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Richard A. Feinberg

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THE RELATIONSHIP OF SUBJECT SEX AND HANDEDNESS TO HAND DIFFERENCES IN PERFORMANCE ON A BRAILLE PAIRED-ASSOCIATE LEARNING TASK

By

Richard A. Feinberg

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In Memory of Bill Kell

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INTRODUCTION

Hemispheric Specialization in Haptic Perception--Left Hand Superiority for Spatial Discrimination

There is a growing body of evidence of hemispheric specialization for tactile perception (see summary in Harris, 1975). In light of what is known of the respective hemispheres, the left hemisphere is specialized for verbal abilities, the right hemisphere is specialized for visual-spatial abilities, and the anatomical connections between hand and hemisphere are primarily contralateral. Thus, one might expect that the left hand, the non-dominant hand for most people, will perform better than the right hand on tactual-spatial discrimination tasks. This does not agree with our common-sense understanding of hand differences, wherein the right hand is assumed superior on all tasks, but it is supported by the available research.

Levy-Agresti and Sperry (1968) gave a task designed to measure ability to think three-dimensionally to adult patients whose forebrain commissures had been surgically divided. The subjects had to visually match three-dimensional forms held either in their left or right hand to the same forms drawn as expanded patterns on cards. Left hand performance was superior.

Milner and Taylor (1972) also found superior left hand performance with cerebral commissurotomy subjects, In a test of matching tactile patterns, for six of seven subjects, left hand performance was unequivocally superior to the right.

A study by Ingram (1975) also suggests left hand superiority in haptic spatial discrimination. She gave 103 normal, right-handed boys and girls a variety of simple tasks. As expected the right hand was superior to the left hand in a test of the rate of tapping a telegraph key with the index finger. However, in tests of hand positioning and finger spacing that required the fingers to be arranged in spatial configuration with reference to each other, the left hand performed better than the right hand.

Witelson (1974) used a different procedure for assessing hemispheric differences in haptic perception with children. She presented both non-linguistic stimuli (unfamiliar meaningless 4- to 8-sided shapes) and linguistic stimuli (cut-outs of English letters) to 47 right-handed boys, ages 6 to 14. On any trial the child felt either two linguistic or two non-linguistic forms and had to identify the forms by pointing to a visual display. The non-linguistic material was recognized more accurately by the left hand across all ages. Thus, by at least 6 years of age, in right-handed boys, the right hemisphere seems to be specialized in processing non-linguistic spatial information in the tactile modality. She also found a non-significant trend towards left hand superiority in the recognition of the linguistic forms. This suggests a possible left hand superiority in haptic perception that is enhanced by the use of non-verbal stimuli.

Witelson (1976) extended her study by investigating 200 right-handed boys and girls, ages 6 to 13. In this experiment she presented only non-linguistic tactual stimuli to the subjects. The results confirmed her previous findings as the boys showed superior performance with the left hand across all ages. The results for the girls will be discussed later.

In a study using Witelson's dichhaptic presentation procedure, Gardner _et al_. (1977) found greater accuracy for non-linguistic shapes felt with the left hand with 60 left- and right-handed adult men and women.

Hand Differences: A Function of Style of Haptic Exploration?

The tactile differences found may be the result of differences in style of haptic exploration, rather than in basic differences in performance between the hands. For example, left hand exploration might be more active and far-ranging, while striving to gain an overall and complete picture of the object being explored, while right hand exploration could be more discrete and piecemeal (Harris, 1975). These modes of exploration would be consistent with the overall cognitive style that Levy-Agresti and Sperry (1968) propose as characteristic of each hemisphere. That is, the right hand (left hemisphere) analyzes information sequentially, in a linear fashion, abstracting the relevant details to which linguistic labels can be attached. The left hand (right hemisphere) operates by perceiving the overall stimulus configuration and processes information in terms of wholes.

Studies using an electro-mechanical stimulator (Carmon and Dyson, 1967) to passively stimulate subjects do suggest that there is a basic difference in performance between the hands. The stimulator is composed of three metal rods arranged in a linear array that can be applied to a subject's palm. A grid is stamped on each subject's hand to insure uniform application. With the apparatus, force, area and direction of stimulation, and duration of application can be controlled. Two studies using this technique (Carmon and Benton, 1969; Fontenot and Benton, 1971) demonstrated that a significant proportion of right-handed adults with right hemisphere disease showed bilateral and equal impairment in identifying the direction of tactile stimulation, while those subjects with left hemisphere disease showed only unilateral contralateral impairment. This result suggests that the right hemisphere plays the dominant role in mediating aspects of spatial perception.

In another study following the same procedure (Benton, Levin, and Varney, 1973), 24 normal right-handed adults were required to match direction of stimulation with a visual display that contained four different directions of stimulation. Again, the left hand was superior, strengthening the hypothesis that the right hemisphere is prominent in mediating spatial aspects of perception.

In an extension of the electro-mechanical stimulation studies, Nachshon and Carmon (1975) tested 80 right-handed adults in four experiments. One set of experiments compared the abilities of the two hands to perform sequential tasks, while another set compared the spatial abilities of the two hands. The results indicated that the subjects performed better with their right hand on the sequential task, but were superior with the left hand on the reproduction of a spatial pattern.

Braille Studies

In their review of Braille research, Nolan and Kederis (1969) conclude that the basic perceptual unit in Braille perception is the individual Braille character. The ease of recognition of Braille characters is affected by various factors including number of dots, configuration of dots, and amount of open space within the character. They also indicate that while most Braille teachers encourage students to use both hands while reading Braille, there has been little systematic study of differences between the hands.

Perhaps the first suggestions of left hand superiority for Braille discrimination came from discussions and experiments reported by Smith (1929) about whether the left or right hand was better for reading Braille, or whether two hands were better than either alone. In an attempt to resolve this issue Graseman (cited in Smith, 1929; no reference given) had blind students read a Braille text with both hands, then with each hand separately. Almost half of the subjects relied more on the left hand while the rest of the subjects split their performance between the right hand and both hands. Based on the results, Graseman (Smith, 1929) concluded that the left index finger is the preferred and proper reading finger of the blind.

White (1969) has reviewed a number of studies which have investigated central processing of tachistoscopically presented visual material. These studies suggest the possibility of the superiority of the left hemisphere in the recognition of linguistic material as a result of acquired, directional reading habits.

In an early report that investigated this possibility, Smith (1929) conducted a study with a sighted woman (of unspecified handedness) that repeated the Braille reading tests used by Graseman. Passages were read by both hands simultaneously followed by the left, then the right hand alone. A right-to-left reading direction was added to the standard left-to-right direction. The results with this one subject indicated a left hand superiority in both reading directions, although there was some indication that the superiority was enhanced by the left-to-right reading direction.

Recent experiments by Hermelin and O'Connor (1971a, 1971b) support these early results. In one experiment (Experiment 1, 1971a; 1971b), 14 right-handed and 2 ambidextrous children, all blind from birth, were required to read Braille passages equated for level of difficulty. Handedness was defined by performing seven ordinary actions. Twelve children read with the index finger of each hand held close together, while the other four children used mainly the index finger of the left hand. However, during the experiment, the children were required to read sentences with both the middle and index fingers of both hands. The results showed that for both hands the scores obtained from the index fingers were superior to the scores of the middle fingers. The left-hand scores were higher than the right-hand scores for the middle finger, but not the index finger. Also, the left index, but not middle, finger was significantly faster than the right index finger.

In a second experiment (1971a), 15 blind adults, 25 to 65 years of age, were tested. Nine subjects had been blind from birth while the other six had lost their sight later in life. The subjects were required to read various orderings of 26 individual Braille letters of the alphabet arranged in vertical columns and to be read from top to bottom with only the middle finger. This procedure was designed to diminish the influence of left-to-right reading direction. Again, left-hand scores were significantly better, although there was no difference in reading speed.

In both experiments, Hermelin and O'Connor compared the results for the index and middle finger. Since the subjects all had previous practice with their index finger, while none apparently had ever used the middle finger of either hand, it was expected that the scores were significantly higher for the index finger when tested against the middle finger, regardless of hand used. But when the unpracticed middle finger was used, the difference favoring the left hand increased. This suggests that hand asymmetries are attenuated by practice, and conversely, that maximal differences are obtained when novel experimental situations are used.

Taken together, these Braille studies strongly indicate that the discrimination of Braille characters is better performed with the left hand. At first glance this finding is surprising, since we know that the left hemisphere is specialized for linguistic processing (Kimura, 1961), one might expect that Braille letters, being symbols of the alphabet, would be better discriminated by the right hand (left hemisphere). But the Braille design may be critical. Hermelin and O'Connor pointed out that Braille characters are composed of a varying number of dots arranged in different configurations, and similar dot patterns presented visually in a tachistoscope are perceived more accurately by the right hemisphere (Kimura, 1969). Hermelin and O'Connor thus hypothesized that Braille dots first must be encoded in the brain as spatial configurations and that the linguistic labels are then added or incorporated to produce the entire Braille letter and its name. It should be noted that they are unspecific about this process. It is unclear whether they mean that the dot configurations are encoded sometime during the course of the learning trials or at any given instant, i.e., while an individual letter is being felt.

Sighted vs. Blind Subjects

One problem with the Hermelin and O'Connor experiments is that of prior experience. All the subjects were blind and had previous training with Braille reading. A right-handed person will write with his right hand but will feel the letters to be copied with his left hand. To control for this early practice effect, Rudel, Denckla, and Spalten (1974) carried out an experiment with 80 sighted children, ages 7 to 14. All subjects were right-handed and had to learn six Braille letters with one hand and six different letters with the other hand. Using a paired-associate procedure, 40 children were trained first with the left hand, then the right hand; the sequence was reversed for the remaining children. Generally, the left hand performed better. However, this difference was significant only among the oldest children. In fact for the youngest children, the right hand was superior. It is possible that with sighted children required to learn verbal labels to spatial configurations, language is involved in the task to a greater degree than with blind subjects who are being tested on a familiar task. It is further possible that in the youngest sighted children the right hand superiority would have been reversed to a left hand superiority after the verbal associations had been well learned. Rudel _et_ _al_. suggest that suggest that any explanation of the left hand Braille superiority that invokes the activity of either hemisphere alone is inadequate. They further suggest that reading by touch only becomes a right hemisphere function only after receiving some sort of "instruction" from the left hemisphere through verbalization.

To further study the relationship between Braille learning and hemispheric asymmetry, Rudel, Denckla, and Hirsch (1977) tested 120 right-handed subjects, 60 boys and 60 girls, ages 7 to 14 as in the previous study, with the addition of an adult group (ages 20 to 40). The purpose of the experiment was to isolate the tactile modality by having the subjects discriminate pairs of Braille letters, without the associated letter names. Subjects were required to compare the two letters in a pair, with the same hand, and to determine whether they were the same or different.

The results revealed no differences between the left and right hands for both the same and different pairs but paralleled the results of the previous study. Overall, the left hand was superior, although the only significant difference again was for the oldest children. Rudel _et al_. concluded that the language requirement in the previous experiment was of minor importance to the results and was far outweighed by the difficulty of the discriminations, just as having names attached to faces does not shift superior recognition from the right to left hemisphere. They also concluded that right hemisphere specialization for spatial functions begins at an early age and may even be innate. They further state that this asymmetry manifests itself at different ages in the course of development depending on the task, difficulty of the discrimination, and prior familiarity with the stimuli.

Left-handers

All the Braille studies reported have used only right-handed subjects to maximize the chances of obtaining the predicted results. But excluding left-handers amounts to excluding the only known variations from the established pattern of lateral hemispheric specialization, when the experimenters have no other assurance that hemispheric specialization is being tested at all. All research on hemispheric specialization depends on the assumption that for right-handers, the speech centers of control are in the left hemisphere. Branch, Milner, and Rasmussen (1964), using the

Wada (1960) technique of anesthetization of each hemisphere separately, found that 90% of the right-handers did have their major speech centers in the left hemisphere. But of the left-handers, 64% had their major speech centers controlled in the right hemisphere, 20% in their left hemisphere, and 16% showed bilateral control. These results supported earlier formulations (Hécaen and Sauget, 1971) that left-handers are less lateralized than right-handers, that is, the separation of function in the hemispheres is not so complete as in right-handers.

A number of studies of hemispheric difference have used handedness as a variable. Kimura (1961) tested left-handers whose speech centers, as determined by the Wada technique, were controlled in the right hemisphere with a dichotic listening procedure. The dichotic technique, devised by Broadbent (1954), uses two simultaneous channels for presenting stimuli. Typically, a spoken digit or letter is delivered to one ear while a different digit or letter is delivered to the other ear. Several pairs of stimuli are delivered during a trial, and the subject is then asked to repeat all the numbers or letters he has heard. Under these circumstances, there typically is a right ear (left hemisphere) advantage (REA) for letters and numbers (Kimura, 1961; Milner, 1962; Kimura, 1967). Subjects remember more sounds delivered to the right ear than to the left ear. In left-handed subjects, Kimura (1961) found the effect is reversed. The left ear (right hemisphere) was superior in recognition of letters and digits, a result contradictory to the notion of weaker lateralization for left-handers.

A few visual-field studies have used handedness as a variable. The usual procedure is to project a target, often numbers or letters, tachistoscopically to either the left or right visual field (LVF, RVF) of either eye. Since for each eye, the visual connections are between the left visual field and the occipital lobe of the right hemisphere, the roles of the cerebral hemispheres can be assessed independently. Results of these experiments typically indicate that for right-handers, letters and digits presented in the right visual field are identified more accurately than those presented in the left visual field (Mishkin and Forgays, 1952; Kimura, 1966; McKeever and Huling, 1971).

Ledlow, Swenson, and Carter (1972) tested a group of ten left-handed men using the tachistoscopic procedure. Consistent with the hypothesis that left-handers are less lateralized than right-handers, no difference was found between left visual field and right visual field scores for the recognition of single letters.

Handedness and Spatial Ability

The hypothesis of weaker lateralization of function for left-handers has led to the suggestion that left-handers are relatively weaker in non-verbal, visual-spatial skills (Levy, 1969; Miller, 1971). In fact there have been some studies reporting that left-handers have poorer spatial ability than right-handers. Levy (1969) tested a group of 10 left-handed and 15 right-handed men using the Wechsler Adult Intelligence Scale (WAIS). The WAIS is subdivided into two major factor-scales: Verbal and Performance. The Performance subtests are assumed to reflect spatial ability. A comparison of the scores for the two groups of the two factors revealed no difference between left- and right-handers on the Verbal factor, but there was a significant difference on the Performance factor that favored the right-handers. Levy's subjects, however, were graduate science students at the California Institute of Technology, and in the extreme upper end of the I.Q. range. Therefore, her results may not be generalized.

Newcombe and Radcliffe (1973) tested 823 left- and right-handed men and women in their survey of nine Oxfordshire, London villages. The test used was a shorthand version of the WAIS. Handedness was assessed by a 7-item questionnaire. The 26 "pure" left-handers, 139 "mixed-handers," and 658 right-handers displayed no significant difference either in Performance level or in the pattern of scores on the subtests comprising either of the two factors, Verbal and Performance.

Whereas the previous studies did not necessarily involve mental transformation, there have been other studies suggesting handedness differences in spatial tests that required more explicit use of mental transformation or rotation of the stimuli. Miller (1971) compared the performance of 29 right-handed and 23 "mixed-handed" left-handed undergraduates on a test of verbal intelligence and another test requiring visual manipulation of two- and three-dimensional shapes. The right-handers significantly outperformed the left-handers on the spatial test, but there was no difference on the verbal test.

In another study using several measures of hemispheric asymmetry, McGlone and Davidson (1973) tested 80 left- and 49 right-handed high school students on spatial abilities tests that required the subjects to mentally rotate two-dimensional figures in order to match identical stimuli drawn in different orientations. The experimenters also administered a dichotic words test and a tachistoscopic dot enumeration test. They found that some left-handers performed poorer than right-handers on spatial tests, those who showed higher left ear scores in the dichotic words test. Thus, spatial performance was poorest in left-handers whose brain functions were "reversed," where the left hemisphere subserves non-verbal functions and the right hemisphere verbal functions. The authors suggest that the left hemisphere is simply not so efficient as the right hemisphere in processing non-verbal information, regardless of handedness.

Nebes (1971) went one step further by directly assessing "gestalt" processing, hypothetically subserved by the right hemisphere. He tested 26 left- and right-handed college men and women on a haptic-visual matching task. The subjects were required to infer a total stimulus configuration from incomplete information by blindly exploring an arc taken from one of three sizes of complete circles lying before him with his index finger. The right-handers performed significantly better than the left-handers on the experimental task of part-whole matching but not on the control tasks in which parts were matched to parts or whole circles to whole circles.

Hardyck and Petrinovich (1977), in their review of left-handedness, cite four replications of the Nebes study that found no differences between left- and right-handed subjects on the part-whole matching task. They conclude that the assumption of cognitive and performance deficits in the left-handed is an artifact of observations on clinic populations. They further emphasize that the validity of the classification of handedness, particularly for left-handers, is open to serious question, and that there is a high possibility of misclassifying left-handers as right-handers.

Hardyck, Petrinovich, and Goldman (1976) conducted their own investigation of handedness differences. They studied 7688 school children, grades 1 through 6, of whom 740 were left-handed. The children were tested on a variety of tests, including a figure copying task, attention tasks, and the

Lorge-Thorndike intelligence test. The results disclosed no differences between left- and right-handers on any of the measures studied. Also, eyedness and socio-economic level were not related to the differences between left- and right-handers. The particularly relevant findings were of no differences on the figure copying test and on the non-verbal parts of the intelligence test.

Based on their findings and literature review, Hardyck and Petrinovich (1977) conclude that there is a systematic relationship between handedness and cerebral dominance, although it is not exact. They also conclude that assessment of family history of handedness increases the precision of the lateralization relationships. They further propose a continuum of handedness which at one end includes right-handers with no familial left-handedness, who are strongly lateralized for verbal and spatial functions, in the left and right hemispheres respectively. At the other end of the continuum are those left-handers with a family history of left-handedness whose functions are least lateralized, i.e., there is more likely to be bilateral representation of verbal and spatial abilities. Between these two extremes are right-handers with familial left-handedness who are presumed to show greater bilateral representation of function than right-handers without familial left-handedness but less bilateral representation than the familial left-handers. The final group is those left-handers with no family history of left-handedness which the authors propose to classify with the right-handers. Their review of the research indicates that localization of function for this group is nearly identical to that of the right-handers.

Hardyck's conclusions serve to emphasize that grouping together all left-handers may conceal important differences. Annett (1970) conducted a thorough analysis of handedness and concluded that the handedness distribution is not discrete, composed of only left- and right-handers and some "mixed"-handers, but is a continuous distribution. Few of the studies using left-handers have taken this finding into account. The present study will apply this rationale to the study of haptic perception.

Sex Differences

Another variable this study will investigate is sex differences in haptic spatial perception. Harris (1976) has viewed a great variety of studies which indicate that males show decidedly superior performance in tests of spatial ability. Harris indicates that a developmental difference in language between boys and girls may be related to the male spatial superiority. He cites evidence that indicates girls progress not only faster than boys in language development but also in verbal fluency and vocabulary, skills subserved by the left cerebral hemisphere, at least for right-handers. This female superiority appears as early as 12 months of age on some tasks and continues through preschool, elementary school, high school, and college.

It is an interesting question whether these sex differences in the development of language skill are reflected by sex differences in the onset of functional lateralization of the cerebral hemispheres. Kimura (1963) tested 120 right-handed children from ages 4 through 9 using the dichotic listening technique where spoken digits were presented simultaneously to both ears. She found a right ear (left hemisphere) superiority for both boys and girls, but there was no indication of an earlier or stronger right ear advantage in girls.

Other studies, however, have reported sex differences in the development of language lateralization. Pizzamiglio and Cecchini (1971) presented dichotic pairs of words to 192 children, ages 5 through 10. They found a stronger lateralization effect (right ear superiority) for girls than boys in the youngest children. Buffery (1971) tested 80 boys and 80 girls, all right-handed, who ranged from age 3 through age 11. The task required the child to draw, simultaneously, with eyes closed, a square with one hand and a circle with the other. The girls of all ages showed a left or non-preferred hand superiority in the drawing of the square. The youngest boys showed a right (preferred) hand superiority but at age 7 and up, they showed a left hand superiority. Among the 3-7 year olds, girls showed a greater degree of right hand preference than did boys.

Buffery suggests that these results are evidence for earlier language lateralization in girls than in boys. The boys drew the square better with their preferred hand for a longer time than the girls even though their left hand is controlled by the right (spatial) hemisphere. The implication is that the boys' cerebral hemispheres remain non-lateralized longer than the girls' hemispheres. The boys' responses will then be more motorically rather than linguistically controlled until laterialization occurs.

Harris (1976) suggests the consequence of boys' slower language development may be a longer period of time during which boys will be primarily encoding information spatially rather than linguistically, perhaps contributing to the overall male superiority for spatial skills. He also suggests another consequence of this sex difference. The females' greater language use and competence in childhood may continue to predispose them in adulthood to use language modes in spatial analysis. Thus, language may compete with spatial modes in the processing of spatial information, and the competition could lead to a performance decrement.

Sherman (1967) says much the same thing in her review of sex differences in spatial perception. She says girls are more likely than boys to satisfy needs by use of social communication mediated by language. Thus girls, already prone to rely on a verbal, socially mediated approach to problems, may not exercise and develop their spatial skills.

Braille is a mixture of verbal and spatial components perhaps providing for different strategies to solve the task. There then may also be sex differences in the approach or solution to learning Braille letters. Rudel _et al_. (1973) found evidence to suggest that females may make use of verbal mediation strategies when learning the names of 12 Braille letters, 6 to each hand. While there were no overall performance differences between boys and girls, they found that 7- and 8-year-old girls did better on a Braille reading test with their right hand, while boys did equally well with both hands. Among 13- and 14-year-olds, however, the boys' left-hand scores were significantly better than their right-hand scores, while there was no statistically significant difference for the girls. From these results, Rudel _et al_. suggested that children required language, either overtly or covertly, to codify the discriminations between the configuration of dots, and that girls did more such linguistic coding than boys. Consequently, boys were better able to make full use of the spatial capacities of their right hemisphere.

It should be mentioned that in their later study, Rudel _et al_. (1977) found the same results when the discriminations did not require the learning of letter names. This suggests that the later emergence of left hand superiority for girls, compared with boys, may reflect delayed onset of right hemisphere mediation of spatial tasks in girls. Although males may display earlier spatial lateralization of function, this does not in itself confer an advantage. Rudel _et al_. found no overall sex differences in either the Braille letter naming or same-different discrimination experiments. The difference favoring the left hand appeared sooner among the males, but also disappeared sooner with some loss of accuracy in the adult male group, at least in the "non-verbal" Braille experiment. The left hand advantage may have disappeared because the discrimination task was too easy.

Witelson (1977) found a left hand superiority in 6-year-old children in her study of dichhaptic presentation of non-verbal tactual stimuli. As in the Rudel _et al_. studies, there were no overall sex differences. The girls also showed no left hand superiority at any age. Witelson argued that for girls there is bilateral hemispheric representation of spatial function and that the same neural structures may have different functions for males and females.

Majeres (1977) suggests that females may have some special skill predisposing them to more efficient verbal encoding of non-verbal material. The experimental task consisted of successive identification of stimuli presented in lists by tapping matching items on response cards. When the identification response was to tap the shapes, no sex differences were found. However, when the response was to tap words or colors, the females were significantly faster in reaction time than the males.

In another study Lake and Bryden (1976) tested 144 right- and left-handed men and women on a dichotic presentation of consonant-vowel syllables to assess the contribution of sex and familial handedness history to cerebral dominance. The results indicated no overall sex or handedness differences for recognition of the dichotic syllables, but there was a significant right ear superiority across subjects that was stronger for males than females. The authors conclude that the stronger laterality among males suggests that there are sex differences in cerebral organization, possibly because men and women employ different strategies on the dichotic listening task. Further analysis revealed that the presence of familial sinistrality increased the likelihood that females would show atypical left ear superiority, while for males the presence of familial sinistrality increased the possibility of right ear superiority.

McGlone and Kertesz (1973) tested adult patients with left and right cerebral hemisphere damage. Spatial impairment was greatest in males with right hemisphere lesions, suggesting that the right hemisphere may be more specialized for spatial processes in men than in women or that women had previously depended more on left hemisphere modes of processing. They also found a significant correlation between verbal scores and spatial scores for females with left hemisphere damage but no such relationship for any of the other patient groups. The implication was that females make more use of verbal mediation strategies than males in at least some non-verbal tasks.

McGlone and Davidson (1973) also looked at sex differences and their relation to hemispheric lateralization. They tested 53 men and 40 women on a tachistoscopic dot enumeration test and a dichotic words test. They found that only females, especially left-handed females, who showed a left ear superiority on a dichotic words test performed less well on the spatial tasks, suggesting that the left hemisphere is not so efficient as the right hemisphere in processing spatial or non-verbal information.

The present study will further explore the relationship between sex, handedness, and cerebral lateralization.

Conjugate Lateral Eye Movements

None of the cited studies of Braille discrimination have directly assessed hemisphere activation, rather hypotheses about cerebral differentiation are generated from hand performance scores. It would be very valuable to have an independent measure to monitor which hemisphere is more activated than the other during the learning of Braille letters.

Kinsbourne (1972) has proposed a hypothesis of hemispheric specialization which assumes that when one cerebral hemisphere is activated more than the other, the eyes and head will move in a direction contralateral to the more activated hemisphere. Kinsbourne (1974) cites evidence from studies of electrical stimulation and hemispheric destruction by disease that shows that each cerebral hemisphere subserves eye gaze and head and body turning toward the opposite side of space. Thus, frontal areas of the brain control turning of the eyes and head, and when the frontal areas of both hemispheres are activated equally, the eyes will focus straight ahead. But when one or the other hemisphere is activated by cognitive functioning, a neural "overflow" is created that causes eye movements contralateral to that hemisphere. Kinsbourne suggests that since each cerebral hemisphere serves the contralateral half of space, orientation to one side of space would coincide with activity within the contralateral hemisphere, and when stimuli enlist either left or right hemisphere processing facilities, attention will bias to the contralateral side.

Kinsbourne (1972) tested this hypothesis on both left- and right-handed subjects. He first asked them spatial, verbal, and numerical questions and then monitored their eye movements. For right-handers, direction of eye movement was related to problem type: subjects moved their eyes to the left in response to spatial questions, to the right in response to verbal questions, and showed no consistent left or right movements in response to the numerical questions. The left-handers showed no left or right preferential eye movements regardless of problem type.

Kinsbourne's results suggest that, at least for right-handers, a subject's conjugate lateral eye movements can be used as a check or monitor to determine which hemisphere is more activated by the subject and thus to determine each subject's mode of information processing. If the predominant strategies during the learning trials are verbal, then right-handed subjects should make right lateral eye movements. If the dot configurations that make up Braille characters are being predominantly processed spatially, then right-handers should make left lateral eye movements.

The Present Study

The present study proposes to investigate, in normal, sighted young adults, the relationship between sex and handedness of subject on performance in a task of haptic perception (Braille learning). The independent variables under consideration are sex and handedness of subjects, while the dependent variables are measures of Braille learning and conjugate lateral eye movements.

While the study is largely exploratory in nature, the following predictions are specified in order to aid conceptualization of the study:

As has been found in previous studies of Braille discriminations, no overall performance differences are predicted in this study between males and females. Also, no overall performance differences are predicted between left- and right-handers.

It is also predicted that right-handers will show a non-preferred hand (left hand) superiority on the Braille discriminations, but familial left-handers, because of weaker cerebral lateralization, will not display a non-preferred hand (right hand) superiority. Non-familial left-handers are hypothesized to perform like right-handers and show a preferred hand (left hand) Braille superiority.

The study will further investigate conjugate lateral eye movements and their relationship to Braille learning for each of the sex X handedness subject groups. For right-handers it is predicted that they will make more left than right eye movements, reflecting greater activation of the right (spatial) hemisphere during the learning trials. Left-handers are predicted not to display any differences in the frequency of left and right eye movements.

METHOD

Materials

Sixteen letters of the alphabet were used, divided into four subsets of four letters each (see Table 1). Subsets 1 and 2 made up set A, and subsets 3 and 4 made up set B (see Table 1). In each subset one letter was composed of 2 dots, two letters were 3 dots, and one letter was 4 dots (see Figure 1). Letters used in each subset were taken from both the beginning and final parts of the alphabet. Further, to minimize auditory confusion, no letters that rhymed or sounded alike were used together in any one subset. Each letter was produced by a Braille typewriter in the middle of an ordinary 3½" X 2½" (8.9cm X 6.4cm) plastic playing card. The cards were coated with lacquer to keep the dots from wearing down after repeated use.

Subjects

The subjects were 48 Michigan State University undergraduate students, 24 men and 24 women. Of the 48 subjects, 12 men and 12 women were right-handed, and 12 men and 12 women were left-handed as determined by use of preferred hand in writing. None of the subjects were familiar with Braille letters.

Table 1

Composition of Sets and Subsets

	Subset 1	Subset 2
Set A	B J N S	K D H R

	Subset 1	Subset 2
Set B	C F U W	I V O M

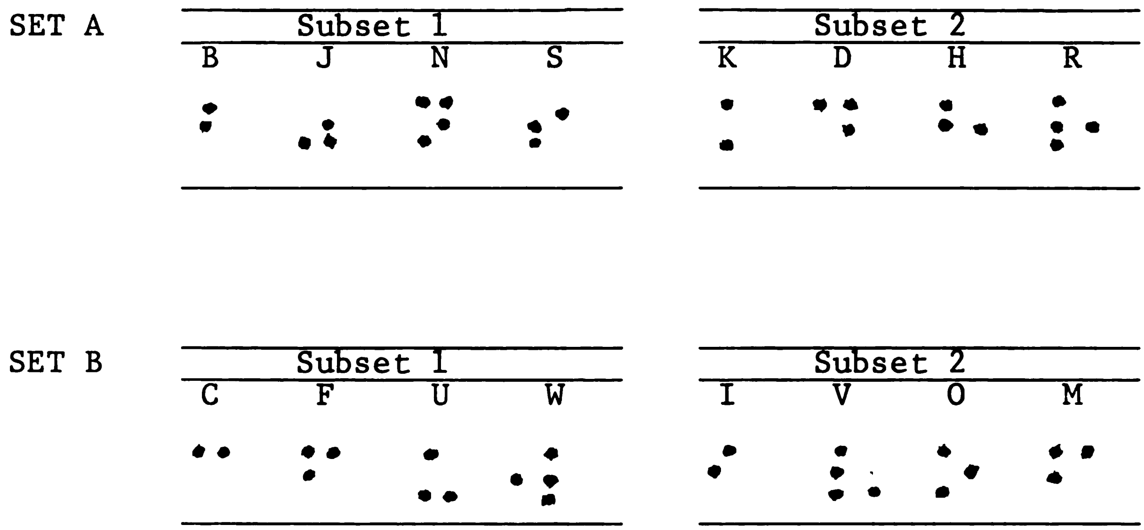

Figure 1

Braille Letters Used in Experiment

Assignment of Subjects to Groups

Each subject was assigned one 8-letter set (one 4-letter subset to each hand). Thus a distinct set of letters was assigned to each hand. The assignment of subsets and sets was counterbalanced across subjects (see Table 2) so that the same combinations of the presentation of the stimuli were represented an equal number of times to each hand within each of the four sex X handedness groups: left-handed males, left-handed females, right-handed males, and right-handed females.

Procedure

The subject sat at a table with his chin in a chin rest. The table was partitioned so that when the subject placed his hands on the table, he could see neither his hands, the experimenter, nor the Braille cards. The walls of the laboratory were covered with brown cloth to provide a completely uniform background.

Each subject was told that he would learn to read Braille letters as blind people do. He would be asked to name and remember various Braille letters by feeling them. It was pointed out that the dot arrangement of the Braille letters had not been designed to physically resemble the names of the letters.

There were three male experimenters. One sat on the floor, hidden from view of the subject, and slid the Braille cards, according to a prearranged schedule, into one or the

Table 2

Assignment of Subjects to Groups

		Handedness of Subjects						
	Left-handed				Right-handed			
	Men		Women		Men		Women	
	Superset A	B	A	B	A	B	A	B
Left hand used	Subset 1	3	1	3	1	3	1	3
	Subset 2	4	2	4	2	4	2	4
Right hand used	Subset 2	4	2	4	2	4	2	4
	Subset 1	3	1	3	1	3	1	3

other of two metal card-holders. The holders could be adjusted in position on the table so that the subject was comfortable feeling the letters while his head was in the chin rest. The holders were placed side by side, anchored to the table, close enough so that the subject's left and right forefingers, the fingers used to feel the letters, were each approximately three inches (7.6cm) to the left and right of the body midline.

The subject held both his hands on the table with his forefingers resting on the card-holders. The trial began as soon as the experimenter had slid the card into position, either to the subject's left or right hand. Immediately the experimenter depressed and then released a wooden key that was connected to a six-pen event recorder that was located in another room of the laboratory. The key activated one of the ink pens and recorded the beginning of each trial. The experimenter had a watch to time the trials. Each subject had five seconds to feel the pattern after which the card was removed from the holder. The experimenter then asked for the name of the letter. The subject had three seconds to respond. Each of the subject's responses was recorded on a sheet of paper by the experimenter.

A correction procedure was used on all trials. Whether the subject gave no name, an incorrect name, or the correct name for that letter, the experimenter gave the correct name. Then the next trial began with a new card being slid into place.

The subject was given two practice trials to become familiarized with the procedure. Two practice letters, different from the letters used in the experimental trials, were used. One letter was first placed under the subject's right hand, and he was asked to feel the dots for five seconds. The experimenter withdrew the letter and named it. The second practice letter was then presented to the subject's left hand. Afterwards, the subject was told he would receive repeated presentations of new letters, and that he must try to learn their names. There was no mention of the number of letters to be presented, or that a distinct set would be assigned to each hand. The subject was told only that letters would be placed under alternate hands on successive trials.

In the experimental trials, one 2-dot, two 3-dot, and one 4-dot Braille letter was given to each hand of every subject. The four letters assigned to each subject's hand were each presented ten times for a total of forty trials per hand. The hands were tested in straight alternation throughout the eighty trials, the first trial always being started with the right hand. The letters were presented so that within a block of eight trials per hand, all four letters were presented twice in random order with the additional constraint that no letter followed itself. The entire procedure took approximately thirty minutes.

Eye Movements

Each subject's eye movements were monitored by a hidden camera and transmitted through a closed-circuit television system to a television monitor in another room of the laboratory.

One of three judges recorded each subject's eye movements from the television monitor. The judge depressed one key on an event recorder for left lateral eye movements, and another key for right eye movements. Each key was held down until the eyes returned to center position. The resulting ink tracings produced a record of the number and duration of eye movements in each direction.

Reliability of the three judges for number of eye movements, but not duration, was checked on practice subjects before any experimental subjects were tested. The correlation coefficient of judge 1 with judge 2 was .95, judge 1 with judge 3 was .98, and judge 2 with judge 3 was .96.

Figure Recall Tests

After the learning trials were completed, each subject was given a booklet of eight 8½" X 11" (21.6cm X 27.9cm) blank white sheets of paper. At the top of each sheet the name of one of the letters was printed. The subject was instructed to draw "as accurately as you can in all respects and details" the dot configuration for each letter that he had been given in the experiment. This procedure was designated as the "memory" condition in the figure recall test.

Immediately after these drawings were completed, the subject was asked to feel each of the letters once again, for five seconds, with the hand to which the letter had been assigned. Before each of these "feeling" presentations, the experimenter named the letter. After the presentation, the subject was asked to draw the configuration on a blank sheet of paper as before. This procedure was designated as the "non-memory" condition in the figure recall test.

Handedness and Eyedness Tests

After the figure recall procedure, each subject was requested to fill out a 12-item handedness questionnaire (Annett, 1970). The subject was then asked whether there was any incidence of left-handedness in his family, either in the immediate family or related by blood in some way.

Three tests were used to determine eye dominance. The subject was asked to look at the experimenter with first one eye closed and then the other eye closed, and then state which eye he preferred to use for the task. Second, the subject was asked to pretend that he was shooting a rifle and to determine which eye he used for sighting. Third, the subject was told to hold a pencil vertically with his preferred hand and to line it up with a pencil held vertically by the experimenter about two feet from the subject. Once this was accomplished, the experimenter noted which eye was used to achieve the alignment of the two pencils.

Two-point Limen Test

The final procedure was a sensitivity test of the two forefingers that each subject used to feel the dots. Using a compass with two sharp points, the experimenter determined the two-point limen for each forefinger by the method of ascending and descending limits.

RESULTS

Learning Scores

For each subject the number of correct letter identifications for each hand was computed. These results are shown for each of the four sex X handedness groups in Table 3. For the right-handed males, 7 subjects showed a non-preferred hand superiority. Five of these 7 subjects showed a "strong" non-preferred hand superiority, defined as a difference of four or more correct identifications. Three right-handed males displayed a "strong" preferred hand superiority.

Seven of the right-handed females showed a non-preferred hand superiority. Three of the 7 displayed a "strong" superiority. Two of the right-handed females showed a "strong" preferred hand superiority.

For the left-handers, 5 (4 "strong") males and 10 (6 "strong") females showed a non-preferred hand superiority. One left-handed male and female displayed a "strong" preferred hand superiority.

An analysis of variance for repeated measures was carried out on these learning scores for the independent variables of sex, handedness, hand used, and trial blocks. For purposes of the analysis, a trial block was defined as five

Table 3

Learning Scores for Individual Subjects

Right-handed Males

Subject	Right hand	Left hand
1	15	23
2	17	17
3	15	20
4	14	7
5	21	29
6	12	20
7	15	28
8	30	25
9	12	5
10	24	25
11	16	13
12	14	16
Mean	17.08	19.00
Standard Deviation	5.35	7.75

Right-handed Females

Subject	Right hand	Left hand
1	24	23
2	21	23
3	19	21
4	29	28
5	10	10
6	15	17
7	8	19
8	24	19
9	20	22
10	21	14
11	9	23
12	7	15
Mean	17.25	19.50
Standard Deviation	7.29	4.91

Left-handed Males

Subject	Right hand	Left hand
1	18	10
2	10	13
3	15	17
4	13	15
5	33	29
6	19	22
7	21	9
8	29	26
9	8	9
10	19	21
11	13	23
12	20	11
Mean	18.17	17.08
Standard Deviation	7.28	6.97

Left-handed Females

Subject	Right hand	Left hand
1	30	29
2	19	16
3	24	19
4	26	17
5	19	18
6	21	26
7	13	13
8	20	10
9	18	11
10	30	28
11	21	14
12	28	27
Mean	22.42	19.00
Standard Deviation	5.25	6.84

consecutive trial presentations to one hand, thus making eight total trial blocks per hand.

The results (see Table 4 for ANOVA table) disclosed non-significant effects for both sex and handedness (both F's < 1.0). The scores for the two handedness groups are illustrated in Figure 2A, the scores for the two sexes in Figure 2B. As can be seen from Figure 2A, the learning curve for the left-handers is practically identical to the curve for right-handers, the left-handers having a slightly, but not significantly, higher overall score. The females did slightly, but not significantly, better than the males (see Figure 2B).

Both parts of Figure 2 show a significant learning effect over trials ($F = 81.77$, $df = 7/308$; $p < .0005$). Performance improved steadily, almost linearly, across trials for all four sex X handedness groups (see Figure 3) so that by the last trial block, all the subjects, as a group, were averaging approximately 3.7 letter identifications for each hand, where maximum score is 5.

While there were no overall significant hand differences (right hand vs. left hand; $F < 1.0$), the pertinent handedness X hand used interaction was significant ($F = 6.97$, $df = 1/44$; $p = .01$; see Table 5). Within each handedness group, the mean score of correct responses was greater for the non-preferred hand.

Post hoc tests of comparison of the main effects of the

Table 4

Analysis of Variance of
Learning Scores

Source of Variance	df	F	Probability of F
Sex	1	.98	.327
Handedness	1	.41	.526
Hand used	1	.00	.980
Trial blocks	7	81.77	$<$ .0005
Sex X handedness	1	.79	.378
Sex X hand used	1	.22	.641
Handedness X hand used	1	6.97	.011
Sex X blocks	7	.48	.852
Handedness X blocks	7	1.26	.268
Hand used X blocks	7	1.03	.411
Sex X handedness X hand used	1	.75	.392
Sex X handedness X blocks	7	.18	.989
Sex X hand used X blocks	7	2.37	.023
Sex X handedness X hand used X blocks	7	.86	.542

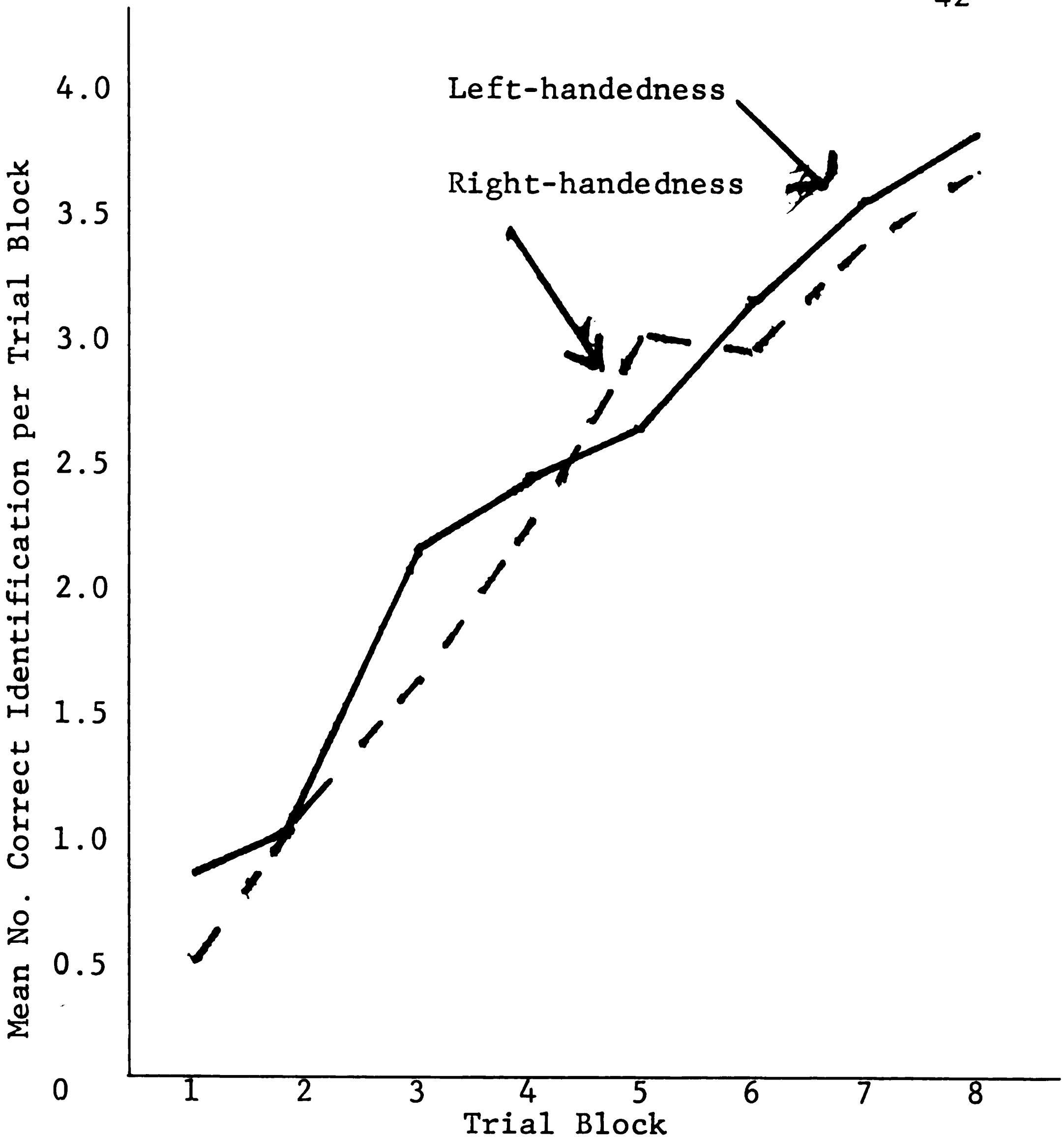

Figure 2A

Handedness Learning Scores
over Trial Blocks

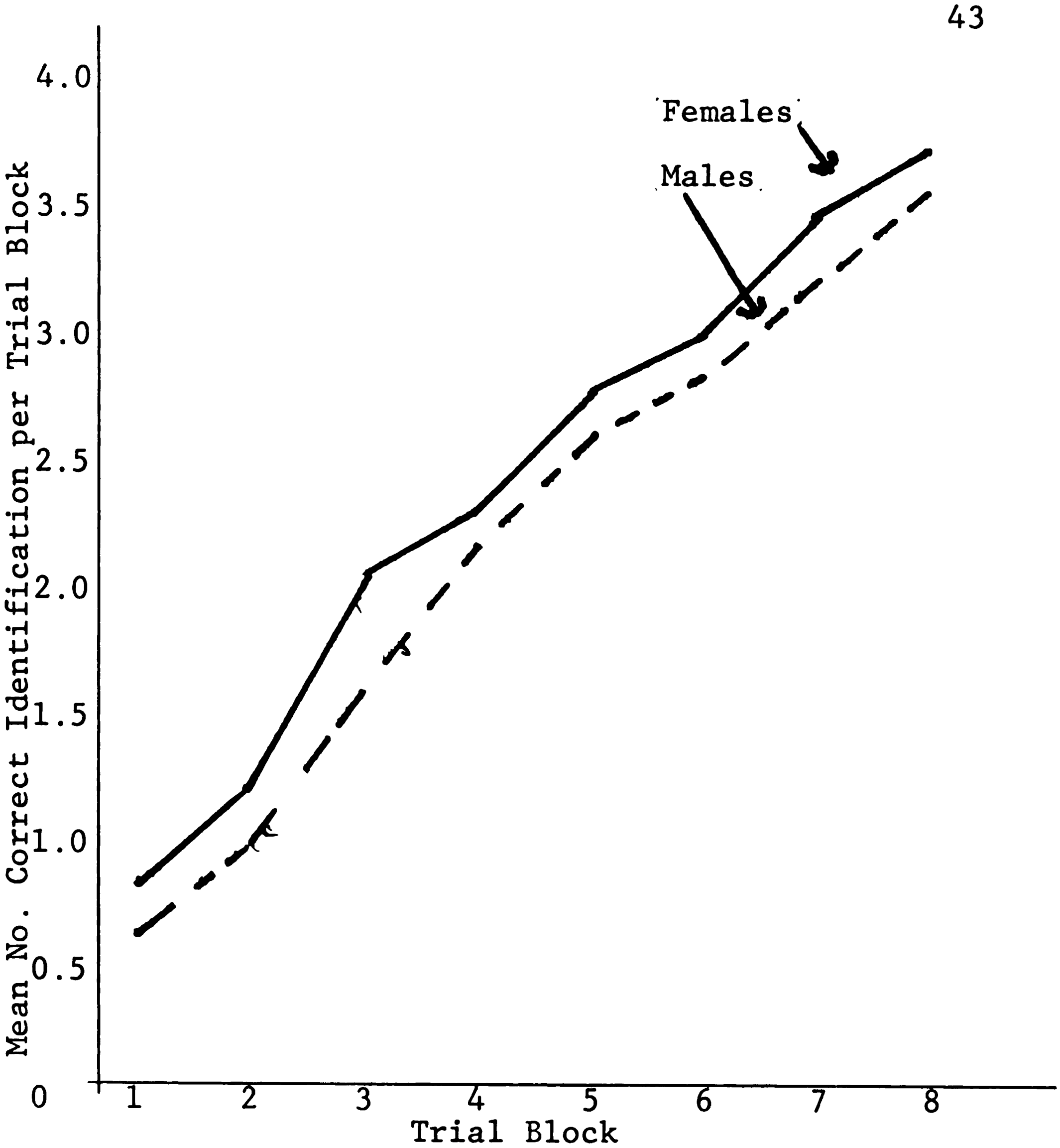

Figure 2B

Sex Learning Scores
over Trial Blocks

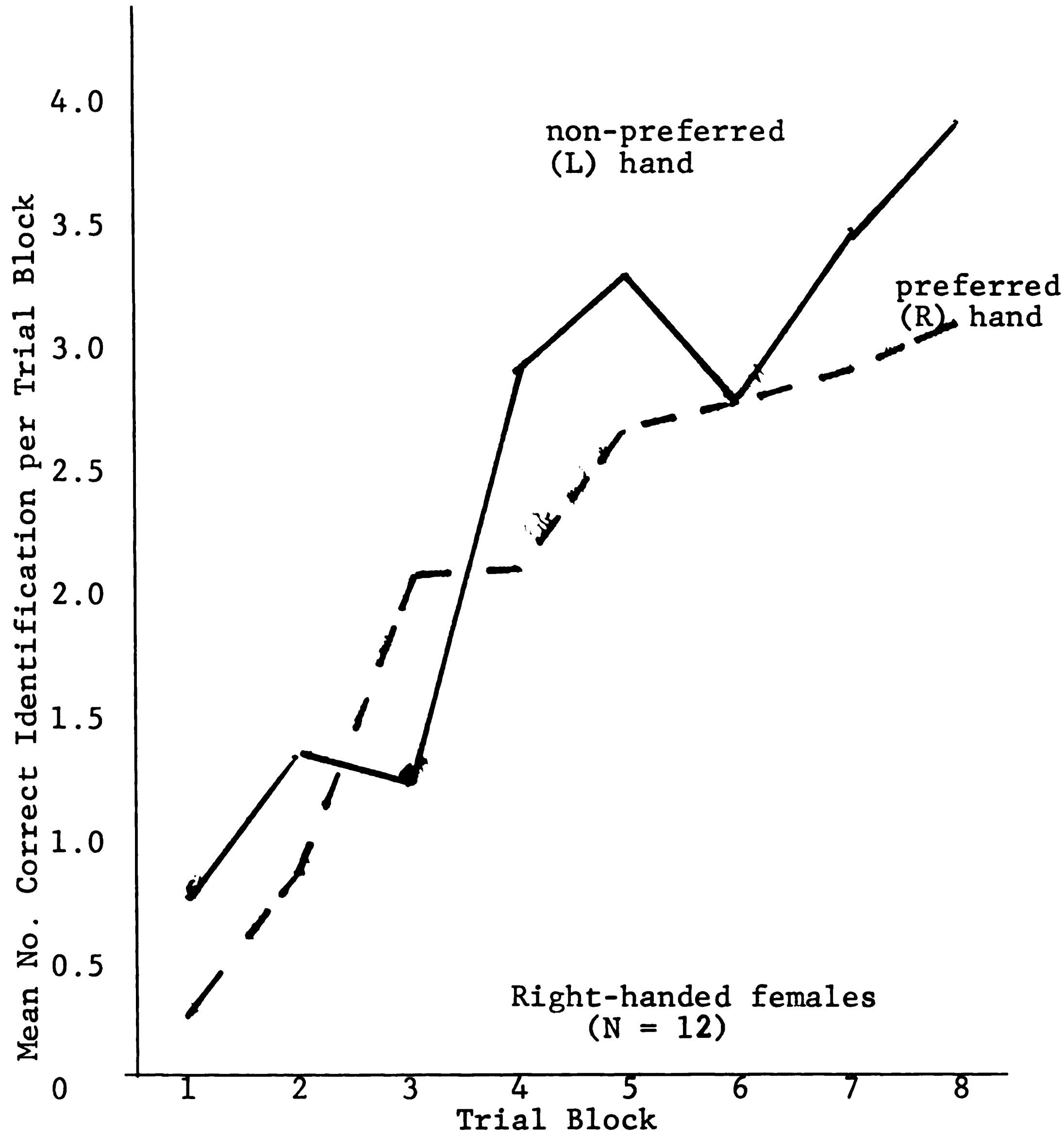

Figure 3A

Learning Scores for
Right-handed Females

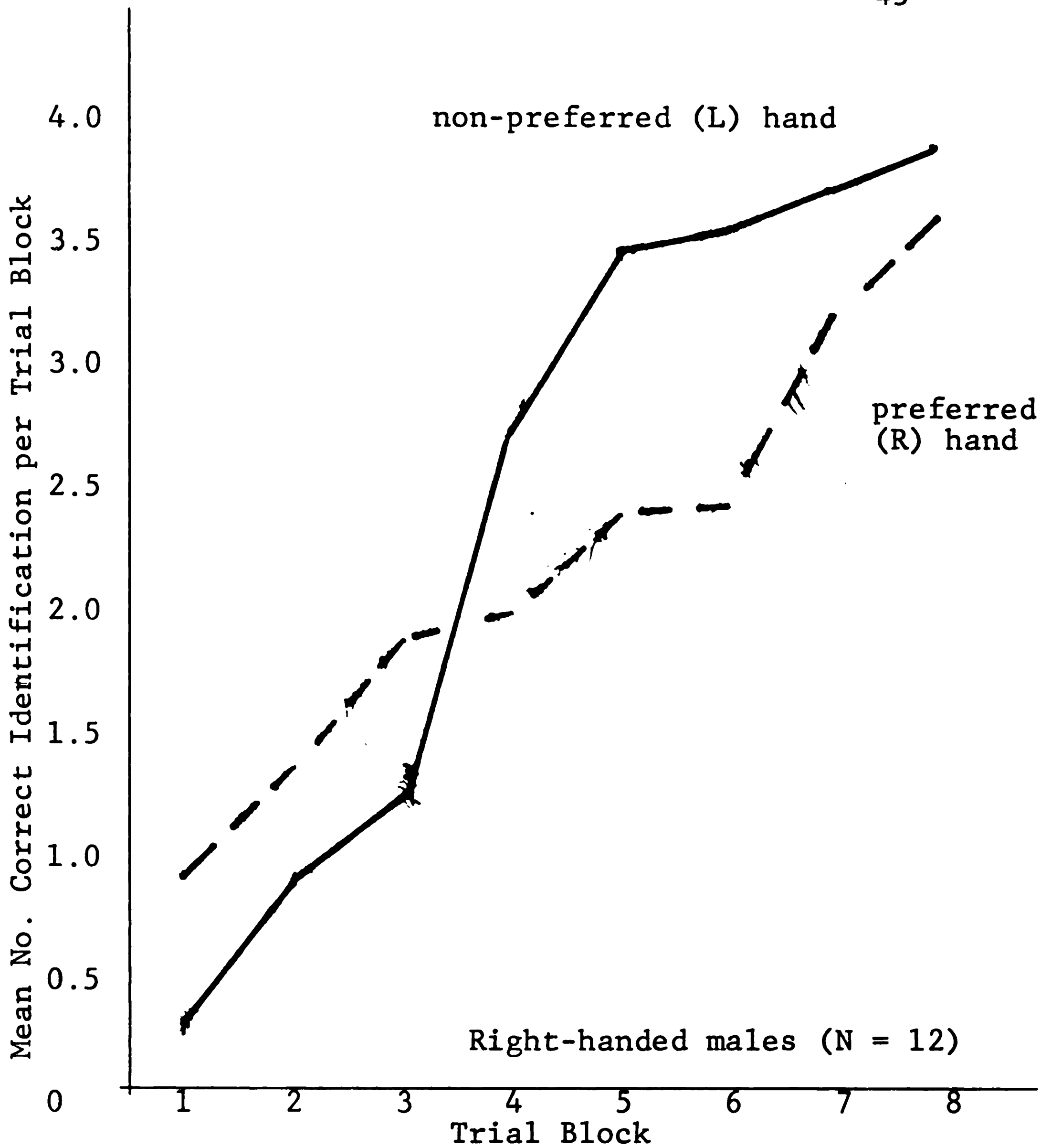

Figure 3B

Learning Scores for
Right-handed Males

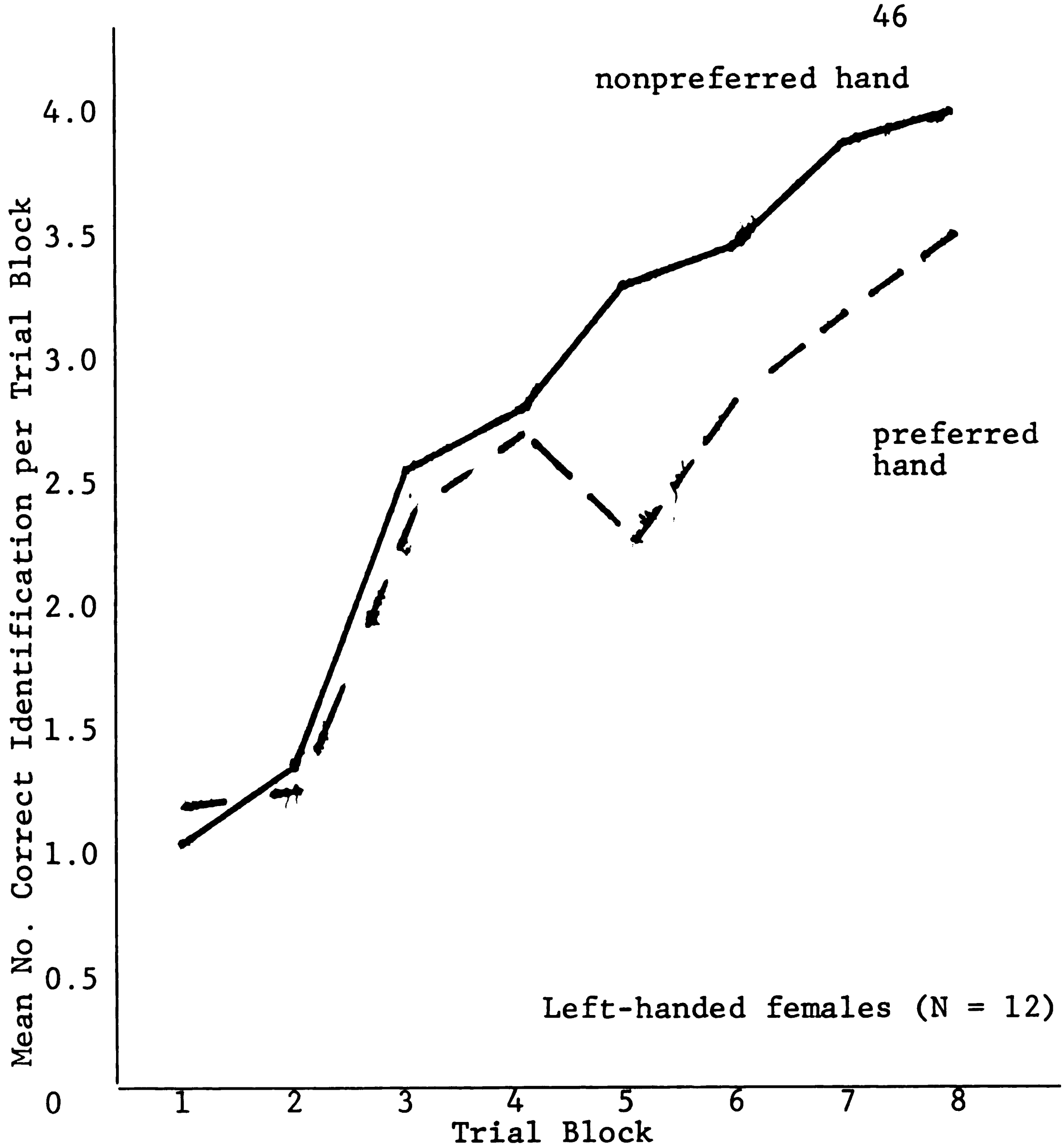

Figure 3C

Learning Scores for
Left-handed Females

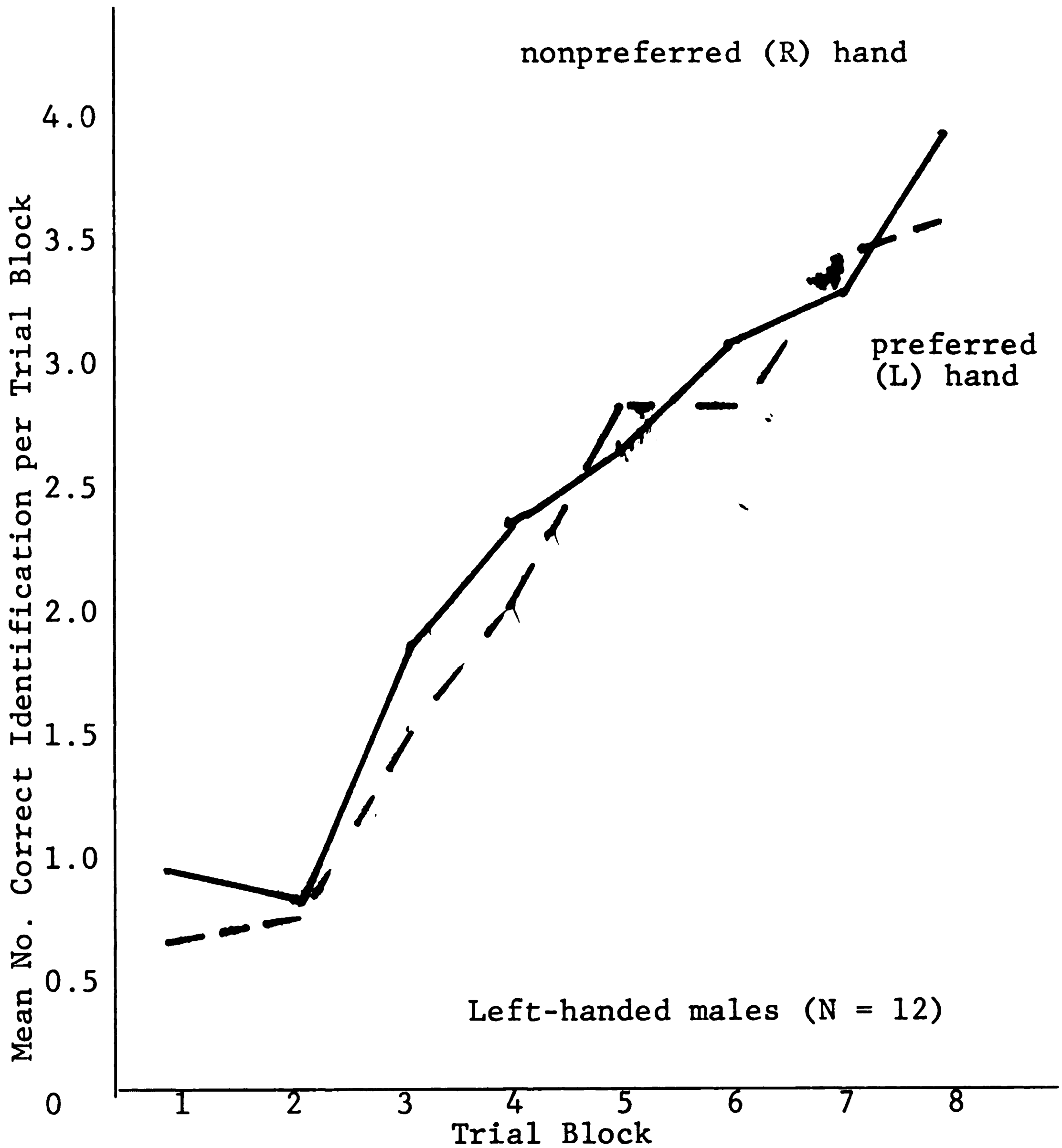

Figure 3D

Learning Scores for
Left-handed Males

Table 5

Learning Scores:
Handedness X Hand Used

HANDEDNESS	HAND USED: Right hand		Left hand	
Right-handers	2.125	[1]	2.406	2.266
	1.431		1.676	
Left-handers	2.536	[2]	2.260	2.398
	1.611		1.590	
	2.330		2.333	Marginals

First line is cell mean.

Second line is cell standard deviation.

[1] $t = 1.88$, $df = 44$; $p < .05$

[2] $t = 1.85$, $df = 44$; $p < .05$

interaction indicated that for the right-handers, the left hand performed significantly better than the right hand ($t = 1.88$, $df = 44$; $p < .05$). Similarly, for the left-handers, the right hand was significantly superior to the left hand ($t = 1.85$, $df = 44$; $p < .05$). This effect is illustrated in Figure 4 which also reveals that the non-preferred hand superiority emerged only by the fourth trial block. The implied interaction of trial blocks with the handedness and hand used variables was significant ($F = 2.37$, $df = 7/308$; $p = .023$).

As can be seen from Figure 4, early in the experimental trials, there was either no difference between the hands, or, in the case of the right-handers, the preferred hand score was greater. But by trial block 4, for both the left- and right-handers, the non-preferred hand scores were greater, and this superiority was retained throughout the remaining trials. By the eighth block of trials, the right-handers' mean non-preferred hand score was 3.8 out of a maximum of 5, with their mean preferred hand score 3.4. For the left-handers, the mean score in the last trial block was 4.0 for the non-preferred hand and 3.5 for the preferred hand.

Sex Differences

As mentioned, there were no sex differences in the learning scores, although the non-significant differences slightly favored the females. However, some additional findings do suggest a difference between males and females.

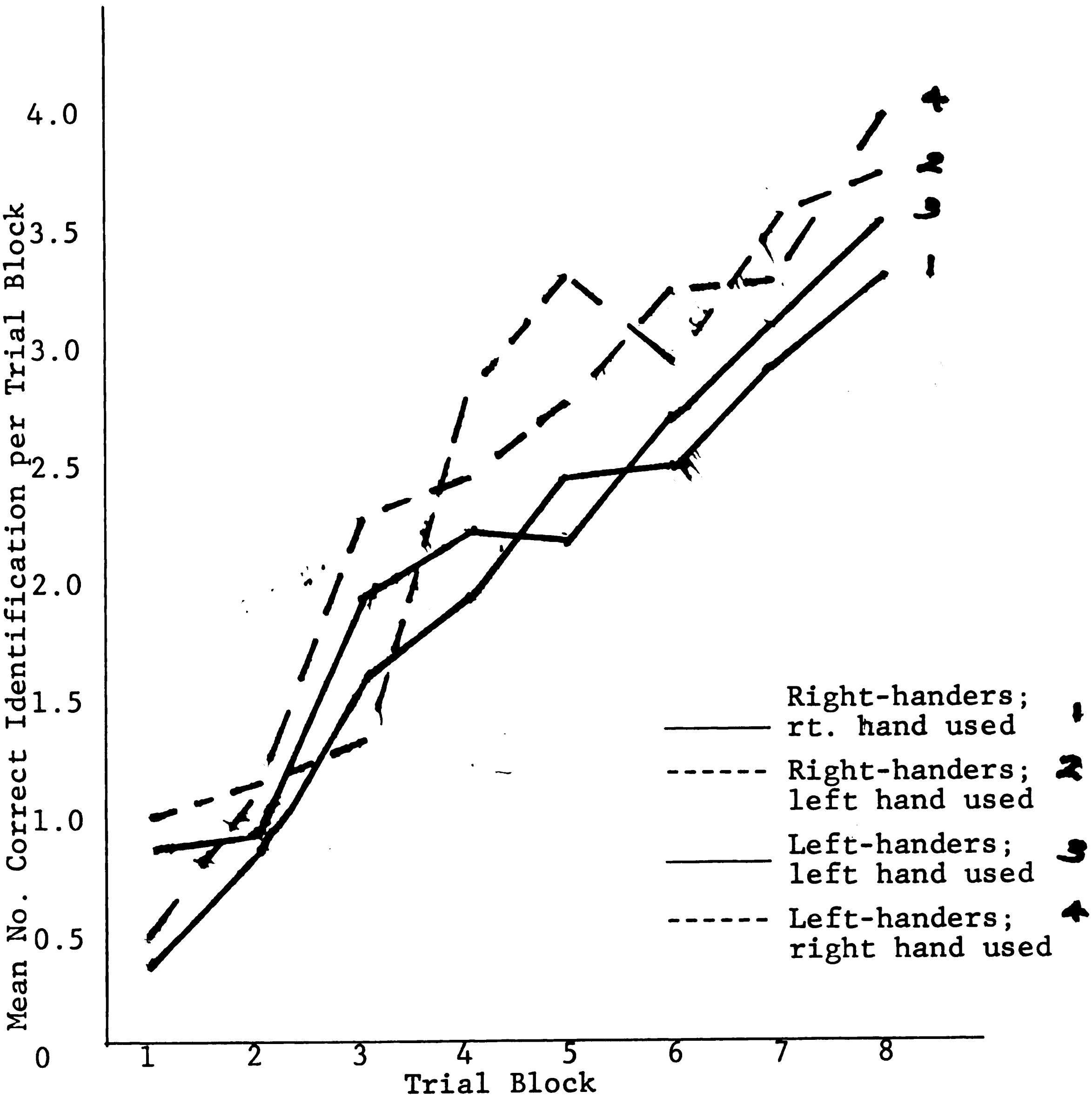

Figure 4

Learning Scores:
Handedness X Hand Used X Trial Blocks

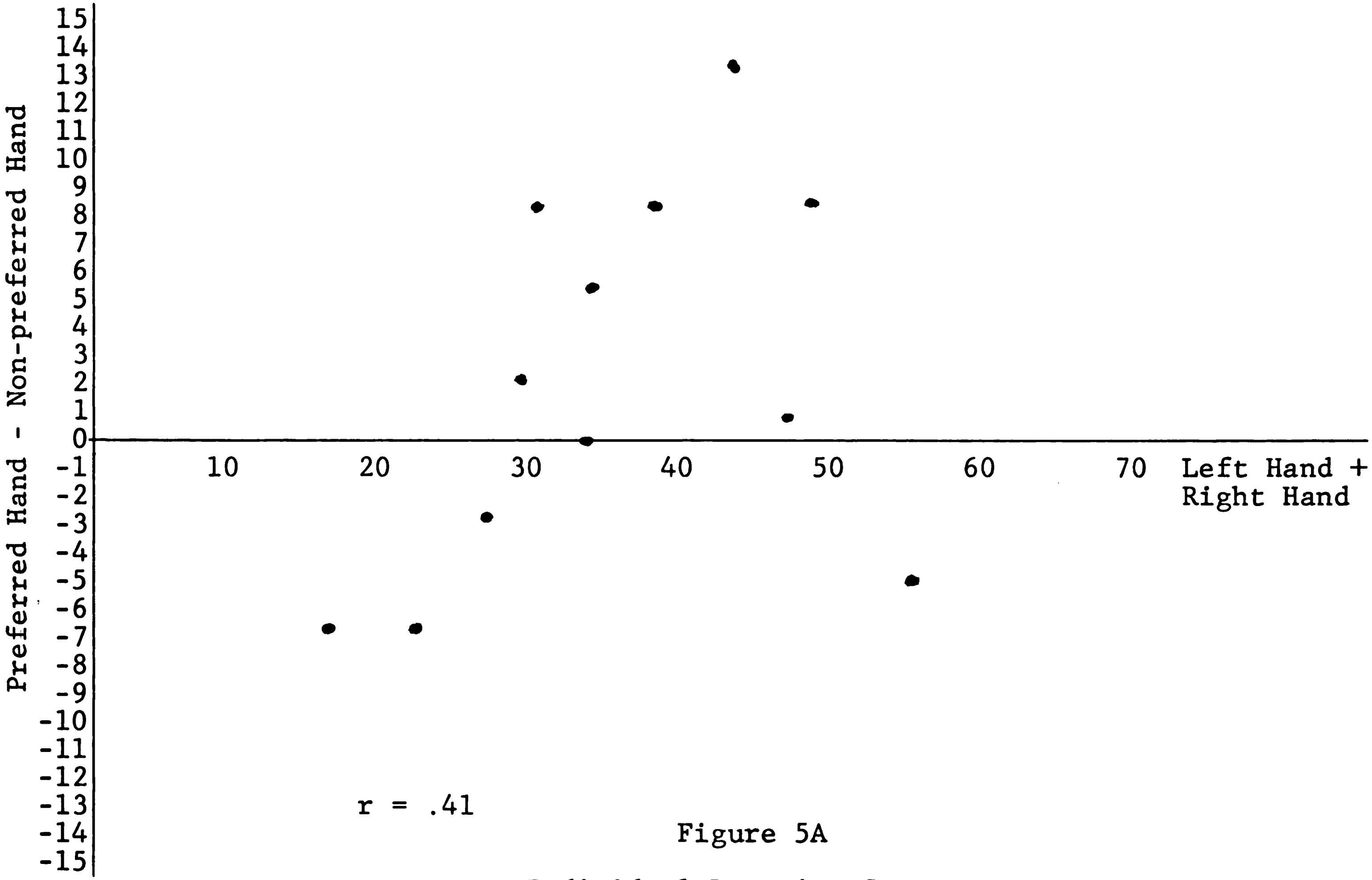

Figure 5A

Individual Learning Scores
for Right-handed Males

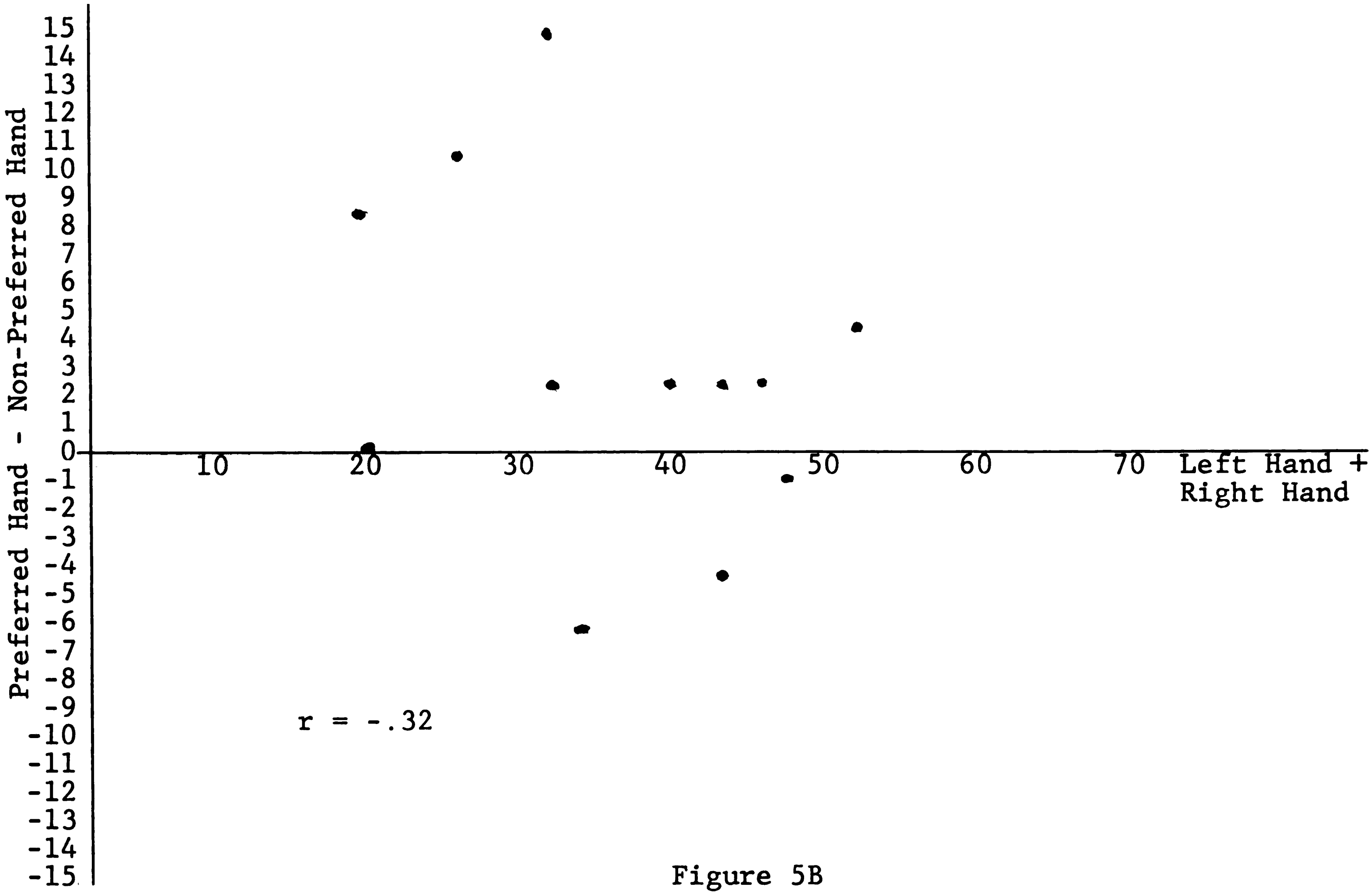

Figure 5B

Individual Learning Scores
for Right-handed Females

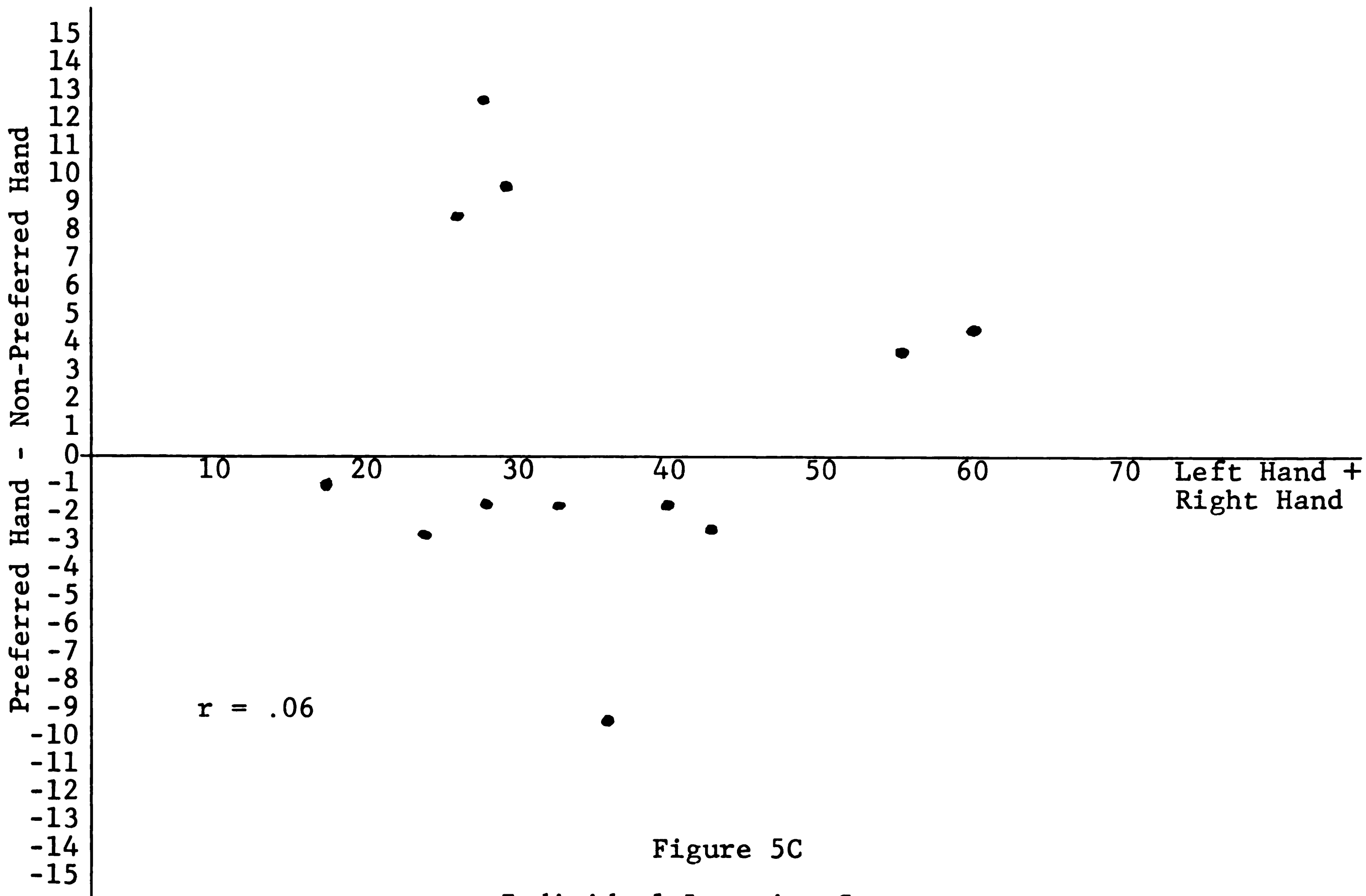

Figure 5C

Individual Learning Scores
for Left-Handed Males

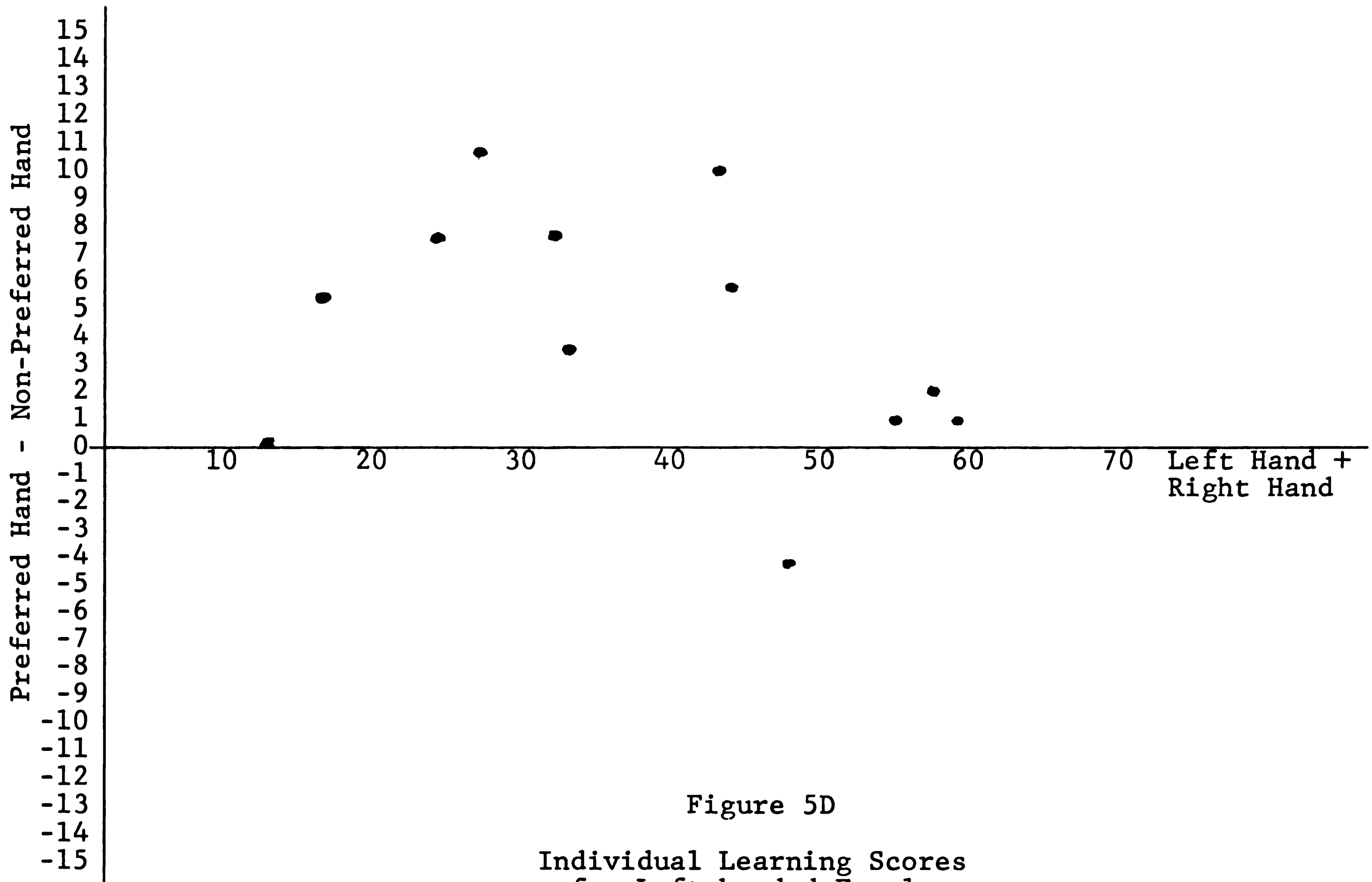

Figure 5D

Individual Learning Scores
for Left-handed Females

Figure 5 graphically shows the relationship for individual subjects between hand asymmetry and total performance on the learning task. Along the vertical axis is plotted the result when the preferred hand score is subtracted from the non-preferred hand score. Subjects above the middle line had higher non-preferred hand scores; subjects below the line had higher preferred hand scores; subjects lying on the line had equal scores for both hands. Total learning scores for both hands combined are plotted along the horizontal axis, where 80 is maximum. Figure 5 also presents the correlations for each of the four sex X handedness groups of the hand asymmetry scores with the total performance scores.

In the case of the right-handers, the correlations, while modest, are of opposite signs for males and females. For the males, the greater the difference favoring the non-preferred hand, the better the total performance. For the females, however, the greater the difference favoring the non-preferred hand, the worse the total performance.

In the case of the left-handed females, the greater the hand asymmetry, the better the overall learning score. There is no evidence of any relationship between the measures for the left-handed males.

Number of Dots

One 2-dot, two 3-dot, and one 4-dot Braille letter was given to each hand of every subject. An analysis of variance (see Table 6) of the learning scores was conducted with the independent variables being sex, handedness, hand used, and dot number (2-dot, 3-dot, and 4-dot).

There was a significant dot number effect ($F = 48.17$, $df = 2/88$; $p < .0005$). The 2-dot letters were identified correctly more often than either the 3-dot or 4-dot letters (see Table 6). The 4-dot letters were identified correctly slightly more often than the 3-dot letters (see Table 6).

There was also a significant sex of subject X dot number interaction ($F = 3.78$, $df = 2/88$; $p = .027$; see Table 7). Tests of comparison revealed that the females performed better than the males on the 2-dot letters ($t = 2.44$, $df = 88$; $p < .01$) and on the 3-dot letters ($t = 1.84$, $df = 88$; $p < .05$). The males performed better than the females on the 4-dot letters, but the difference was not statistically significant ($t = 1.12$, $df = 88$; $p < .20$).

The triple interaction of sex X handedness X dot number was marginally significant ($F = 2.88$, $df = 2/88$; $p = .061$; see Table 8). The females, both left- and right-handed, performed better than males on 2-dot letters. Right-handed males did slightly better than right-handed females on both 3- and 4-dot letters. Left-handed females correctly identified more 3-dot letters than left-handed males, while left-handed males were superior on the 4-dot letters.

Figure Recall Tests

The figures that the subjects drew after the experimental procedure were scored for accuracy in number of dots

Table 6

Analysis of Variance
of Dot Number

Source of Variance	df	F	Probability of F
Sex	1	1.02	.317
Handedness	1	.71	.404
Hand used	1	.08	.784
Dot number	2	48.17	< .0005
Sex X handedness	1	.43	.516
Sex X hand used	1	.06	.809
Handedness X hand used	1	6.34	.016
Sex X dot number	2	3.78	.027
Handedness X dot number	2	.04	.956
Hand used X dot number	2	.53	.588
Sex X handedness X hand used	1	2.28	.138
Sex X handedness X dot number	2	2.88	.061
Sex X hand used X dot number	2	1.15	.321
Handedness X hand used X dot number	2	.42	.661
Sex X handedness X hand used X dot number	2	1.44	.243

Table 7

Sex X Dot Number

SEX		DOT NUMBER 2-dot	3-dot	4-dot	
Males		6.063	3.531	4.708	4.767
		2.409	2.172	2.021	
		1	2	3	
Females		7.042	4.271	4.229	5.181
		2.324	1.943	2.354	
		6.552	3.901	4.469	Marginals

First line is cell mean.

Second line is cell standard deviation.

[1] $t = 2.44$, $df = 88$; $p < .01$

[2] $t = 1.84$, $df = 88$; $p < .05$

[3] $t = 1.12$, $df = 88$; $p < .20$

Table 8

Sex X Handedness X Dot Number

MALES

HANDEDNESS	DOT NUMBER 2-dot	3-dot	4-dot	
Right-handers	6.042	3.854	4.292	4.729
	2.216	2.315	1.989	
Left-handers	6.083	3.208	5.125	4.806
	2.636	2.016	2.007	
	6.063	3.531	4.708	Marginals

FEMALES

HANDEDNESS	DOT NUMBER 2-dot	3-dot	4-dot	
Right-handers	6.792	3.625	4.208	4.875
	2.265	1.831	2.167	
Left-handers	7.292	4.917	4.250	5.486
	2.404	1.869	2.575	
	7.042	4.271	4.229	Marginals

First line is cell mean.

Second line is cell standard deviation.

represented. Table 9 summarizes the analysis of variance of the resulting scores for both the memory and non-memory conditions with the independent variables being sex, handedness, hand used (i.e., comparison between recall scores for letters assigned to preferred hand and letters assigned to non-preferred hand in the learning task), and recall task (memory and non-memory).

The error scores were higher on the memory task than on the non-memory task ($F = 9.66$, $df = 1/44$; $p < .003$; see Table 10). But on both tasks, females were more accurate than males in depicting the correct number of dots in the various configurations ($F = 4.64$, $df = 1/44$; $p = .037$; see Table 10). This sex difference was stronger in the memory task than in the non-memory task, although the implied interaction between task type and sex was not significant ($F = 3.26$, $df = 1/44$; $p = .078$; see Table 10).

The sex X handedness interaction was marginally significant ($F = 3.79$, $df = 1/44$; $p = .058$; see Table 11) indicating that the sex difference was stronger for the left-handers than for the right-handers.

With the exception of left-handed males, the error scores were lower for the non-preferred hand than the preferred hand. The left-handed males showed the smallest overall hand differences favoring the non-preferred hand in depicting the correct number of dots.

Table 9

Analysis of Variance
of Figure Recall Tests

Source of Variance	df	F	Probability of F
Sex	1	4.64	.037
Handedness	1	.83	.366
Hand used	1	1.00	.322
Task type	1	9.66	.003
Sex X handedness	1	3.79	.058
Sex X hand used	1	2.67	.109
Handedness X hand used	1	.07	.793
Sex X task type	1	3.26	.078
Handedness X task type	1	.95	.334
Hand used X task type	1	.19	.669
Sex X handedness X hand used	1	1.00	.322
Sex X handedness X task type	1	.55	.463
Sex X hand used X task type	1	.19	.669
Sex X handedness X hand used X task type	1	.39	.537

Table 10

Figure Recall =
Sex X Task Type

SEX		TASK TYPE: Memory	Non-memory	
	Males	4.458	2.729	3.594
		2.982	2.304	
	Females	2.708	2.229	2.469
		2.379	2.868	
		3.583	2.479	Marginals

First line is cell mean.

Second line is cell standard deviation.

Table 11

Figure Recall =
Sex X Handedness

SEX		HANDEDNESS Right-handers	Left-handers	
	Males	2.729	4.458	3.594
		1.987	3.202	
	Females	2.958	1.979	2.469
		2.946	2.198	
		2.844	3.219	Marginals

First line is cell mean.

Second line is cell standard deviation.

Strength of Handedness

To ascertain whether strength of handedness was related to the performance scores on the Braille task, a handedness quotient (HQ) was computed for each subject (Annett, 1970). The HQ was derived from the answers to the 12-item handedness questionnaire (Annett, 1970). The HQ was computed by adding the number of questions that were answered "right hand only" to one-half the total number of questions answered by saying "either hand," and dividing this sum by 12, the total number of questions on the questionnaire. The HQ could range from .00 (left-handed on all tasks) to 1.00 (right-handed on all tasks).

Table 12 shows the correlations between the HQ and absolute learning score difference between the left hand and right hand. None of the correlations were statistically significant. The correlations for the right-handers were small and positive. For the left-handers, the correlations were negative, larger for females than males.

An arbitrary eyedness quotient (EQ) was similarly computed for each subject. If a subject was right-eyed on all three eye tests, his EQ = 1.00, if right-eyed on two of the three tests EQ = .66, if right-eyed on one of the tests EQ = .33, and if right-eyed on none of the tests EQ = .00.

An arbitrary family history quotient (FQ) was also computed. If a subject had no left-handers related to him, his FQ = 1.00, if a left-hander was related to him, but not in his immediate family, FQ = .50, and if a left-hander was in

Table 12

Correlations between HQ and Absolute Learning Score Difference

	Males	Females
Right-handers	.07	.10
Left-handers	-.12	-.39

his immediate family, FQ = .00.

Finally, a lateralization quotient (LQ) was computed, which was the average of the HQ, EQ, and FQ $\left(\frac{HQ + EQ + FQ}{3}\right)$.

Inspection of the data revealed no patterns or relationships among any of the quotients and the strength of the hand difference scores on the learning data.

Eye Movements

Table 13 shows the percentage of lateral eye movements made by each of the four sex X handedness groups to the left (right hemisphere), right (left hemisphere), and center (no lateral eye movements). As can be seen, the percentages of looking time were all similar, with by far the largest portion of time being spent with the eyes looking straight ahead. For all four groups there was a slight, but not significant, tendency for more left than right eye movements. Table 13 also gives the number of subjects in each group who had a higher percentage of left eye movements (left-lookers) or a higher percentage of right eye movements (right-lookers).

Table 14 displays the correlations between percent looking in each direction and a differential learning task score calculated by subtracting the preferred hand score from the non-preferred hand score. None of the correlations were statistically significant. All the correlations were small except for the right-handed males. In that group a high percentage of left looks is associated with a negative differential learning score (preferred hand superiority), while a high percentage of center looking is associated with a larger differential score (non-preferred hand superiority).

For each subject it was determined whether his first eye movement following the presentation of each Braille

Table 13

Percent Looking Time
for Conjugate Lateral Eye Movements

	Left	Right	Center	t^1	# of Left Looks	# of Rt. Looks
Right-handed males	9.7	6.1	84.2	1.07	8	4
	8.2	8.4	10.4			
Right-handed females	15.2	13.0	71.8	.53	9	3
	8.2	11.8	11.4			
Left-handed males	10.3	10.2	79.5	.02	5	7
	13.8	10.5	15.4			
Left-handed females	16.5	12.6	70.9	1.08	7	5
	8.7	9.1	6.1			

First line is cell mean.

Second line is cell standard deviation.

[1] t- score for left vs. right looks.

Table 14

Correlations
between Percent Looking Time
and Hand Asymmetry

	Eye Movement Direction		
	Left	Right	Center
Right-handed males	-.56	.01	.43
Right-handed females	-.01	.13	-.13
Left-handed males	-.14	-.05	.16
Left-handed females	.09	.13	-.32

stimulus card was to the left or to the right. Then the percentage of "first looks left" was computed. Table 15 shows the correlations of first looks left with overall percent of left eye movements for each group of subjects. The correlations were all extremely high and statistically significant.

Two-point Limen

As can be seen from Table 16, the mean two-point limens for each hand were very close for each of the four sex X handedness groups. A low limen score means greater finger sensitivity, while a higher score means less sensitivity. There were no statistical differences in sensitivity between the left and right hands for any of the groups.

As a further sensitivity check, correlations were computed between limen scores and learning scores (see Table 16). The limen and learning scores were obtained by subtracting the preferred hand limen and learning scores for each subject from his non-preferred hand limen and learning scores respectively. The correlations were all small and non-significant. The largest correlation ($r = .23$) was for right-handed males, indicating a slight tendency for a non-preferred hand limen score (greater preferred hand sensitivity). For the right-handed females, the correlation was small and negative, implying a slight association between a higher non-preferred hand learning superiority with a higher preferred hand limen score (greater non-preferred hand sensitivity).

Table 15

Correlations between First Looks Left
with Overall Percent of Left Eye Movements

Subject Group	*r*
Right-handed males	.98*
Right-handed females	.97*
Left-handed males	.94*
Left-handed females	.96*

* $p < .005$.

First looks left computed by determining percentage of first eye movements to the left following each stimulus presentation.

Table 16

Two-point Limen Scores

	Left hand	Right hand	t[1]	Correlation[2]
Right-handed males	.31 .04	.27 .06	1.61	.23
Right-handed females	.28 .07	.28 .07	0	-.17
Left-handed males	.30 .06	.28 .04	.65	.03
Left-handed females	.27 .05	.26 .05	.47	.03

[1] t- score for left vs. right hand.

[2] Correlations are between limen scores and hand asymmetry scores calculated by subtracting preferred hand score from non-preferred hand score.

DISCUSSION

Learning Scores

The overall results are consistent with the prediction of non-preferred hand superiority in learning the names of Braille dot configurations. The findings, therefore, agree with the previous findings of Hermelin and O'Connor (1971a, 1971b) and Rudel _et al_. (1974).

In the case of the right-handers, the demonstrated superiority of the non-preferred hand is consistent with Hermelin and O'Connor's view that Braille symbols are encoded first as spatial configurations and only then are processed as meaningful patterns, so that overall, one would expect better left hand (right cerebral hemisphere) performance.

The left-handers' scores, however, were not expected in that their non-preferred hand superiority was just as strong as the difference found for the right-handers. The hand asymmetry effect, in fact, has been contributed to predominantly by the women (see Figure 3). For the right-handers, both men and women, the non-preferred hand scores were higher, and the cross-over to the non-preferred hand superiority appeared at about the same time, the fourth trial block.

For the left-handed women, the hand asymmetry effect was also clear, though in this case in the early trials, rather than a cross-over, there was no hand difference. Again at trial block four, the non-preferred hand superiority emerged. For the left-handed males, however, though the mean overall non-preferred hand score was higher than the preferred hand score, there was no increasing difference between the hands as occurred with the other sex X handedness groups. In fact, as late as trial block seven, the scores were equal for the two hands and then differed again at trial block eight. The implied interaction of sex X handedness X hand used was not significant because the left-handed males' non-preferred hand scores were at least in the same direction, though not as strong, as for the other three groups of subjects.

Previous studies of Braille learning and reading have not included left-handers, so there is no basis for comparison of similar tasks. But what is generally known about left-handers suggests weaker cerebral lateralization than for right-handers. This is a presumed explanation for the hand usage pattern of left- and right-handers. Right-handers report using their preferred hand in almost all tasks, while left-handers describe themselves as more bi-dextrous, using one hand for some tasks, the other hand for others. To the extent that the present findings are not due to sampling error, the present study does not support the view of weaker lateralization for left-handed women, but instead suggests reverse lateralization. It is less clear for left-handed men in that they showed some asymmetry effects favoring the non-preferred hand but clearly it was not so strong as for the left-handed women.

To the extent that the Braille task has a true spatial component, the results for the left-handers are also inconsistent with the view that left-handers have poorer spatial ability than right-handers. They did slightly, but not significantly, better than the right-handers in the learning situation. The current findings, therefore, agree with Hardyck and Petrinovich (1977) that left-handers do not display cognitive and performance deficits when compared to right-handers.

Modes of Information Processing

The significant interaction of handedness X hand used X blocks suggests a change in trials in the manner or mode of detection and processing of the dot configurations. Insofar as the preferred and non-preferred hand can be assumed to reflect the use of a verbal and spatial mode of information processing, then early in training verbal and spatial modes seem to have been involved to equal degrees. In fact, for right-handers, the preferred hand performance was superior. It is as though the subject fairly early in training had learned which letters of the alphabet comprised the letters in the task, but was not yet familiar with the dot patterns themselves which, of course, were unfamiliar pre-experimentally. As the trials continued the subject was able to concentrate more on the spatial aspects of the task so that the non-preferred hand's superiority began to appear. The significant triple interaction and inspection of the learning curves imply that, except for the left-handed males as mentioned, the difference between the hands increased as the trials progressed. It is as though once the spatial processing was successful, the non-preferred hand continued to use the spatial mode with increasing success, while the preferred hand was not able to make direct use of spatial processing and fell behind the non-preferred hand.

Bryden and Allard (1976) propose a theory of visual field differences that is relevant to the discussion. They suggest that the right hemisphere is more efficient in global preprocessing operations where pattern recognition is accomplished by segregating the relevant components of the input, refining the initial representation, and excluding irrelevant detail. By contrast, the left hemisphere is already known to be superior for analytic and naming identification. They found that 24 undergraduate students better recognized letters that were more scriptlike than printlike in the left visual field (right hemisphere) instead of the usual right visual field superiority because of the necessity of more extensive preprocessing that script letters presumably require. Perhaps a similar explanation can be applied to the non-preferred hand (right hemisphere) superiority in Braille learning. Braille characters, being composed of unfamiliar arrays of dots, would require extensive preprocessing. The right hemisphere is more effective than the left hemisphere in that operation and after completing its processing shunts the stimuli to the left hemisphere for the attachment of letter names.

One can speculate about how the learning curves would look if the trials had been continued. The subject eventually might have done as well with the preferred hand as the non-preferred hand, once the spatial aspect of the task had been mastered. This could be the result of "instruction" in spatial processing from the spatial hemisphere (non-preferred hand) or because of the perseverance of use of verbal processing of the dots, which then eventually succeeds in the learning of the subset of letters. If, in fact, equality of the hands is eventually restored, then measurement of reaction times could be used to determine whether the non-preferred hand still retains some sort of superiority. Possibly by then, through transfer of information through the corpus callosum, the preferred hand would be able to react as fast as the non-preferred hand. Such a reaction time study could shed light on some of the relevant theoretical issues.

Two-point Limen

It is conceivable that the overall hand asymmetry effect stemmed from a basic difference in sensitivity between the index fingers of the preferred and non-preferred hands. It is difficult to know what the direction of difference might be, favoring the preferred hand because it is more practiced, or favoring the non-preferred hand because, being less used, it would be less hardened. The results showed, however, that there were no sensitivity differences of any kind. Further, there was no relation between sensitivity scores and hand differences in the learning task. It does not appear, therefore, that the non-preferred hand superiority in learning can be attributed to its greater sensitivity, thus confirming the findings of Carmon and Benton (1969) using the electro-mechanical stimulator. This finding increases the likelihood of an explanation of the hand asymmetry effect in terms of cerebral specialization.

Sex Differences

As predicted, there was no evidence of a sex difference for Braille accuracy. The results therefore agree with earlier findings for sighted children (Rudel *et al*., 1974, 1977).

The absence of a sex difference in overall performance suggests that the experimental task is solvable in a variety of ways. This is what Rudel *et al*. (1974) suggested in their study of Braille reading with sighted, right-handed children. Recall that the left (non-preferred) hand superiority was significant only among the oldest children, the 13- and 14-year-olds, while for the 7- and 8-year-olds, the right hand was better. Boys and girls, however, contributed unequally to this effect. At ages 7 and 8, the boys performed equally well with both hands, while the girls' right hand scores were superior. At ages 13 and 14, however, both boys' and girls' left hand scores were superior, but the difference was statistically significant only for the boys. The older girls' left hand superiority in fact appeared only among those girls tested with the right hand before the left hand. By contrast, the older boys' right hand scores declined slightly when the left hand was tested first. Rudel *et al*. suggest that in the Braille learning task, girls do more linguistic coding than boys, while boys make better or greater use of the spatial capacities of their right or spatial hemisphere. Rudel *et al*. thus see their findings as evidence that girls depend to a greater degree and for a longer time than boys on left hemisphere modes in the solution of spatial configuration problems.

The results in the present study are consistent with this proposal. Women, using left hemisphere processing modes, may have been able to do as well as men, who were likely to be more predisposed to the use of right hemisphere modes of information processing. This would explain the non-significant sex difference, but, of course, does not explain the women's non-preferred hand superiority, present for both left- and right-handers.

Perhaps new experiments are needed to investigate women's supposed spatial inferiority. The non-preferred hand superiority found for the women is not easy to explain in terms of a theory that presupposes general spatial deficits for women. It appears that women's poorer spatial ability becomes evident only in certain tasks or situations, and these tasks then need clarification. The male superiority may emerge only on more complex spatial tests, like those regarding three-dimensional mental rotation of the stimuli. The experimental task used in the current study, therefore, may not have been complex enough in its spatial aspects to bring out sex differences in overall performance. But the results may disclose sex differences in the mode of information processing used to discriminate the Braille pattern.

Females and Language

Harris (1978) has reviewed the evidence and found a fair amount of support for the possibility that women are more predisposed to use linguistic modes of analysis than men. In the current study, some additional findings similarly suggest a difference between the men and women in the mode of solution of the discriminations.

Figure 6 displays the relationship between hand asymmetry and total performance on the learning task. The opposite pattern of correlations for right-handed men and right-handed women suggests a different strategy for the two sexes. For the men, the greater the difference favoring the non-preferred hand, the better was total performance, suggesting a greater reliance on the right hemisphere. For the women, the greater the difference favoring the preferred hand, the better the total performance, suggesting a greater reliance on the left hemisphere.

In the case of the left-handers, the women showed the same pattern as the right-handed women, again suggesting linguistic processing of the dot configurations. The left-handed men showed no evidence of any relationship between hand asymmetry and total performance. This is consistent with the finding that they showed the smallest hand asymmetry effects of the four groups on the learning task.

Dot Number

Not surprisingly, a significant dot number effect was found. The 2-dot letters were the easiest to recognize and usually were learned before the more complex 3- and 4-dot letters. The 4-dot letters were actually recognized slightly more often than the 3-dot letters, perhaps because there were twice as many 3-dot letters as 4-dot letters assigned to each hand resulting in more confusion among the 3-dot letters. The 4-dot letters, with more dots than any of the other letters, also may have been more distinctive than the rest of the letters.

The most interesting result from the analysis of the dot number variable was the sex X dot number significant interaction in which women significantly outperformed men on 2- and 3-dot letters, but did worse, although not significantly, on 4-dot letters. The women's greater reliance on linguistic modes may have given them an advantage on the simpler patterns for which verbal strategies could be as effective as spatial strategies. But on the more complicated 4-dot letters, which presumably require a higher level of spatial analysis, linguistic coding would be less effective, and the men, relying more on spatial modes, would be better able to process and learn the dots.

It should be noted that part of the sex X dot number effect must be accounted for in terms of a handedness effect, even though the triple interaction of sex X handedness X dot number was not quite significant. On the 4-dot letters the right-handed men did only a little better than right-handed women. But the left-handed men were markedly superior to the left-handed women. Thus the sex difference was strongest among the left-handers. It is hard to know how to interpret this result, especially in light of the learning data which disclosed the weakest lateralization effects for the left-handed males.

Figure Recall

As expected, the error scores were higher on the memory task than on the non-memory task. Once the subjects were allowed to feel the dots again, they were better able to depict the correct number of dots.

Again there is evidence of a sex difference: the women did better than the men, in both the memory and non-memory conditions, in depicting the number of dots. This sex difference was stronger in the memory than the non-memory condition, but the sex X task type interaction was not significant.

Semmes (1968) has characterized the difference between the left and right hemispheres by saying that the left or language hemisphere analyzes stimulus information sequentially and thus focuses on relevant details or parts of the stimulus. The right hemisphere, by contrast, is more concerned with a synthesis of the overall stimulus configuration. It organizes and processes perceptual information in terms of wholes. It seems reasonable that if a subject was using a predominantly linguistic or analytic strategy, he would have more information about the number of dots in the pattern. But, if a spatial or synthetic strategy was used, the subject would be less likely to be able to represent the number of dots, since the stimulus information would be processed as a whole. In other words, the subject's strategy may have been to just count the dots.

Perhaps the sex difference on the dot number task can be explained in this light. Females were more accurate because of a greater reliance on verbal modes of information processing. Their greater use of analysis of the parts of the pattern allowed them to receive more information about the individual dots, including the number of dots. In other words, they were more likely than men to count the number of dots as a strategy in learning the letter names. It should be noted again that while women were more accurate in depicting the dots, they did not learn the discriminations faster than the men. Obviously, identifying the number of dots is only one aspect of learning the dot pattern. Thus there is some evidence that on a Braille task verbal mediation strategies can be as effective as spatial encoding strategies.

As with the dot number effect, this sex difference was stronger for the left-handers than the right-handers. The interaction of sex X handedness was marginally significant, and the women's margin over the men was much stronger for the left-handers.

Finally, in both the memory and non-memory conditions, except for the left-handed men, the error scores were lower for the non-preferred than for the preferred hand. This result is consistent with the significant hand difference scores found for those groups in the learning trials. The left-handed men, of course, showed the smallest hand difference favoring the non-preferred hand.

Strength of Handedness

Overall, the lateralization measures of handedness and eyedness contributed little to the understanding of the hand asymmetry scores on the Braille task.

There is evidence that handedness cannot be divided into just right- and left-handers, but is distributed continuously (Annett, 1970).

The handedness quotient (HQ) was computed as a measure of the strength of handedness, instead of dividing the subjects into further handedness groups. None of the correlations between the HQ and hand asymmetry scores for the four sex X handedness groups were significant.

For the right-handers, the correlations were small and positive, while for left-handers, the correlations were negative. Positive correlations mean the larger the hand difference, the higher the HQ, while negative correlations mean the larger the hand difference, the smaller the HQ. A high HQ is associated with strong right-handedness, while a low HQ is associated with strong left-handedness.

The hand asymmetry score used in the correlational computations was an absolute hand difference score, not non-preferred hand score minus preferred hand score. And when the overall size of the correlations is considered, it is clear that strength of handedness was not a useful predictor of any hand asymmetries in this study. The only group who showed any degree of correlation, although not significant, was the left-handed women.

The results for the left-handers are hard to explain. A sample of 24 left-handers may be too small to permit meaningful conclusions about strength of handedness. It is also possible that the nature of the Braille learning task had something to do with the results obtained, and that it is not a good task to use for the study of handedness because of the difficulty of separating the verbal and spatial abilities.

A number of studies (e.g., Gur and Gur, 1974) have suggested that a measure of eye dominance can be used to improve predictions of relationships between handedness and certain dependent variables. However, in this study there was no evidence that eyedness was related to the scores on the Braille learning task. Perhaps this is to be expected inasmuch as strength of handedness itself was not related to the learning scores.

Similarly, no relationship was found between the familial handedness measure and the learning scores. When all the handedness and eyedness measures were combined to produce an overall measure of lateralization, no meaningful relationships emerged. These results emphasize the complexity of the relationship of Braille learning to cerebral lateralization. The measures themselves may have been too gross to detect possible existing complex relationships.

Eye Movements

Eye movements were recorded for all the subjects as a means of monitoring which hemisphere was more activated during the experimental task. However, the findings do not agree with the predicted results. All groups showed a slight, but not significant, tendency to make more left (greater right hemisphere activation) than right (greater left hemisphere activation) conjugate lateral eye movements. But, like the handedness and eyedness data, none of the eye movement data could be related to the learning score results. The correlations of eye movements with learning score differences produced no significant patterns. The only sizable correlations were obtained for right-handed males, and then in a direction opposite to that expected. Left-looking (greater right hemisphere activation) was associated with a preferred hand superiority, and center-looking (no eye movements) was associated with a non-preferred hand superiority. These results do not fit any kind of explanation in terms of handedness or lateralization.

The correlations between "first looks left" and overall proportion of time spent looking to the left were all extremely high and significant (.94 to .98). One wonders whether the first eye movement would reflect an early "processing stage" of the Braille stimuli that is primarily spatial, whereas later eye movements would reflect a subsequent processing stage that would have a larger verbal component arising from the combining of letter names to the dot configuration. However, the extremely large correlations suggest instead that there is no shift in processing the Braille dots from predominantly right hemisphere (spatial) modes of information processing to left hemisphere (verbal) modes of processing. Assuming eye movements were an accurate measure of cerebral activation, then it would appear that for each of the four subject groups, there was slightly, but not significantly, greater activation of the right than the left hemisphere, and this was true in both the early and later stages of the stimulus trials.

In sum, when the results are examined, an almost random pattern of eye movements seems to emerge. This suggests an explanation in terms other than cerebral specialization.

Gur, Gur, and Harris (1975) found that subjects will respond with eye movements appropriate to problem type only when the experimenter is behind the subject. When the experimenter is facing the subject, they found that the subjects reverted to a preferential mode of looking, irrespective of problem type, which they proposed was because of interpersonal anxiety. In the current study, though the subjects could not see the experimenter, they knew he was sitting in front of them and could hear his voice. Further, the experimental situation was novel and may have been an additional source of anxiety. Also, Kinsbourne (1974) reports that the eye movement effect is weakened if the subjects are asked to hold central fixation. While this was not done explicitly, the subjects were told to keep their chin in the chin rest at all times, and this may have had the same effect as central fixation in inhibiting the eye movement effect. The eye movement data that resulted therefore may be spurious.

Another possible explanation is suggested by recent studies of the effect of verbal and spatial questions on eye movements. Ehrlichman, Weiner, and Baker (1974) tried to replicate Kinsbourne's results under various experimental conditions. Their results did not support the idea that asymmetrical hemispheric activation by different types of questions is responsible for differences in direction of lateral eye movements. Indeed, there was some indication that vertical, rather than horizontal, eye movements were related to verbal and spatial questions. The authors concluded that it may be premature to use initial eye movements as an indicator of ongoing cognitive process.

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