significant result on this test indicates that the variables are correlated, thus meeting a major assumption for use of MANOVA (Keppel, 1982, pp. 98; Norusis, 1988, pp.B-110 - B-111).

Finally, the multivariate test of significance chosen was Pillai's Trace test. In comparison with other multivariate tests of significance (e.g., Hotelling's Trace, Roy's Largest Root), this test lends the greatest power (its ability to detect differences when they exist) and robustness (not affected much by departures from the major assumptions for the use of MANOVA) (Norusis, 1988, pp.B-125 - B-127). When the result of this test was not significant, the univariate tests were not conducted, as recommended by Norusis (1988, p.B-128).

The results of the MANOVA procedures are shown below in Table 14. The results disclosed only a single significant between-groups difference. This was for the 114 drawings of the "delayed recall" condition.

Table 14. Sex By Handedness Differences on the ROCF (Delayed Recall Condition): Results of MANOVA Procedures

I. SEX by HANDEDNESS (Right- versus Left-Handedness)

- Box's M Test = 42.6, df = 30, Chi-Square = 39.66, p = .11
- Bartlett's Test of Sphericity = 206.8, df = 6, p < .001

A. Handedness Effects
- Pillai's Trace Test = .04, F = 1.23 (4, 107), p = .304

B. Sex Effects
- Pillai's Trace Test = .09, F = 2.73 (4, 107), p = .033

	Univariate F Tests with DF = 1, 110			
Variable	Hypoth. MS	Error MS	F Value	Signif.
Accuracy Score	377.67	68.24	5.54	.020
Intersections	62.29	6.81	9.15	.003
Alignments	27.80	3.65	7.63	.007
Organization Level	8.63	1.41	6.12	.015

C. Handedness By Sex Effects
- Pillai's Trace Test = .102, F = 3.03 (4, 107), p = .021

	Univariate F Tests with DF = 1, 110			
Variable	Hypoth. MS	Error MS	F Value	Signif.
Accuracy Score	.23	68.24	.00	ns
Intersections	22.07	6.81	3.24	ns
Alignments	14.08	3.65	3.86	.050
Organization Level	.21	1.41	.15	ns

II. SEX by HANDEDNESS SUBGROUPS (CLH, ILH, RH)

- Box's M Test = 79.9, df = 50, Chi-Square = 69.13, p = .038
- Bartlett's Test of Sphericity = 199.0, df = 6, p < .001

A. Handedness By Sex Effects
- Pillai's Trace Test = .15, F = 2.08 (8, 212), p = .039

	Univariate F Tests with DF = 2, 108			
Variable	Hypoth. MS	Error MS	F Value	Signif.
Accuracy Score	63.34	68.17	.93	ns
Intersections	20.23	6.70	3.02	.053
Alignments	13.14	3.52	3.74	.027
Organization Level	.91	1.42	.64	ns

The differences were not between handedness groups (right-versus left-handers) or between CLH, ILH, and RH subgroups. Instead, only significant sex differences for performance on all four dependent measures of the ROCF "delayed recall" condition were found, with males outperforming females on each measure of the ROCF task. The descriptive statistics for each group, across all four measures of performance on the "delay" condition, are shown below in Table 15.

Table 15. Descriptive Statistics for Each Subject Group for the "Delayed Recall" Measures of the ROCF

	Mean	Standard Deviation	Standard Error	Range
I. ACCURACY SCORE				
A. Females	49.52	8.67	1.12	26 - 64
B. Males	53.22	7.62	1.04	32 - 64
A. Females	5.67	2.48	.32	1 - 11
B. Males	7.37	2.78	.38	1 - 12
A. Females	4.85	1.96	.25	1 - 9
B. Males	6.01	1.91	.26	1 - 9
IV. ORGANIZATION				
A. Females	1.57	.93	.12	1 - 5
B. Males	2.15	1.41	.19	1 - 5

In addition to the statistically significant sex differences found on the delayed recall condition of the ROCF (see Tables 14 and 15), a significant handedness by sex interaction effect for the measure of "alignments" was found (see Table 14). The interaction indicated that only the males showed significant between groups differences, with right-handers (N = 33, mean = 6.46, S.D. = 1.62) outperforming left-handers (N = 21, mean = 5.33, S.D. = 2.15) in the number of correctly placed alignments (F = 4.74, df = 1, p = .034). When handedness was subdivided into the three subgroups (CLH, ILH, RH), however, significant sex by handedness interaction effects were revealed for both the "intersections" and "alignments" variables, but now the differences were only between <u>female</u> subject groups. As shown in Table 16 and 17, for the females, the ILH subgroup recalled significantly more intersections than the RH subgroup, whereas the ILH subgroup remembered more alignments that the CLH subgroup (not the RH subgroup).

No significant between-groups differences were found for the "direction of execution" during the delayed condition (Chi-Square = 6.01, df = 4, p = .19, Contingency Coefficient = .224 [ns]). Furthermore, no significant handedness (or handedness subgroup) or sex differences were found for <u>any</u> of the ROCF dependent variables during either the "copy" or "immediate" recall conditions. Similarly, no handedness by sex interaction effects were found on these two testing conditions of the ROCF. Thus, only performance on the ROCF during the 20-minute <u>delayed</u> recall condition was able to distinguish between any of the subject groups under study. It seems, then, that the only significant

Table 16. Sex by Handedness Subgroup Differences on the "Intersections" Measure of Performance on the Delayed Recall Condition of the ROCF

I. Females

Analysis of Variance

Source	DF	SS	MS	F	Signif.
Between Groups	2	41.15	20.57	3.64	.033
Within Groups	57	322.19	5.65		

Subgroup	N Size	Mean	S.D.	S.E.	Range
CLH	16	5.56	2.58	.65	2 - 10
ILH	8	7.75	2.25	.80	5 - 10
RH	36	5.25	2.30	.38	1 - 11

Note: ILH and RH subgroups are significantly different (Tukey-B = 1.68, $p \leq .05$)

II. Males

Analysis of Variance

Source	DF	SS	MS	F	Signif.
Between Groups	2	7.66	3.83	.487	.617
Within Groups	51	400.93	7.86		

Subgroup	N Size	Mean	S.D.	S.E.	Range
CLH	11	7.00	3.03	.92	1 - 12
ILH	10	6.80	2.62	.83	3 - 10
RH	33	7.66	2.78	.48	1 - 12

Note: No two subgroups are significantly different at the .05 level

Table 17. Sex by Handedness Subgroup Differences on the "Alignments" Measure of Performance on the Delayed Recall Condition of the ROCF

I. Females

Analysis of Variance

Source	DF	SS	MS	F	Signif.
Between Groups	2	22.80	11.40	3.204	.048
Within Groups	57	202.85	3.56		

Subgroup	N Size	Mean	S.D.	S.E.	Range
CLH	16	4.38	1.78	.45	1 - 8
ILH	8	6.38	1.69	.60	3 - 8
RH	36	4.72	1.97	.33	1 - 9

Note: CLH and ILH subgroups are significantly different (Tukey-B = 1.334, $p \leq .05$)

II. Males

Analysis of Variance

Source	DF	SS	MS	F	Signif.
Between Groups	2	16.22	8.11	2.340	.107
Within Groups	51	400.93	7.86		

Subgroup	N Size	Mean	S.D.	S.E.	Range
CLH	11	5.27	2.49	.75	1 - 9
ILH	10	5.40	1.84	.58	3 - 8
RH	33	6.46	1.62	.28	2 - 9

Note: No two subgroups are significantly different at the .05 level

between-groups differences occurred during the single condition wherein <u>memory</u> for visual information is as important for performing well as is visuospatial processing without a memory component. Because no differences were found on the copy or immediate recall conditions, where mnestic abilities are not relied on as much, there were no trends in the data to suggest any evidence of between-groups differences on the portions of this test that examine visuoconstructive skill in the absence of a strong memory component. For this reason, and in light of the time required for scoring the ROCF drawings, as mentioned earlier, the decision was made to forgo the scoring of the rest of the drawings.

<u>Three-Dimensional Drawing Test</u>. As described in the Methods section, the five-item Three-Dimensional Drawing Test (3DD) was scored for all subjects by two independent raters who were blind as to subject group membership. As mentioned previously, each rater sorted the drawings into five piles, corresponding to five levels of organizational quality: (0) no attempt; (1) completely failed attempt; (2) poor attempt; (3) reasonable/good construction; and (4) excellent construction. Sample drawings from each of the latter four categories are shown below in Figure 9a - 9d.

Figure 9a. Sample 3DD Drawing: "Completely Failed Attempt."

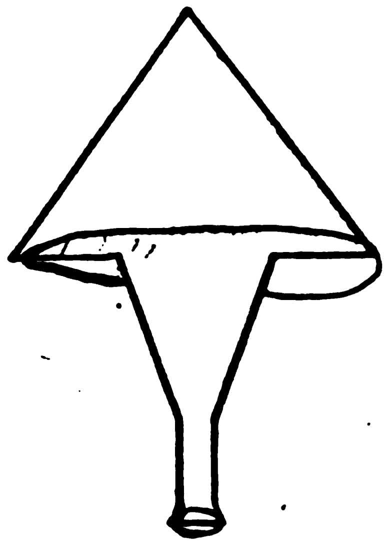


Figure 9b. Sample 3DD Drawing: "Poor Attempt."

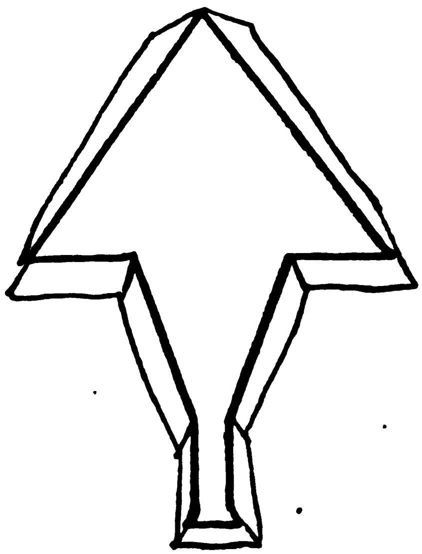


Figure 9c. Sample 3DD Drawing: "Reasonable/Good Construction."

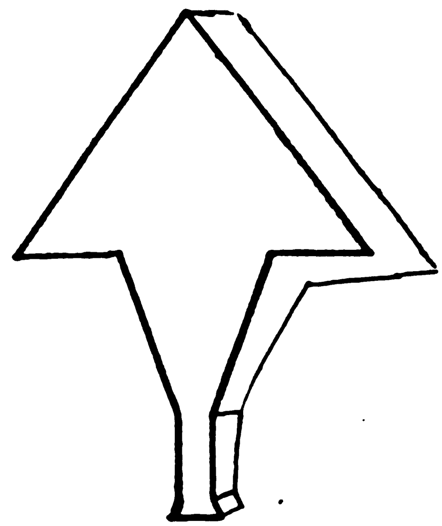
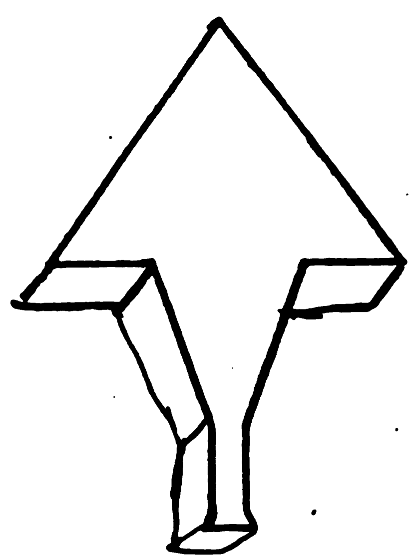


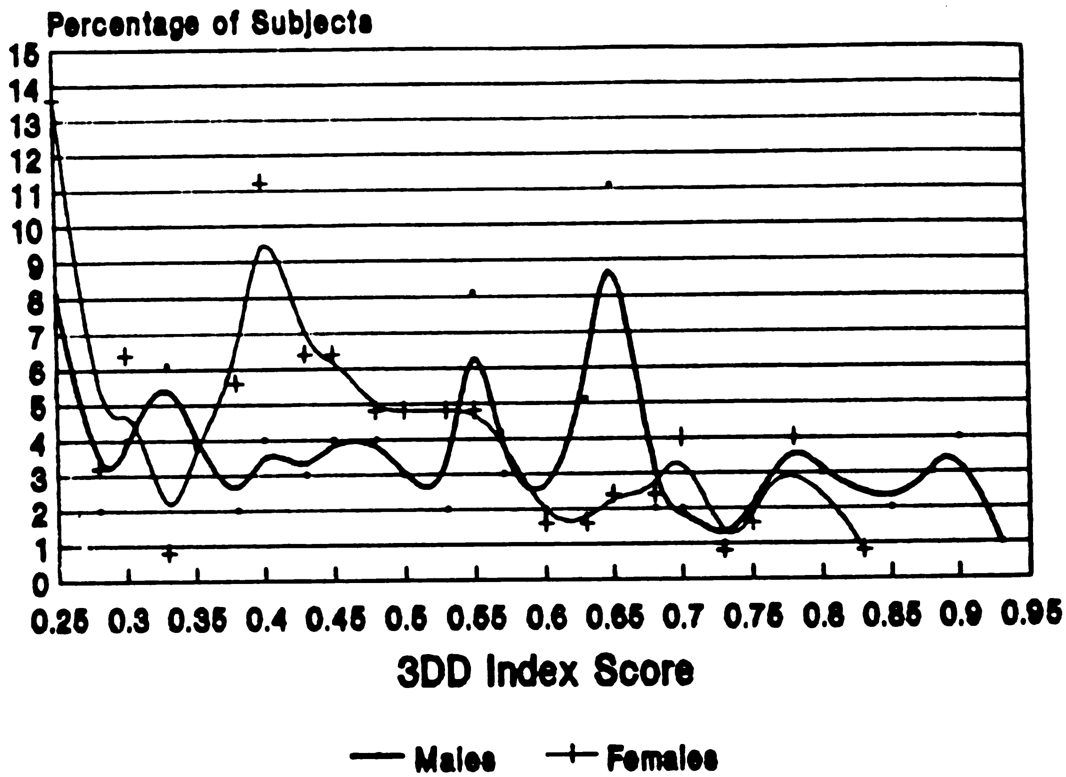
Figure 9d. Sample 3DD Drawing: "Excellent Construction."



To ensure inter-rater reliability, the total scores derived by the raters for each subject were compared by a Pearson correlation coefficient. The result was a Pearson-R of .768 (2-tail, $p \leq .002$), indicating a high degree of inter-rater reliability. Next, this coefficient was used to calculate a Spearman-Brown coefficient, using the Spearman-Brown prophecy formula (see Anastasi, 1982, p.114; R Spearman-Brown = N x Pearson-R / 1 + ([N-1] x Pearson-R); where N = number of independent raters). The Spearman-Brown correlation coefficient was calculated to be .87. The increase in the R Spearman-Brown over the value of the Pearson-R is attributed to the direct increase in reliability of having two raters, rather than one, leading to a subsequent decrease in random error of measurement.

Following this statistical check to ensure high inter-rater reliability, the two total scores for each subject (derived from the two independent ratings) were averaged together. This score was then divided by 20 (the maximum raw score on this test), yielding a value ("index score") for each subject that ranged from zero (poorest possible performance) to one (best possible performance). The distribution of index scores for the male and female subjects are shown separately in Figure 10.

Figure 10. Distributions of Three-Dimensional Drawing Test (3DD) Index Scores for Both Males and Females, Where a High Score Indicates Better Performance on the 3DD.



As can be seen in Figure 10, 23.2 percent of the females, but only 14% of the males, achieved low index scores (less than .33) on the 3DD. Contrariwise, only 14% of the females received high index scores (.70 or higher) compared to 22 percent of the males. An analysis of variance revealed a statistically significant sex difference for performance, with males ($N = 99$, mean = .54, S.D. = .191) outperforming females ($N = 125$, mean = .46, S.D. = .460; $F = 14.08$, df = 1, $p < .001$). The analysis, however, failed to show significant main effects for handedness (left- versus right-handers; $F = .27$, df = 1, $p = .60$), handedness subgroup (CLH, ILH, RH; $F = .28$, df = 2, $p = .76$), or sex by handedness subgroup interaction ($F = 1.33$, df = 2, $p = .27$).

Further analyses of variance revealed a significant three-way interaction among sex, handedness subgroup, and FS ($F = 4.08$, df = 2, $p = .018$), although five of the individual cells within this matrix were too small (e.g., only 6 ILH, FS+ females) to reliably control for sampling error. Further ANOVAs were conducted (one for the females, and one for the males) with subjects separated into left- versus right-handedness groups, rather than being partitioned into the three subgroups. The results of this procedure, shown below in Table 18, reveal overall significant handedness by FS interaction effects for both sexes, although no two subject groups appear to be significantly different from each other at the .05 level.

Table 18. Handedness by FS Differences on the Index Scores for the Three-Dimensional Drawing Test (3DD).

I. Females

Analysis of Variance

Two-Way Interaction	DF	SS	MS	F	Signif.
Handedness by FS	1	.104	.104	4.44	.037

Subgroup	N Size	Mean	S.D.
FS- Dextrals	53	.450	.142
FS+ Dextrals	9	.533	.203
FS- Sinistrals	48	.468	.166
FS+ Sinistrals	14	.400	.101

Note: No two subgroups are significantly different at the .05 level

II. Males

Analysis of Variance

Two-Way Interaction	DF	SS	MS	F	Signif.
Handedness by FS	1	.164	.164	4.45	.038

Subgroup	N Size	Mean	S.D.
FS- Dextrals	43	.565	.177
FS+ Dextrals	9	.494	.250
FS- Sinistrals	29	.489	.189
FS+ Sinistrals	18	.610	.199

Note: No two subgroups are significantly different at the .05 level

IV. Correlation Between Spatial Measures

The strength of any linear correlation between performance on the SIBT and on the Three-Dimensional Drawing Test (3DD) was examined by calculating a Pearson correlation coefficient. The overall Pearson-r coefficient for all 224 subjects considered together was .448 (2-tail, $p \leq .002$), indicating that approximately 25 percent of the variance is shared between these two tests and also indicating that this correlation is reliable. The implication is that these two visuospatial measures are measuring similiar but not identical abilities. That is, although certain neuropsychological abilities are required to perform well on <u>both</u> tests, good performance on one test does not necessarily imply good performance on the other test. The correlation coefficients for these two measures were calculated for each subject group separately. These results are shown below in Table 19.

Table 19. Pearson-r Correlation Coefficients for the SIBT and 3DD

Subject Group	Pearson-r	Subject Group	Pearson-r
FEMALES	.397	CLH Females	.318
MALES	.426	ILH Females	.430
All CLH Subjects	.388	RH Females	.454
All ILH Subjects	.378	CLH Males	.514
All RH Subjects	.506	ILH Males	.320
		RH Males	.471

As shown in Table 19, the largest correlation between performance on the two spatial tests was found in the CLH male subgroup and for the right-handers considered together. The smallest correlations were found for the CLH females and the ILH males.

V. Multivariate Analysis (MANOVA) of the Dependent Measures

As stated in the Methods section, the next step in the treatment of the data was to run a MANOVA with the SIBT and 3DD entered as the dependent variables, and with sex and handedness subgroup entered as the two independent, or grouping, variables. The advantage of the MANOVA procedure is that several covariates can be entered to control for covariation between subject groups along several selected domains.

The covariables selected for this analysis were FS and performance on the vocabulary test. FS was selected because of the significant interaction found between FS and performance on the SIBT (described above). The vocabulary test was selected because, unlike the results found for the Chimeric Faces Test or for academic major, a significant sex difference was found on the vocabulary test, in the same direction as those found on the SIBT and 3DD tests.

Despite the use of these covariates, the results of the MANOVA test were virtually identical to those reported previously for the dependent measures. No new main or interaction effects were discerned, and only <u>marginal</u>

changes (increases or decreases) for mutivariate or univariate F values (and the corresponding significance levels) were observed.

VI. Discriminant Function Analyses

Finally, following Lewis and Harris (1990), several related discriminant function analyses were conducted to assess the contributions of the two remaining visuospatial tests (the ROCF was excluded) to the accurate classification of all subjects into their respective sex and/or handedness groups.

Discriminant function analysis offers two advantages. First, low sample sizes for subject subgroups can be handled confidently as long as the prior probabilities for the groups are supplied (R.J. Frankman, December, 1987, pers. comm.). A prior probability for a given group is an estimate of the likelihood that a randomly selected case belongs to that particular group in the absence of information about group differences. Because the prior probabilities for each group were calculated and entered for each analysis, corrections could be made for low sample sizes for some of the subgroups. A second advantage of discriminant function analysis is that the criteria for variable selection (into the regression equation) can be chosen by the experimenter. For the analyses listed below, the Mahalonobis' Distance (D2) was used to select variables for inclusion. D2 is a generalized measure of the distance between two groups when a given variable is being used to discriminate between them. For these analyses, the D2 between all pairs of groups was calaculated first. The dependent variable with the largest D2 for the two closest groups was selected first for inclusion in the regression equation. This procedure was repeated until the largest possible percent of variance between groups was accounted for by the variables included in the regression.

For the current discriminant function analyses, the independent variables on continuous scales (SIBT, 3DD; and Vocabulary Test for the evaluation of overall sex differences) were used as discriminating variables with which to predict membership of subjects into their actual groups and/or subgroups.

Sex Differences. The first analysis examined the ability of the two spatial tests to reliably discriminate between male and female subjects. The results are shown below in Table 20.

Table 20. Discriminant Function Analysis Between Male and Female Subject Groups, with the SIBT, 3DD, and Vocabulary Tests as the Discriminating Variables

Groups	(N)	Prior Probabilities Entered
Females	125	.56
Males	99	.44

Fcn	Eigen Value	% Var.	Canonical Correlation	Chi-Sq.	DF	Signif.
1	.1205	100	.3280	25.09	3	.0001

Classification Results:

Actual Group Membership	Predicted Group Membership Females	Predicted Group Membership Males
Females	99 (79.2%)	26 (20.8%)
Males	46 (46.5%)	53 (53.5%)

As shown in Table 20, when all handedness groups/ subgroups are examined together, performances on the two spatial tests and the vocaulary test led to the accurate prediction of _female_ group membership for 99 of 125 cases. That is, nearly 80 percent of the females were correctly identified as members of that group on the basis of their performance on those measures. On the other hand, only 53.5 percent of the males were correctly classified, indicating that the evaluation of performance on these three measures leads to the accurate identification of male subjects at only chance level.

Handedness Subgroups. The next set of discriminant analyses sought the ability of subjects' performances on the two spatial tasks to predict handedness subgroup membership. Separate analyses were run for females and for males, and these results are shown in Tables 21 and 22, respectively.

Table 21. Discriminant Function Analysis Between Female Handedness Subgroups, with the SIBT and 3DD as the Discriminating Variables

Groups	(N)	Prior Probabilities Entered
CLH Females	34	.27
ILH Females	28	.22
RH Females	63	.51

Fcn	Eigen Value	% Var.	Canonical Correlation	Chi-Sq.	DF	Signif.
1	.0457	98.66	.2091	5.51	4	.24
2	.0006	1.34	.0249	.08	1	.78

Classification Results:

Actual Group Membership	Predicted Group Membership: CLH	ILH	RH
CLH Females	1 (2.9%)	0 (0.0%)	33 (97.1%)
ILH Females	0 (0.0%)	0 (0.0%)	28 (100.0%)
RH Females	0 (0.0%)	0 (0.0%)	63 (100.0%)

Table 22. Discriminant Function Analysis Between Male Handedness Subgroups, with the SIBT and 3DD as the Discriminating Variables

Groups	(N)	Prior Probabilities Entered
CLH Males	24	.24
ILH Males	23	.23
RH Males	52	.53

Fcn	Eigen Value	% Var.	Canonical Correlation	Chi-Sq.	DF	Signif.
1	.0951	89.21	.3247	11.12	4	.038
2	.0006	10.79	.1224	1.44	1	.230

Classification Results:

Actual Group Membership	Predicted Group Membership CLH	ILH	RH
CLH Males	7 (29.2%)	0 (0.0%)	17 (70.8%)
ILH Males	2 (8.7%)	0 (0.0%)	21 (91.3%)
RH Males	4 (7.7%)	0 (0.0%)	48 (92.3%)

As shown in Table 21, comparing the _female_ subjects' performance on the two spatial tests did not contribute _any_ predictive value for separating those subjects into the CLH and ILH handedness subgroups. All of the right-handed females were correctly distinguished from their left-handed counterparts, however, on the basis of their performance on the two tests. Although this finding held true in part for the _male_ subjects (see Table 21), there was some marginal success in identifying the CLH males on the basis of their performance on the two measures (7 of 24 CLH males, or 29.2%, correctly identified).

In an attempt to improve on the predictive value of the two spatial tests, subjects were separated into different sex by handedness (CLH, ILH, RH) by FS subgroups. It was hypothesized that when the handedness by sex subgroups were further differentiated on the basis of family histories of sinistrality, the predictive value of performance on the spatial tests in distinguishing between subject types would improve. For females treated separately, this did not prove to be the case. The same pattern of results was observed as that reported above in Figure 21. All 53 of the FS- right-handed females were correctly identified, and all nine of the FS+ right-handers were classified as FS- right-handers. Aside from these findings, almost none of the other 63 female subjects were correctly classified in their respective handedness by FS subgroups.

For the males, however, there was some limited success in discriminant classification of subjects based on their performance on the two spatial tests (see Table 23).

Table 23. Discriminant Function Analysis Between Male Handedness By FS Subgroups, with the SIBT and 3DD as the Discriminating Variables

Groups	(N)	Prior Probabilities Entered
CLH, FS- Males	11	.11
CLH, FS+ Males	13	.13
ILH, FS- Males	18	.18
ILH, FS+ Males	5	.05
RH, FS- Males	43	.44
RH, FS+ Males	9	.09

Fcn	Eigen Value	% Var.	Canonical Correlation	Chi-Sq.	DF	Signif.
1	.2165	88.94	.4219	20.92	10	.022
2	.0269	11.06	.1619	2.50	4	.645

Classification Results:

Actual Group Membership	Predicted Group Membership CLH, FS-	CLH, FS+	ILH, FS-	ILH, FS+	RH, FS-	RH, FS+
CLH, FS- Males	0 (0.0%)	2 (18.2%)	0 (0.0%)	0 (0.0%)	9 (81.8%)	0 (0.0%)
CLH, FS+ Males	0 (0.0%)	7 (53.8%)	0 (0.0%)	0 (91.3%)	6 (46.2%)	0 (0.0%)
ILH, FS- Males	0 (0.0%)	1 (5.6%)	0 (0.0%)	0 (0.0%)	17 (94.4%)	0 (0.0%)
ILH, FS+ Males	0 (0.0%)	1 (20.6%)	0 (0.0%)	0 (0.0%)	4 (80.0%)	0 (0.0%)
RH, FS- Males	0 (0.0%)	1 (2.3%)	0 (0.0%)	0 (0.0%)	42 (97.7%)	0 (0.0%)
RH, FS+ Males	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	9 (100.0%)	0 (0.0%)

As shown in Table 23, seven of the 13 CLH males with family histories of sinistrality (53.8%) were correctly classified on the basis of their performance on the two spatial measures. Although the percent of these subjects rests above the chance level, these seven subjects may be the same seven who were correctly classified as CLH subjects (see Table 22) before FS was added as a grouping variable. Finally, all 52 of the right-handed males were correctly distinguished from the left-handers, but no distinction was drawn, on the basis of spatial test performance, between RH males with and without family histories of familial sinistrality.

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DISCUSSION

The data from this study are extensive and complicated because of the use of multiple combinations of subject grouping variables, dependent measures, and covariables. For this reason, the discussion of the results will begin with a review of the analyses of the demographic characteristics of the subject groups, then move to a review of group differences in the presence and influence of the covariables on the dependent measures (spatial tests), and then to a discussion of the dependent measures. At the end, some general conclusions for the study as a whole will be drawn, and some areas for further work will be proposed.

Handedness Subgroups and Unilateral Hand Performance

First, the results confirm the existence of the CLH and ILH subgroups (as defined by Peters and Servos, 1989). They also indicate that these subgroups are about equally prevalent in the general population of left-handed American college students. This is consistent with the reports by Johnson and Harley (1980) and Peters and Servos (1989), both of which reported having little difficulty obtaining roughly equal sample sizes of CLH and ILH undergraduate subjects, but without specifying any details about sampling. The present results also suggest that the two subgroups are equally prevalent among men and women, which suggests that the higher incidence of left-handedness among males in the general population (Oldfield, 1971) does not represent a surplus of a particular subgroup of left-handed males relative to females. Of course, we cannot say that there is no sex difference between the two subgroups (this would be tantamount to proving the null hypothesis). The data obtained in the present study nevertheless suggest that this may be the case. To further support this position, a replication of the present study, with larger sample sizes, would be desirable.

In assigning the left-handers to subgroups based on their responses to the 9-item handedness questionnaire, inspection of the pattern of responses proved to be revealing. All left-handers reported using their left hand for writing (as was the case in Peters and Servos' Canadian university sample). That all of the left-handers in Peters and Servos' study would write with their left hand is not unexpected, given the general easing of traditional restrictions against left-hand writing in western societies since World War II (Harris, 1990). The same reasoning also applies in the case of the young American sample in the current study. There was, however, a modest difference between the CLH and ILH subgroups for drawing, such that all CLH subjects reported "always" using their left hand for drawing, whereas 12 percent of the ILH subjects reported that they occasionally draw with their right hand. Still, it was the responses to the remaining seven items that differentiated the two subgroups. For example, the majority of ILH subjects favored the right hand for throwing a ball, whereas the majority of the CLH subjects favored the left hand (a finding consistent with Peters and Servos' [1989] report; see Table 7). We therefore can be reasonably sure that, at least for unimanual hand use tasks, the ILH group is phenotypically similar to Peters and Servos' ILH group (1989). Interestingly, 38 percent of the CLH subjects in the present study reported preferring their right hand for cutting with a scissors, whereas less than six percent reported a right hand preference for any of the other unimanual tasks. This difference may reflect the general unavailability of "left-handed scissors" in the classroom or home, so that at least a substantial minority of left-handers, by necessity, must learn to cut with their right hand.

In contrast to the left-handers, at least 96 percent of the RH subjects reported preferring their right hands for all nine tasks. Right-handers thus are clearly more homogeneous than left-handers with regard to hand preference across a variety of unimanual tasks, which indicates that it would be more problematic to divide right-handers than left-handers into consistent versus inconsistent hand use groups.

The CLH and ILH subgroups, although different (by definition) on the handedness inventory, were not different on the performance test of motor speed (whether the sexes were analyzed together or separately). This result looks consistent with Peters and Servos' results for their finger-tapping, Purdue Pegboard, and square-tracing tests; tests that, like the motor performance test in the current study, recruit small, distal muscle groups. For these tests, Peters and Servos likewise found no differences between their CLH and ILH subgroups.

By contrast, Peters and Servos's ILH subjects were more skilled with their non-dominant (right) hands than with their dominant (left) hands for tasks requiring the coordination of larger and more proximal sets of muscle groups, such as throwing a ball or using a racquet, whereas their CLH subjects were more skilled with their dominant hands whatever the specific physical demands of any unimanual task. Recall that for these types of unimanual motor tests that require the coordination of the larger and more proximal muscle groups of the upper arms, the ILH subjects in both Peters and Servos' and in the current study reported that they prefer to use the right hand.

In the current study, there was, however, a significant difference in motor performance between right- and left-handers, with the left-handers being faster with their right hand than the right-handers were with their left hand, the result being that the left-handers showed smaller between-hand differences. This finding further demonstrates that right-handers are homogeneous in strongly preferring, and being more skilled with, their dominant hand across a wide range of tasks, whereas left-handers are more inconsistent in hand preference and skill (in some cases even showing superior performance with their non-dominant hands). Finally, no sex differences were found on the motor speed test.

Familial Sinistrality

The familial sinistrality data revealed that FS+ was twice as common in left-handers as in right-handers. This finding agrees with that of McKeever (1990), who found that in a sample of 4,031 college students, roughly half the left-handers were FS+ compared to only a third of the right-handers.

The discrepancy between these two reports may be due to differences in how FS was defined. Whereas McKeever categorized subjects as FS+ if they reported a first-degree relative (including siblings) who used their left-hand for writing, for the current study reports of sibling hand use were omitted, as it was felt that family size could be a confounding variable. Unlike the current study, McKeever found a significant sex difference in his sample (more FS+ females in both the left- and right-handed groups).

Although FS was more common in left-handers than in right-handers, when both sexes were included in the same analysis no significant differences in FS were found between the CLH and ILH subgroups. Similarly, for the female subjects, there were no significant differences between the three subgroups. For the males, however, there was a significant difference between the left-handed subgroups, FS+ being more than twice as common in the CLH subgroup as in the ILH subgroup (see Figure 5). At least for males, then, more than twice as many CLH as ILH subjects have familial histories indicative of a genetic basis for left-handedness. Inasmuch as the base rate of FS+ in the ILH subgroup was equal to that found in the RH group, the possibility arises that (some) ILH subjects come from a population of "genetic right-handers" with a sub-clinical amodal organization of function, leading to the partial expression of left-handedness. If so, it is conceivable that some of these FS- ILH subjects developed left-hand preference in response to an early pathological event, making them "pathological left-handers" (see review by Harris and Carlson, 1988). This possibility is strengthened, in part, by the finding that those CLH subjects with positive histories of FS were somewhat more likely to report exclusive use of the left hand than those with negative FS histories (the same comparison could not be made for ILH males because of the small number of FS+ subjects), implying that more exclusive left-hand use is associated with a genetic predisposition for left-handedness.

Vocabulary Test Performance

Because a test of verbal reasoning ability was not included, we cannot say whether differences in verbal reasoning ability had contributed to any between-groups differences on the dependent measures. The test of vocabulary (a measure of "crystallized" verbal knowledge, without an abstract reasoning component), however, failed to disclose any differences between right- and left-handers, nor any significant main or interaction effects involving sex and handedness. Therefore, we can say that any between-groups differences in visuospatial ability are unrelated to any group differences in verbal ability, as measured by this vocabulary test.

Unexpectedly, the vocabulary test resulted in a significant overall sex difference. Although the scores for both sexes were distributed in a "bell-shaped" fashion over the same range of possible scores, more females scored at the low end of the distribution, whereas more males scored at the high end. At first glance, the male superiority may seem surprising given other evidence that females usually excel on tests of verbal ability. Where females have the advantage most consistently, however, is on expressive language tasks (e.g., tests of verbal fluency; see review by Maccoby and Jacklin, 1974) and not on tests of vocabulary. For example, among American high school students, boys typically outperform girls on both the arithmetic and verbal portions of the Scholastic Achievement Test (SAT). Note, however, that the verbal portion of the SAT is, almost entirely, a test of "crystallized" information (e.g., vocabulary; Cattell, 1971; Horn, 1976), and not more "fluid" verbal reasoning abilities (e.g., verbal fluency).

Chimeric Faces Test

The results on the free-viewing Chimeric Faces Test (CFT), strongly support previous studies (Levy et al., 1983; Harris & Snyder, 1990), in that the "left visual hemifield effect" (LVH; Figure 7) proved to be the modal effect. That is, most of the subjects on most of the trials made their choices based on the left-side location of the target emotion (LVH), whereas only a small minority of subjects made a preponderence of right visual hemifield (RVH) choices. What is also noteworthy is that the minority were just as consistent in making RVH choices, which is consistent with prior evidence of a genuine stylistic reliance on the unilateral activation of one cerebral hemisphere, more than the other, for this (and other) type(s) of perceptual task(s).

Despite the agreement of these results with previous CFT studies, no significant differences were found in the pattern of responses between the right- and left-handers, or between handedness subgroups for either males or females (treated together or separately). That is, the minority of subjects who made RVH choices did not include disproportionately more of one subgroup than another.

Although the results thus provide further evidence that the LVH bias on the CFT is the modal bias, they showed neither the expected weaker LVH bias for left-handers nor a significant correlation between performance on this test and any of the spatial tests (linear correlations or extreme groups comparisons), including the SIBT, the putatively purest measure of right-hemisphere functioning. This lack of any relationship between performance on the CFT and the three tests of spatial ability suggests that if CFT performance provides an index of hemispheric arousal style (e.g., Levy, Heller, and Banich, 1983), then increased right-hemisphere arousal, as indexed by an LVH bias, does not help us predict which individuals will excel on spatial tests that draw heavily on lateralized, right hemisphere functions.

Visuoperceptual Ability: The SIBT

On the SIBT, the males, as expected, did significantly better than the females, but there was no evidence for the predicted handedness effect. There was, however, a significant sex by handedness subgroup interaction, such that for males, but not for females, there were significant differences across the three handedness subgroups. For males, the CLH group had the lowest scores, the RH subgroup the highest, with the ILH group in between, and with the RH group significantly outperforming the CLH group (there was a trend towards significance, with the CLH males performing worse than the ILH males as well). This finding is consistent with Johnson and Harley's (1980) finding that CLH college students (both males and females) did significantly worse on a spatial perception test than their ILH subjects did (it is unclear what criteria they employed to distinguish between handedness subgroups). In the present study, the subgroup with the highest incidence of familial sinistrality (see Figure 5) did least well on this mental rotation test.

As expected, given these findings, a significant difference was found between _all_ subjects (both males and females) with histories of FS+ versus those who were FS-, with the FS+ subjects performing more poorly on this test. Finally, subjects pursuing academic majors that presumably make greater demands on visuospatial abilities did not do significantly better than those pursuing academic majors that presumably make fewer such demands.

Visuospatial Memory: The ROCF

The ROCF was originally chosen as a measure of visuoconstructive skill because this test requires subjects to copy a complex drawing, which is scored for accuracy of detail and organization. It was understood, of course, that two of the three testing conditions for this measure (the "immediate" and "delayed" recall conditions) were designed to examine "figural" or visuospatial _memory_. Nonetheless, it was expected that at the very least, a sex effect would emerge for the "copy" condition, as it did on the SIBT.

Initial analyses (on half the drawings), however, failed to show any significant handedness or sex differences for the first two ROCF conditions, or any handedness effect in the third condition for any scoring category (following the Waber and Holmes, 1985, scoring system). It was for this reason that the decision was made not to score the remaining drawings. In the third condition, however -- the 20-minute delayed recall condition -- a sex difference was found, with the males significantly outperforming females across all scoring indices. This sex difference, however, accounted for only about 2% of the overall variance.

Despite the small amount of variance accounted for, there is reason to have some confidence in the finding. The reason is that although this evidently is the first study to report a sex difference on this test for college students (Kaplan, 1988, was unaware of any previous reports), sex differences on the ROCF have been reported at least once before, but in a sample of older subjects. Read (1987) administered the ROCF to 734 neurologically normal volunteers between the ages of 50 and 79 years. Each subject completed the "copy" condition of the ROCF modified by Jones-Gotman (1986) for use with elderly populations. The subjects then performed an interpolated 5-minute verbal fluency task, followed by a delayed recall drawing. The result was that the men significantly outperformed the women under the delayed condition ($p < .0001$). Like the current study, the sex difference, although statistically significant, accounted for only approximately 2% of the overall variance. Nevertheless, the two studies suggest that sex differences on the "delayed" portion of the ROCF are continuous across the life span.

In summary, the only significant between-groups differences on the ROCF occurred during the delay condition, when a <u>memory</u> component (20-minute delayed-recall for the visual stimulus) strongly influenced the nature of the task demands. It is possible that the slight, but statistically significant, male advantage on this part of the test emerged because of the addition of the mnestic component. In this way, the task was made more difficult, thereby amplifying the male superiority for performance on visuoconstructive measures.

<u>Visuoconstructive Ability: The Three-Dimensional Drawing Test</u>

The Three-Dimensional Drawing Test (3DD) was specially designed for this study to provide a more nearly pure measure of visuoconstructive skill in the absence of any confounding by task demands requiring figural memory. Specifically, the test was designed to provide a spatial <u>constructive</u> analogue to the SIBT, with both tests requiring the subject to visualize a 2-dimensional design as if it were 3-dimensional, but with the SIBT requiring the subject to mentally rotate each 2-dimensional stimulus to imagine a 3-dimensional configuration, whereas on the 3DD test, the subject had to actually create 3-dimensional representation of a 2-dimensional design.

Although there were no overall handedness nor handedness subgroup differences on this test, a significant sex difference was found, with males once again outperforming females. In contrast to the SIBT, there were no further interaction effects between sex and handedness subgroups. There was, however, a three-way interaction effect for sex, handedness subgroup, and FS, although simple effects tests indicated that no two subgroups were significantly different from one another.

The results also revealed a modest correlation between performance on the SIBT and the 3DD. These two visuospatial tests, therefore, seem to be measuring similar abilities, although the tests by no means are redundant. That is, although certain cognitive abilities are required to perform well on both tests, good performance on one test does not necessarily imply (or predict) good performance on the other. Depending on the subgroup, the correlations between these two spatial tests ranged from .318 to .514, and no subjects were found to score in the upper quartile on one test and in the lower quartile on the other. This absence of a stronger correlation between performance on the two tests perhaps reflects the fact that one test (the SIBT) lacks any constructive component, whereas the other (3DD) requires the subject to create a three-dimensional representation, although not necessarily by mentally "rotating" a two-dimensional figure in three-dimensional space.

Prediction of Subject Group Membership Based on Performance on the Dependent Measures

When all handedness groups/subgroups were examined together by discriminant function analysis, performance on the SIBT, 3DD, and vocabulary tests predicted group membership with nearly 80 percent accuracy for females (99 of the 120 female subjects being correctly identified), but only 53.5 percent accuracy for males. The high "success" rate for predicting group membership for females is due to the uniformly lower performance on the visuospatial and vocabulary measures across all subgroups of females, thereby making it likely to correctly classify as a female any subject who failed to excel on all three of these measures.

When the sexes were examined separately, there was limited success in identifying the CLH male subjects, whereas for the other (sex by handedness) subgroups, no unique patterns of performance on the two spatial tests could be discerned. The success rate for predicting CLH male subgroup membership also was marginally increased when subjects were further divided by FS (see Table 23).

GENERAL DISCUSSION

The basic operational model in human neuropsychological research links performance on psychological measures to cerebral and/or subcortical organization for subserving "higher order" functions. In this study, it was predicted that males would outperform females on all spatial tests and that one subgroup of left-handers (CLH subjects) would do relatively poorly on "right-hemisphere" tests of mental rotation. To test this prediction, spatial tests that were either primarily visuoconstructive or visuoperceptual in their task demands were selected, as at least two separate components of spatial reasoning are discernible: the visual-spatial analysis of a design, and the ideomotor praxis to execute a design (Teng et al., 1989).

With regard to the hypotheses listed in the Introduction, the prediction that males would outperform females on all of the spatial tasks was borne out. The prediction that this effect would be stronger on the SIBT than on the ROCF was confirmed as well. These two findings support previous meta-analytic studies showing that the male advantage is more robust and consistent on mental rotation tests than on tests that include a constructive, or praxic component. They also imply that males are more adept at using multiple strategies (both verbal and non-verbal) to solve spatial tasks (see Ornstein et al., 1980). The possibility occurs that this is the result of greater lateralization for language functions in men (see review by

Galaburda, Rosen, and Sherman, 1990), leading to less competitive antagonism between higher cognitive functions (Levy, 1969).

In contrast to the positive results for sex differences, no main effects for handedness (or handedness subgroups) were found on the spatial tests. To the extent that left-handers have a greater measure of mixed dominance for speech and/or language functions, causing "crowding" of largely spatial functions, the current findings do not indicate that this condition is invariably associated with poorer spatial ability. In addition, the hypothesis that some left-handers may rely on more bilateral cortical control for manual praxis (Kimura, 1983), insofar as this is more involved in a drawing test like the 3DD, was not supported. That is, there were no important differences in performance between the visuoconstructive and visuoperceptual tests for either of the left-handed subgroups. The results, however, did reveal a significant sex by handedness subgroup interaction on the visuoperceptual measure, with the CLH males performing more poorly than the other two male subgroups. The CLH males also showed a robust linear correlation between the visuoperceptual and visuoconstructive tests.

It is of special interest that the largest correlation between performance on the two spatial tests was found for the CLH males and for all right-handers considered together. Thus, in support of Peters and Servos' (1989) conclusions, based entirely on their examination of hand motor skill, the two groups who looked the most homogeneous with respect to familial sinistrality, as well as to phenotypic pattern of hand preference, also showed the most consistent performance on both the visuoperceptual and visuoconstructive tasks. The CLH males had the highest incidence of FS+, the strongest preference for consistent left hand use, and the poorest performance on the SIBT, which was strongly correlated to their performance on the 3DD. Conversely, the right-handers (both males and females) had a low incidence of FS+ (similar to ILH subjects), the strongest and most consistent dominant- [right] hand use, and, along with the ILH males, the best performance on the SIBT, which was strongly correlated to their performance on the 3DD.

It should be emphasized, however, that the ILH and RH subjects appear to be the most similar groups (for both sexes) for both FS and for SIBT performance. For males, then, the CLH and RH groups are phenotypically similar in the <u>strength</u> of hand preference, whereas the ILH and RH groups are phenotypically similar in both the incidence of FS and in the <u>direction</u> of performance on the visuoperceptual measure (in contrast to the findings of Sheehan and Smith [1986], who had a smaller sample of 8 CLH, 14 ILH, and 25 RH males).

Perhaps some of the strongest evidence presented so far to support the separation of left-handers (at least in the case of males) into CLH and ILH subgroups is that FS+ is more than twice as common in the CLH group as in the ILH group, which suggests a stronger genetic predisposition towards left hand preference in the CLH subgroup. If the CLH phenotype suggests a stronger genetic predispostion toward left hand preference, one wonders whether there would be any other indications. For example, would CLH individuals be more resistent to right hand training? Indeed, are the CLH subjects in the current study individuals who have successfully resisted such training? Note that in America today, as in Canada, the training would not be explicit, since both countries are "liberal" in their views and practices, but instead would be "tacit," such as is posed by the relative scarcity of left-handed utensils and tools. Gloning, Gloning, Haub, and Quatember (1969) described a subgroup of left-handers who expressed their resistance to attempts on the part of society (parents, teachers) to convert them to right-hand use by resuming left-hand use after the pressure to shift handedness had been removed. If the tendency to resist right-hand training is a sign of a stronger genetic predispostion for left-handedness, this predisposition presumably would be found more frequently among the CLH subjects than among the ILH subjects in the present study.

If we accept the popular assumption that mixed speech dominance is more common in left-handers than in right-handers, we might expect this to be especially true of those who are resistant to right-hand training (and who may be primarily CLH individuals). In fact, this does seem to be the case. Gloning et al. (1969) found that this subgroup of left-handed subjects recovered speech and language functions more quickly than other left-handers (and right-handers) after left-hemisphere injuries, suggesting that, for these individuals, the right hemisphere was more readily able to mediate such activities. Although it is premature to predict anatomical differences between subgroups of left-handers, this finding supports the hypothesis that amodal lateral specialization for speech and language functions (with potentially negative effects on the development of spatial abilities) may be largely restricted to CLH and not ILH individuals.

The single most important conclusion to be derived from the current study is that left-handers can be subdivided into discrete subgroups (based on consistency of dominant-hand preference) not only on the basis of motor performance (Peters and Servos, 1989), but also (at least for males) on the basis of family history of FS and performance on visuospatial tasks. These findings have important consequences for several of the models, presented earlier, that have sought to elucidate the connection between handedness and spatial ability. For example, although the current results cannot be said to have refuted Levy's (1969, 1974) hypothesis that a more bilateral distribution of language functions in left-handers is detrimental to the development of spatial reasoning abilities, they do indicate that the hypothesis must be refined to take subgroup membership into account. That is, the results suggest that in prior studies (e.g., Levy, 1969) that have found a significant decrement in visuospatial abilities in left-handers, the decrement may have been in only a subset of left-handers, presumably in CLH left-handers. If so, Levy's model would have to be amended to reflect the possibility that only a subset of left-handers, those with distinct motor, family history, and possibly other neuropsychological characteristics as well, have more mixed- or right-hemisphere speech dominance, leading to a "crowding" of spatial functions.

The seemingly different neuropsychological profiles for CLH and ILH males may also have implications for Harshman et al.'s (1983) hypothesis linking handedness, sex, spatial ability, and reasoning ability. For example, although they found that among "high reasoners," right-handed males outperformed left-handed males on all of 15 separate spatial tests, a disproportionate amount of the variance accounting for this between-groups difference may have been due to the performance of CLH subjects.

Left-handers challenge classical models of cerebral organization. It was not until the 1940's, and work by investigators such as Subirana on crossed aphasics, that it became clear that left-handers are not merely mirror-image reversals of right-handers. The present study has shown that normal left-handers can be subdivided into two subgroups not only on the basis of motor skill (Peters, 1990), but also, at least in males, on the basis of family history and neuropsychological profile. Despite the apparent limitation of this effect to males, the data suggest that roughly equal numbers of males and females comprise these two subgroups. A deeper understanding of the phenotypic differences between these two subgroups of left-handers therefore may further our understanding of genetic and neurobiological mechanisms underlying handedness.

CLINICAL IMPLICATIONS AND FUTURE DIRECTIONS

The present study proved to be extremely complex, as numerous subject grouping variables, dependent measures, and covariables had to be taken into account. It was for this reason that the study had to recruit larger subject sample sizes than are typically used in studies on handedness and cerebral laterality. Nevertheless, because the potential for sampling error cannot be ruled out, replication should be the next step. Although the validity of the CLH/ILH distinction has been demonstrated by Peters (1990) on the basis of differences in motor skill, the present study represents one of the first attempts to compare the two subgroups in spatial skill and familial history of sinistrality. As such, this endeavor should be repeated before any conclusions can be drawn with full confidence.

A second direction for further research is refinement and elaboration of the 3DD test. The results on this new measure -- a statistically significant sex difference in the same direction and with the same strength as that found on the SIBT as well as other spatial tests -- suggests that it has important potential as a new test of visuospatial ability. That it correlates moderately (but not perfectly) with the SIBT indicates that the two tests are not identical and that the 3DD test is tapping some additional dimension of spatial ability. The 3DD perhaps represents a visuoconstructive analogue to the more widely known mental rotation tests (e.g., SIBT, Shepard-Metzler test), which the ROCF or Block Design subtest clearly do not.

Once again, the next step should be a replication. Before this is undertaken, however, the 3DD test may need modification. For example, the five stimuli were not created according to any increasing or decreasing order of complexity, and presenting them in an increasing order of spatial complexity might help to control for any practice effects. Secondly, the scoring system was not designed to allow for the use of multiple methods of representing the stimuli in three dimensions. It is reasonable, for example, to give "credit" for the use of multiple ideomotor strategies, such as adding lines to the stimulus in such a way as to give the impression that the stimulus has been rotated in space. Finally, it would be desirable to give the test to a large normative sample of males and females, stratified by age cohort. This would be a major step towards the goal of standardizing an easily administered (visuoconstructive) spatial visualization task that could be included in clinical neuropsychological batteries, when the integrity of right parietal lobe functioning is in question.

Two of the dependent measures selected for use in this study, the SIBT and 3DD, are not clinical tests, and there are no reliability studies or normative data that would allow them to be used with confidence in a clinical setting at this time. Their potential for clinical use in the future, however, is strong in that they provide measures by which more fine-grained analyses of (different aspects of) visuospatial functions may be obtained. For instance, rather than relying on rather crude indices of visuospatial deficits (e.g., a significant PIQ/VIQ split as a confirmation of a diagnosis of a nonverbal learning disability [NLD; Goldberg and Costa, 1981]), adding these independent measures of visuoconstuctive and visuoperceptual abilities to a neuropsychological test battery might aid in the delineation of separate types of NLD, with potentially different developmental manifestations in neurological disease (Rourke, 1987, 1988).

NOTES

1 Kimura (1961, 1983; Kimura & D'Amico, 1989) assumes that on a dichotic listening test with verbal stimuli, speech is represented predominantly in the hemisphere opposite the ear with the higher score. Based on her own research, Kimura (1983) reports that the right hemisphere is at least partly responsible for the production of speech in 30% of her sample of 48 left- and mixed-handed subjects. Her statement that the dichotic listening task "can give an accurate picture of speech representation for a group," however, is at odds with other evidence (e.g., Zaidel, 1983; Chiarello, 1988) that speech and other receptive language functions are not always lateralized to the same hemisphere. Nor does a review of the literature on dichotic listening studies (Hiscock, 1988) support her assertion that speech can be accurately localized to a specific hemisphere on the basis of a strictly receptive language task. It can be assumed that although a majority of neurologically normal individuals may have both speech and (most) receptive language functions co-lateralized to one hemisphere or the other, approximately 25% to 30% of dextrals will

not show an REA on dichotic listening, leading to a high error rate if these right-handers were to be labeled as right hemisphere speech-dominant on the basis of this test alone.

2 Peterson and Lansky's (1974) figure of 16.3%, however, is only about 3% above recent estimates for the prevalance of left-handedness in general college populations. For example, Spiegler and Yeni-Komshian (1984) found that the incidence of sinistrality ranged from 13.8% for males and females together, to 15% for males alone.

3 Virtually every study mentioned in this section divided handedness phenotypes on the basis of questionnaire data. Bishop (1983) reviewed the literature on the use of this method to assess hand-use patterns and found that a "left-hander" identified in one study, with a specific set of questionnaire items, might be classified as a mixed- or even right-hander in another. For example, for the item, "which hand do you use to hold an umbrella," Wile (1934; cited in Bishop, 1983) found that 80% of people reported right hand use if the umbrella was open, but only 30% did so when the umbrella was closed.

4 The question arises whether the order of presentation of the questionnaires and dependent measures will lead to undesirable subject response biases. Some reassurance on this point has been provided by van Eys and McKeever (1988). Two groups of subjects were tested: Subjects who were recruited on the basis of handedness and then given an FS questionnaire prior to presentation of a dichotic listening test, and a comparable group with the reverse order of test administration (and who were not recruited on the basis of handedness). The groups differed only minimally on the dichotic listening test. For the current study, it seemed, then, that there would not be any problem in presenting the personal data survey and hand preference questionnaires towards the beginning of data collection for the current study.

APPENDIX A

QUESTIONNAIRES, TESTS, AND ANSWER SHEETS

Table of Contents

Subject No.:__________

PERSONAL DATA SURVEY

1. To the best of your recollection, did anyone try to "switch" your writing hand when you were learning to write?

   ______ No _____ Yes: If yes, why? __________________

2. What is your age? ______________

3. What is your sex? ______ Female ______ Male

4. What is your academic major? _____________________ If you have not yet decided on an academic major, what field of study are you interested in? _________________

5. Were you part of a multiple birth and, if so, what type?

   ______ No _____ Twin, fraternal _____ Twin, identical

6. Were you your mother's first child? _____ No _____ Yes

7. If you have any brothers or sisters, please list their sex (F for female and M for male) and writing hand (L for left hand, R for right hand, and U for unknown).

	Sex	Writing Hand		Sex	Writing Hand
#1	___	_____	#5	___	_____
#2	___	_____	#6	___	_____
#3	___	_____	#7	___	_____
#4	___	_____	#8	___	_____

8. When you read a map, do you turn the map into the correct orientation, or do you perform that rotation in your head?

   ___________ turn map to correct orientation
   ___________ rotate map "in my head"

9. When you back up your car, do you look into the rear view mirror, or through the rear window?

   ___________ look through rear view <u>mirror</u>
   ___________ look through rear view <u>window</u>

10. Rate your sense of direction:

/----------/----------/----------/----------/
POOR FAIR AVERAGE GOOD EXCELLENT

11. What is the handedness of your:

Mother: ____ left ____ right ____ both _____ unknown

Are you sure? _______ yes _______ no

Maternal grandmother:
____ left ____ right ____ both _____ unknown

Are you sure? _______ yes _______ no

Maternal grandfather:
____ left ____ right ____ both _____ unknown

Are you sure? _______ yes _______ no

Father: __ left ____ right ____ both _____ unknown

Are you sure? _______ yes _______ no

Paternal grandmother:
____ left ____ right ____ both _____ unknown

Are you sure? _______ yes _______ no

Paternal grandfather:
____ left ____ right ____ both _____ unknown

Are you sure? _______ yes _______ no

Subject No.:__________

HAND PREFERENCE

Please check the category that most accurately describes your hand preference for each of the following 13 tasks. Hand use may differ from item to item, so carefully consider your answer to each question separately.

Indicate hand preference for:	Always left	Usually left	Both hands equally	Usually right	Always right	Don't know
1. Writing a letter legibly:	____	____	____	____	____	____
2. Drawing a picture:	____	____	____	____	____	____
3. Throwing a ball to hit a target:	____	____	____	____	____	____
4. Holding a racquet in tennis or badminton:	____	____	____	____	____	____
5. Hammering a nail into wood:	____	____	____	____	____	____
6. Holding your toothbrush while cleaning teeth:	____	____	____	____	____	____
7. Cutting with scissors:	____	____	____	____	____	____
8. Holding a match while striking it:	____	____	____	____	____	____
9. Guiding thread thru the eye of a needle:	____	____	____	____	____	____

Continued on next page....

Indicate hand preference for:	Always left	Usually left	Both hands equally	Usually right	Always right	Don't know
10. Unscrewing the lid of a jar:	____	____	____	____	____	____
11. Dealing playing cards:	____	____	____	____	____	____

If you responded <u>always left</u> or <u>always right</u> for <u>all 11</u> of these tasks, please answer the following questions:

Left Handers:

Are there any one-handed tasks for which you use the <u>right</u> hand? If so, please record them here:

____

____

____

Right Handers:

Are there any one-handed tasks for which you use the <u>left</u> hand? If so, please record them here:

____

____

____

Which writing position most closely resembles your own?

HAND PERFORMANCE TEST

1. Use the hand that you write with

```
Start
 here ->  o o o o o o o o
                        o
                        o
                        o
                        o
                        o
                        o
          o o o o o o o o
          o
          o
          o
          o
          o
          o
          o o o o o o o o
                        o
                        o
                        o
                        o
                        o
                        o
          o o o o o o o o
          o
          o
          o
          o
          o
          o
          o o o o o o o o
                        o
                        o
                        o
                        o
                        o
                        o
          o o o o o o o o
          o
          o
          o
          o
          o
          o
          o o o o o o o o
```

Which hand did you use?
(circle one)

L R

2. Use your other hand

```
Start
 here ->  o o o o o o o o
                        o
                        o
                        o
                        o
                        o
                        o
          o o o o o o o o
          o
          o
          o
          o
          o
          o
          o o o o o o o o
                        o
                        o
                        o
                        o
                        o
                        o
          o o o o o o o o
          o
          o
          o
          o
          o
          o
          o o o o o o o o
                        o
                        o
                        o
                        o
                        o
                        o
          o o o o o o o o
          o
          o
          o
          o
          o
          o
          o o o o o o o o
```

Which hand did you use?
(circle one)

L R

Examples of Happy, Sad, and Composite Chimeric Face Stimuli

Subject #:________

ANSWER SHEET FOR FACES PACKET

FOR EACH OF THE 16 PAIRS OF FACES IN THE PACKET, WHICH FACE IN EACH PAIR IS HAPPIER? PLEASE CIRCLE THE LETTER CORRESPONDING TO THE FACE IN EACH PAIR THAT YOU CHOOSE TO BE THE HAPPIER FACE.

Pair 1:	A	B	Pair 10:	A	B
Pair 2:	A	B	Pair 11:	A	B
Pair 3:	A	B	Pair 12:	A	B
Pair 4:	A	B	Pair 13:	A	B
Pair 5:	A	B	Pair 14:	A	B
Pair 6:	A	B	Pair 15:	A	B
Pair 7:	A	B	Pair 16:	A	B
Pair 8:	A	B			
Pair 9:	A	B			

VOCABULARY TEST

Please provide brief and accurate definitions for the 32 vocabulary words listed below. You will have 10 minutes to complete this test.

1. WINTER: ______________________________

____

2. BREAKFAST: ______________________________

____

3. REPAIR: ______________________________

____

4. FABRIC: ______________________________

____

5. ASSEMBLE: ______________________________

____

6. ENORMOUS: ______________________________

____

7. CONCEAL: ______________________________

____

8. SENTENCE: ______________________________

____

9. CONSUME: ______________________________

____

10. REGULATE: ______________________________

____

11. TERMINATE: ______________________________

____

12. COMMENCE: ______________________________

____

13. DOMESTIC: ______________________________

____

14. TRANQUIL: ______________________________

____

15. PONDER: ______________________________

____

16. DESIGNATE: ______________________________

____

17. RELUCTANT: ______________________________

____

18. OBSTRUCT: ______________________________

____

19. SANCTUARY: ______________________________

____

20. COMPASSION: ______________________________

____

21. EVASIVE: ______________________________

____

22. REMORSE: ______________________________

____

23. PERIMETER: ______________________________

____

24. GENERATE: ______________________________

____

25. MATCHLESS: ______________________________

____

26. FORTITUDE: ______________________________

____

27. TANGIBLE: ______________________________

____

28. PLAGIARIZE: ______________________________

____

29. OMINOUS: ______________________________

____

30. ENCUMBER: ______________________________

____

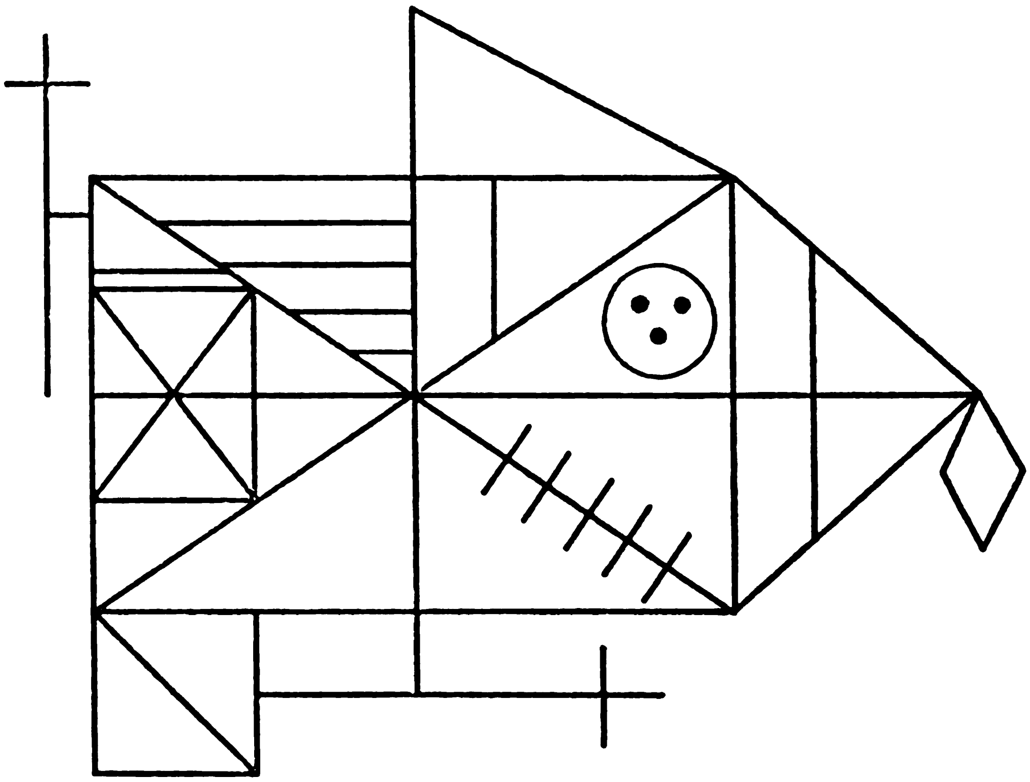
31. AUDACIOUS: ______________________________

____

32. TIRADE: ______________________________

____

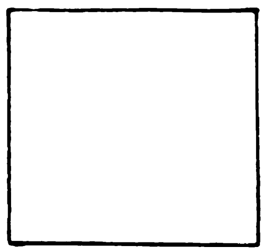
THE REY-OSTERRIETH COMPLEX FIGURE



Subject #: __________

THREE-DIMENSIONAL DRAWING TEST

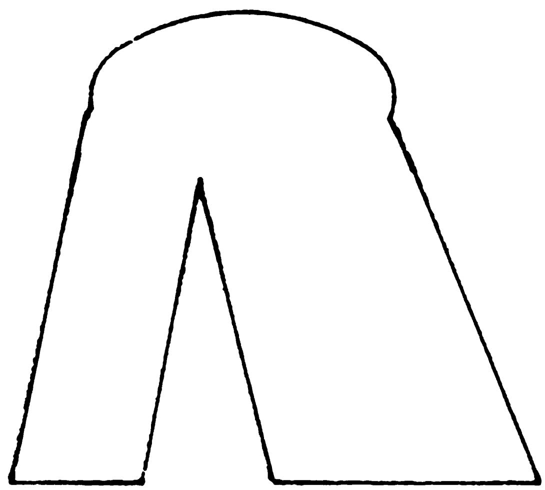
This is a line drawing of a SQUARE:

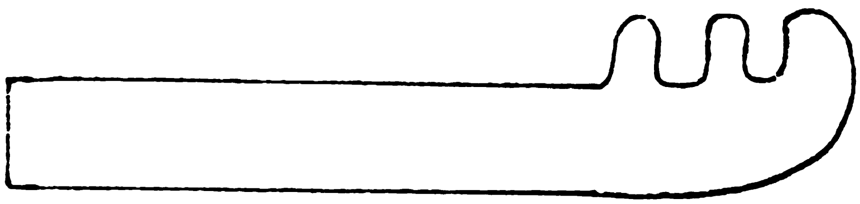


By adding extra lines to the drawing, the square can appear to be represented in THREE DIMENSIONS. Please draw a "three-dimensional" drawing of a square below.

On the following 6 pages you will be provided with a different line drawing on each page. Try to add whatever lines that are necessary in order to make it look like a three-dimensional object. You will be given 30 SECONDS to finish your drawing, and you will be told when to start.

PLEASE WAIT FOR THE EXPERIMENTER TO TELL YOU TO START.



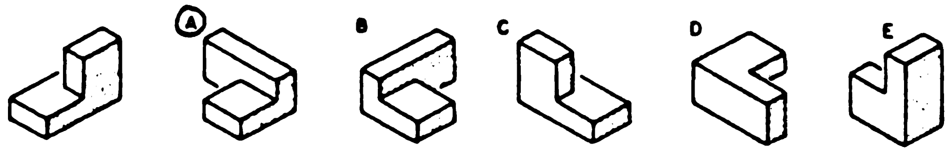


PLEASE DO NOT WRITE IN THIS BOOKLET

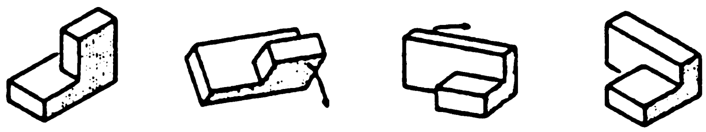
IDENTICAL BLOCKS
FORM AA

№ 0842

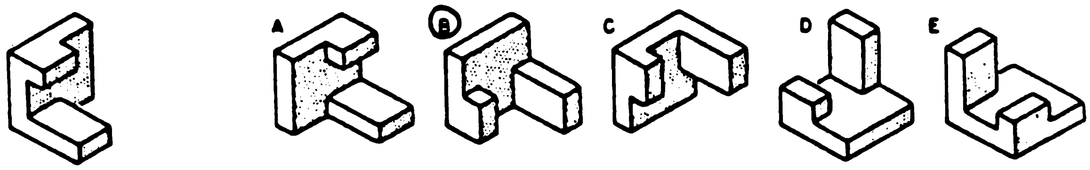
This test is made up of pictures of blocks turned different ways. The block at the left is the reference block and the five blocks to the right are the answer blocks. One of these five blocks is the same as the reference block except that it has been turned and is seen from a different point of view. The other four blocks could not be obtained by turning the reference block. For Example:

I. 

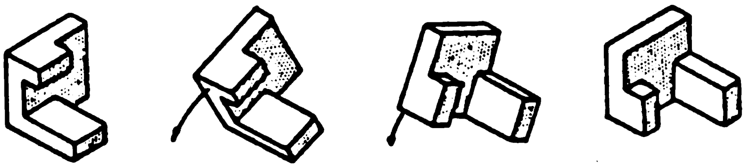
Block "A" has the same shape as the reference block, but it has been turned as shown in the figure below.



Here is another example.

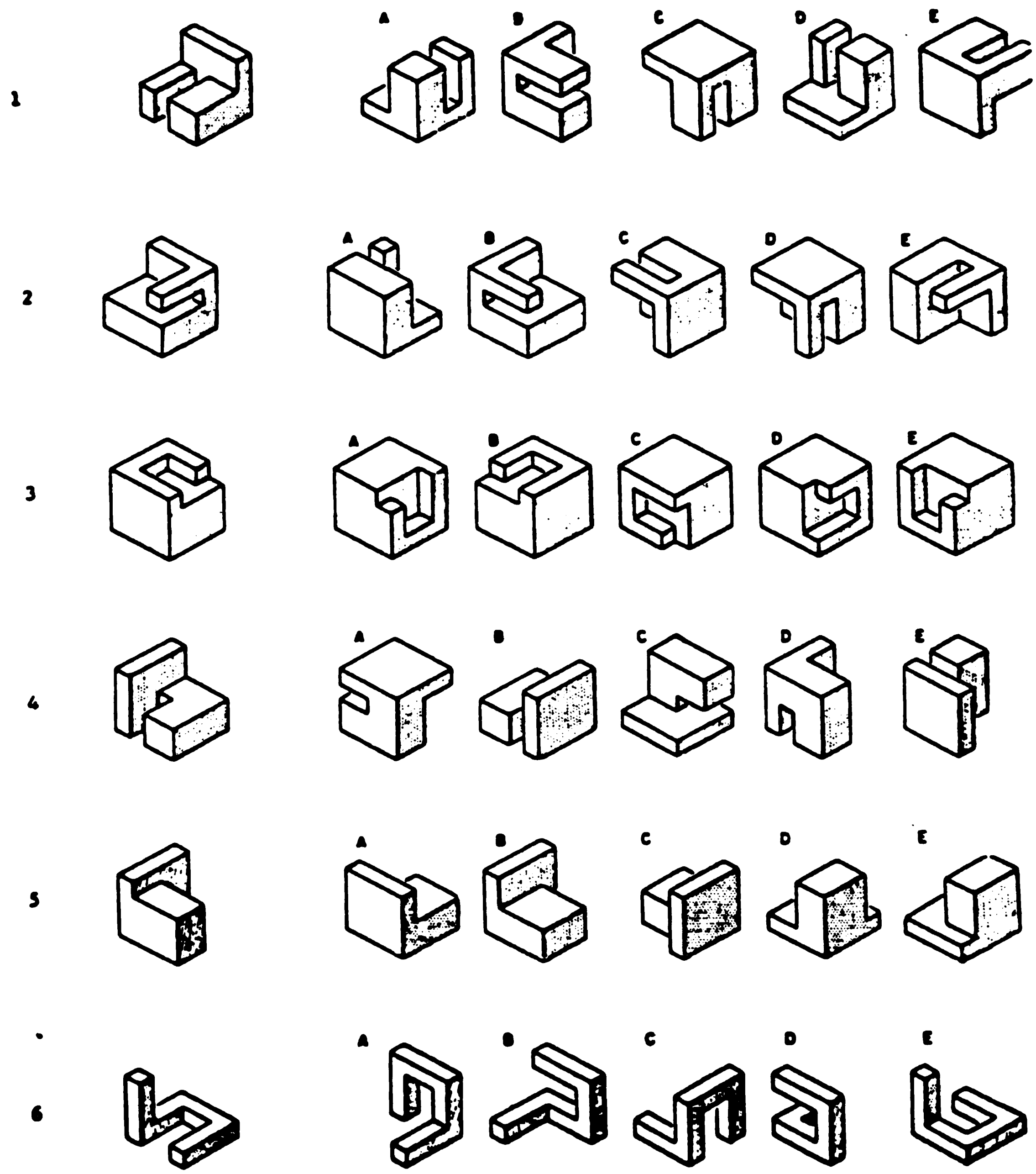
II. 

The illustration below shows that "B" is the correct answer.



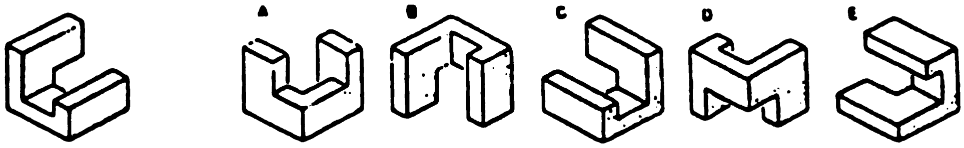
For each of the 30 items in the test, you are to find which block is the same as the reference block and blacken the corresponding letter on your answer sheet. If you should get stuck on any item, skip it and come back to it later. This is a <u>timed</u> test. You must wait until you are given the signal to begin.

PLEASE DO <u>NOT</u> TURN THIS PAGE UNTIL TOLD TO START



1
A
B
C
D
E
2
3
4
5
6

7



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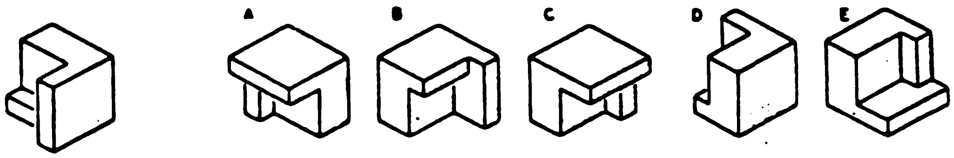

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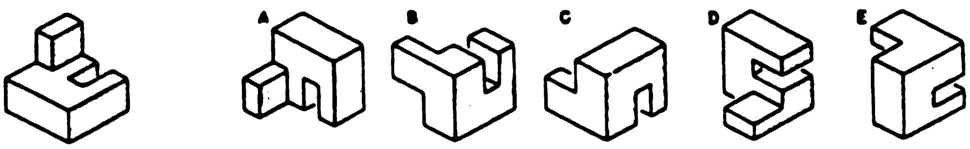

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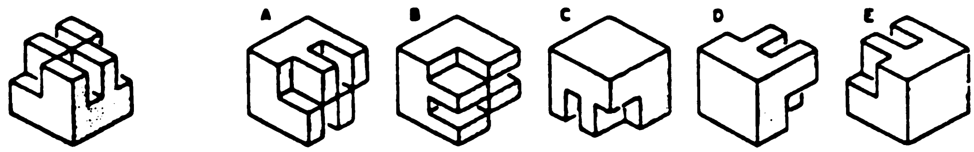

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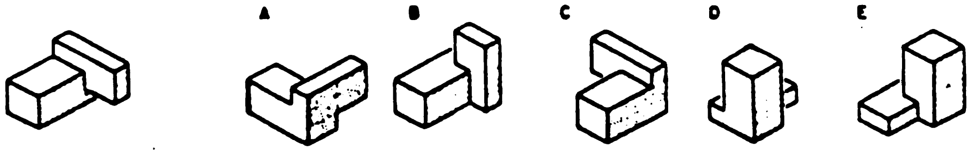

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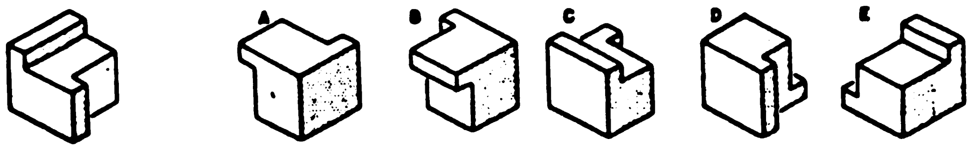

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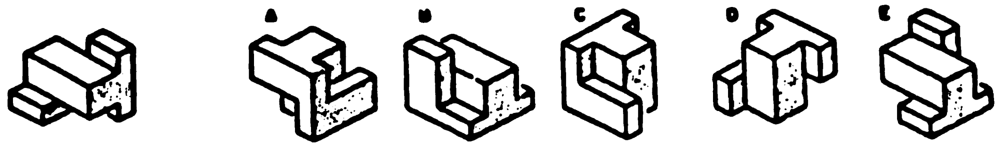

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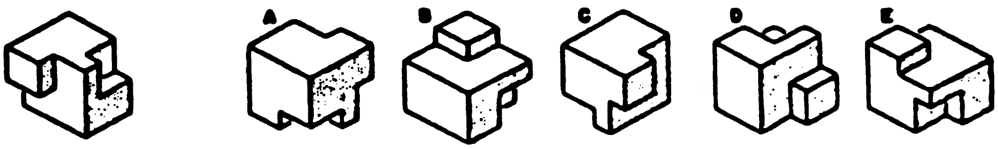

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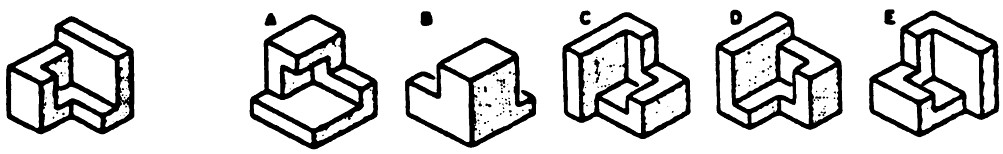

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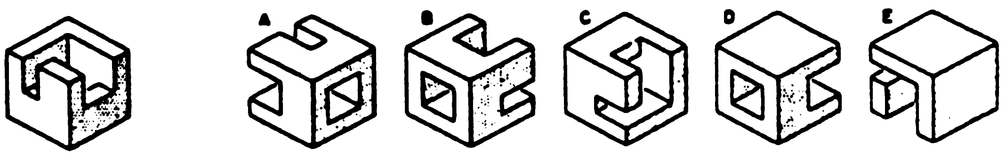

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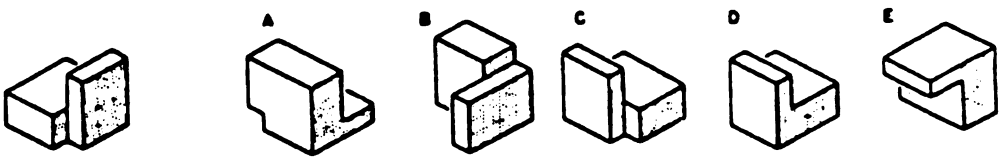

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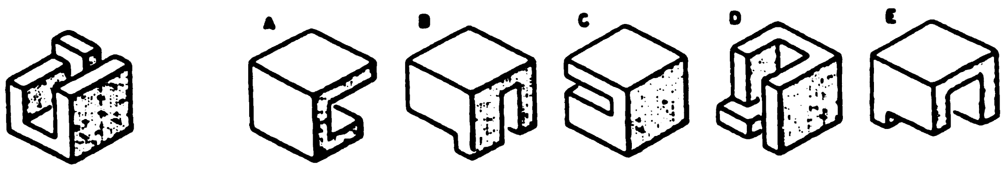

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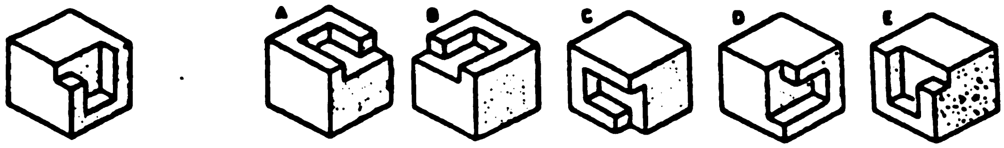

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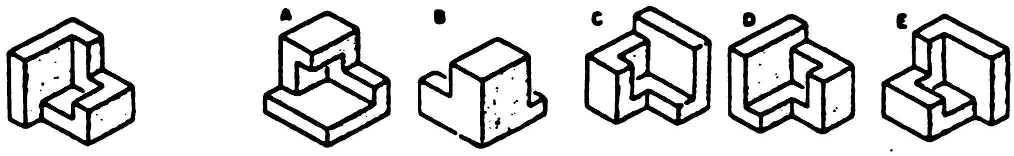

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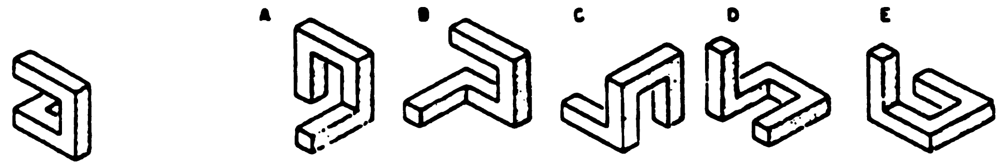

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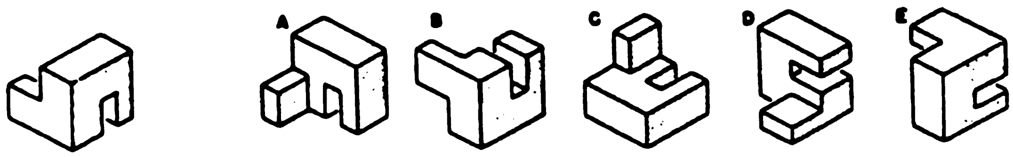

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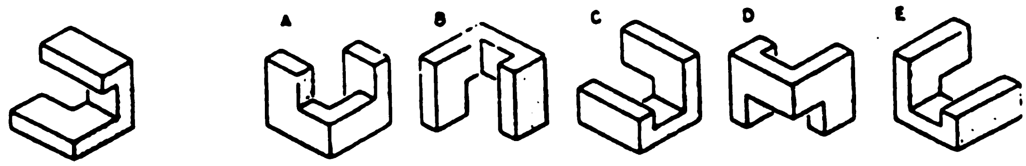

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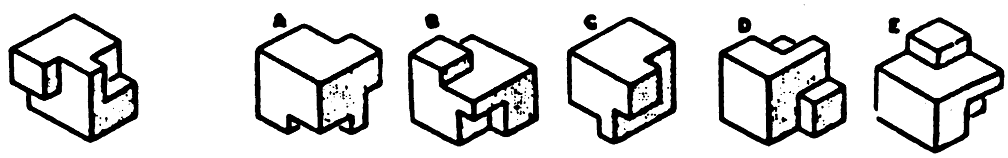

ANSWER SHEET FOR IDENTICAL BLOCKS TEST

Directions: For each of the 30 items in the test, please find which block is the same as the reference block and circle the corresponding letter on this answer sheet.

1)	A	B	C	D	E
2)	A	B	C	D	E
3)	A	B	C	D	E
4)	A	B	C	D	E
5)	A	B	C	D	E
6)	A	B	C	D	E
7)	A	B	C	D	E
8)	A	B	C	D	E
9)	A	B	C	D	E
10)	A	B	C	D	E
11)	A	B	C	D	E
12)	A	B	C	D	E
13)	A	B	C	D	E
14)	A	B	C	D	E
15)	A	B	C	D	E
16)	A	B	C	D	E
17)	A	B	C	D	E
18)	A	B	C	D	E
19)	A	B	C	D	E
20)	A	B	C	D	E
21)	A	B	C	D	E
22)	A	B	C	D	E
23)	A	B	C	D	E
24)	A	B	C	D	E
25)	A	B	C	D	E

Continued on next page...

ANSWER SHEET FOR IDENTICAL BLOCKS TEST (continued)

26)	A	B	C	D	E
27)	A	B	C	D	E
28)	A	B	C	D	E
29)	A	B	C	D	E
30)	A	B	C	D	E

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Be

Be

Bi

B

B

B

B

B

B

B

B

B

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